BIOTECHNOLOGY VALUE CHAINS AS A CASE STUDY OF THE KNOWLEDGE ECONOMY:

The Relationship between Knowledge, Space and Technology

A thesis submitted for the degree of Doctor of Philosophy at Oxford Brookes University.

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DECLARATION

I declare that this thesis is my own work and has not been submitted in any form for a degree or diploma at any other university or institution of higher education. Where material has been obtained from other sources, they are acknowledged in the text.

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ABSTRACT

The overall scope of this thesis is to consider the relationship between knowledge, space and technology in the 'knowledge economy' by drawing upon biotechnology value chains as a case study of the knowledge economy. Central to this is the claim that although biotechnology is an internationally distributed sector, it is also concentrated in specific places because those locations provide an advantage through dynamic innovation processes. Such processes are embedded in places because those places have a particular set of knowledge inputs and provide access to other knowledge inputs outwith those places. In this sense, the knowledge economy can be seen as dependent upon different places and scales that all contribute to the innovation process and therefore necessitate relationships within and between different and diverse locations.

The major contribution to knowledge that the thesis provides is the development of a new conceptual understanding of innovation processes called the *knowledge-space* dynamic that focuses on the knowledge and spatial features of the innovation process rather than assuming that the concentration of innovation necessarily entails specific knowledge and spatial characteristics. Consequently the thesis picks apart the current emphasis on certain types of knowledge (e.g. tacit and explicit) to explore the ways in which these are combined in the innovation process and embedded in particular places. Thus the research approach in the thesis adopts a new methdological framework to collect and analyse secondary and primary data that has not been previously undertaken. Overall the thesis

conclusion is that the knowledge economy – and especially the biotech industry – may not represent the best method for regional development.

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ABBREVIATIONS

BBSRC	Biotechnology and Biological Sciences Research Council (UK)
BIA	BioIndustry Association (UK)
BIO	Bio Industry Organisation (USA)
CAFC	Court of Appeals for the Federal Circuit (USA)
CSO	Chief Scientific Officer
CTO	Chief Technology Officer
DBF	Dedicated biotechnology firm
DETR	Department of Environment, Transport and the Regions (UK)
DNA	Deoxyribose Nucleic Acid
DTI	Department of Trade and Industry (UK)
DvC	*Diamond versus Chakrabarty*
EC	European Commission
EMEA	European Medicines Agency
EPO	European Patent Office
EU	European Union
FDA	Food and Drug Administration (USA)
GATT	General Agreement on Trade and Tariffs
GDP	Gross domestic product
HEI	Higher education institution
HGP	Human Genome Project
IP	Intellectual property
IPO	Initial public offering
IPR	Intellectual property rights
LSE	London Stock Exchange
MLE	Medium and large-sized enterprise
MRC	Medical Research Council (UK)
MSE	Micro and small-sized enterprise
NERC	Natural and Environmental Research Council (UK)

NIH	National Institutes of Health (USA)
NHS	National Health Service (UK)
NUTS	Nomenclature of territorial units for statistics (EU)
ODPM	Office of the Deputy Prime Minister (UK)
OECD	Organisation for Economic Co-operation and Development
PPG	Planning Policy Guidance (UK)
PRO	Public research organisation
RAE	Research Assessment Exercise (UK)
rDNA	Recombinant DNA
RDA	Regional Development Agency (UK)
R&D	Research and development
SAB	Scientific advisory board
SERC	Science and Engineering Research Council (UK)
SME	Small and medium-sized enterprise
TIM	Territorial innovation model
TRIPS	Trade-related Aspects of Intellectual Property Rights
UK	United Kingdom
USA	United States of America
USPTO	United States Patent and Trademark Office
VC	Venture capital
WTO	World Trade Organisation

CHAPTER 1

INTRODUCING THE KNOWLEDGE ECONOMY

> "Most of us make our money from thin air: we produce nothing that can be weighed, touched or easily measured. Our output is not stockpiled at harbours, stored in warehouses or shipped in railway cars." (Leadbeater 1999: viii).

1.1 INTRODUCTION

As the world economy has globalised through direct and indirect state support for global institutional bodies like the General Agreement on Trade and Tariffs (GATT) and the World Trade Organisation (WTO), local and regional economies have been presented as increasingly important sites of industrial research and production (see Scott 2000a, b; Dicken 2003; Scott and Storper 2003). These changes have been associated with declining manufacturing and industrial bases in advanced economies as deindustrialisation in such countries (see Williams 1992) has led to an increasing reliance on the service sector as well as the 'new economy' and 'creative' industries (e.g. Leadbeater 1999; Rifkin 2001). In the United Kingdom (UK), for example, the number of people employed in manufacturing jobs fell by over 1 million between 1996 and 2005 and now represents less than 12% of total employment (Cumbers et al 2006). The long-term trends are evident across much of Western Europe as **Table 1.1** illustrates. However, perhaps more significantly, the changing economic structure of these countries is unevenly spread across regions. Some locations are witnessing higher rates of

deindustrialisation and lower levels of service sector growth compared with others which is reproducing and embedding uneven economic development.

Table 1.1 Industrial Employment in Western Europe 1965-1995

	Relative Industrial Labour Force (%)			
	1965	**1975**	**1985**	**1995**
Austria	45	n.a.	38.1	35.4
Belgium	46	39.9	31.8	28.3
Denmark	37	31.5	27.9	27.1
Finland	36	n.a.	31.9	27.9
France	39	38.7	32.4	26.9
F.R. Germany	48	46	41	36
Greece	24	29.2	25.7	23.2
Ireland	28	30.5	30	31.4
Italy	42	39.1	33.5	32.1
Luxembourg	n.a.	46.3	32	25.5
Netherlands	41	34.6	28.2	22.8
Portugal	31	33.8	33.9	32.2
Spain	35	38.3	31.8	30.2
Sweden	43	n.a.	29.9	26.6
United Kingdom	47	40.7	34.6	27.4
EU15	n.a.	n.a.	n.a.	30.3

Source: Adapted from Williams (1992: 51) for 1965 and Hudson (1999a: 33) for 1975-1995.

Note: n.a. means “not available”.

The changing economic structure of these societies has been variously described by a number of commentators over the last fifty years as a shift to 'post-industrial society', 'post-Fordism', 'information society', 'knowledge-based economy' and now the 'knowledge economy' (see Webster 1995; Sokol 2003, 2004; Godin 2006). In these theories one characteristic stands out, namely the importance of knowledge and technology to economic change. For these 'knowledge economies' the loss of comparative advantage to 'newly industrialising' and emerging global centres of manufacturing in the Far East, South America and, more recently, Eastern Europe has centred on the lower labour costs in these economies. Consequently, the differences between 'developed' and 'developing' economies has produced a new international division of labour in which head office activities such as research and development (R&D), marketing and decision-making are performed in developed economies, whilst manufacturing and assembly is performed in developing economies (Simmie 2003). Thus in the 1990s the Organisation for Economic Co-operation and Development (OECD) argued that about half of its members' economies were now 'knowledge-based' with the growth rate in such industries outpacing overall growth rates (OECD 1996, 1999b). Furthermore the World Bank contended that "knowledge has become the most important factor determining the standard of living" (quoted in DTI 1999c: 11).

As mentioned above, the spatial distribution of the knowledge economy, in terms of specific industrial sectors and knowledge production sites (e.g. research organisations), is as uneven as in any other economic activity, including resource dependent industries, across both the world and national economies (Fagerberg 2005). Consequently to

understand the role of knowledge in economic development we need to consider its embedding in space. In classic formulations of knowledge as an economic input it is presented as both non-rivalrous and non-excludable in that it is difficult to stop others from using knowledge you produce and that the use of knowledge does not deplete it (Malecki 1997; Jessop 2000). Consequently there should be few barriers to the use of knowledge across different regions and countries, implying that an uneven distribution of knowledge industries should not occur. However, because such an uneven distribution does exist and persist, several authors have argued that we need to understand the different spatial embedding of different knowledge. Thus different forms of knowledge – usually identified on a continuum from codified (or explicit) to tacit (Polanyi 1973, Senker and Faulkner 1996) – can be seen as particular to specific places (e.g. Howells 2002; Lever 2002; Gertler 2003; Asheim and Gertler 2005; Fagerberg 2005).

The overall aim of this thesis is to address a number of these issues by exploring the relationship between knowledge, space and technology using the British biotechnology industry as a case study in the knowledge economy. The central hypothesis is that although the biotechnology industry is an internationally distributed sector, innovation is concentrated in specific places because those locations provide an advantage through a *knowledge-space* dynamic that features functional, relational and associational characteristics. The thesis seeks to explain the knowledge and spatial processes involved in biotechnology innovation as well as how and why they are concentrated in particular places (Chapter 5). It then considers how such place-specific processes operate across difference spaces and scales necessitating interaction both within and beyond these

concentrations of innovation (Chapter 6). Finally, it addresses the question of how the knowledge economy depends on different spaces and scales because of the positioning and embedding of innovative 'assets' across and within these spaces and scales (Chapters 4, 5 and 6).

1.2 THE KNOWLEDGE ECONOMY

Since the 1950s and the work of Robert Solow, knowledge has been recognised as an important driver of economic growth. Subsequent theories and concepts like the 'information society', 'knowledge-based economy' and 'knowledge economy' reflect a growing concern with such issues as well as the growing importance of the production and utilisation of knowledge (Temple 1999; Brint 2001; Soete 2002; Simmie 2003; Sokol 2003, 2004; Godin 2006). According to Cooke and Leydesdorff (2006) the concept of the knowledge economy originates in the 1950s and has a long pedigree that is perhaps obfuscated by more recent discussions. In the European Union (EU), the knowledge economy has been identified by regional, national and European governments as a vital element in economic development because of the structural changes in advanced economies; i.e. declining manufacturing employment and rising service sector employment (EC 2002). For example, in its 1998 Competitiveness White Paper *Our Competitive Future* the British government defined the 'knowledge-driven economy' as;

> "…one in which the generation and the exploitation of knowledge has come to play the predominant part in the creation of wealth. It is not simply about pushing

> back the frontiers of knowledge; it is also about the more effective use and exploitation of all types of knowledge in all manner of economic activity" (DTI 1998)

Several features of this knowledge economy were highlighted as particularly important including (a) the development of information and communication technologies (ICT), (b) the role of new scientific knowledge, (c) the growth in global competition, and (d) changing patterns of consumption based on increased incomes (DTI 1999c: 12). These four characteristics may appear arbitrary – they are also contentious for a number of reasons (Sokol 2004; Thompson 2004) – but they do illustrate the view that the factors relied upon by developed economies are different from those relied upon by industry dominated economies. These factors are largely presented as intangible, 'weightless' or as Charles Leadbeater (1999: viii) contends we "make our money from thin air" (see also Rifkin 2001).

The empirical definition of the knowledge economy has consisted of different metrics (e.g. employment, expenditure on ICT), but more generally concentrates on both high-tech manufacturing and services sectors. These include aerospace, telecommunications, information technology (IT), pharmaceuticals, biotechnology, old and new media, advanced business services, and creative/cultural industries (Cooke 2004d), as well as education and healthcare and other public or non-profit services (see Malecki 2000; Cooke 2002c). Such sectors are characterised as knowledge sectors because of the higher than usual research intensity (i.e. R&D expenditure as proportion of revenue) and higher

levels of scientific and technical employment, both of which are meant to indicate a higher level of innovativeness and creativity (Rifkin 1996; Malecki 1997; Florida 2002). However, there is little to distinguish the empirical definition of the knowledge economy from its theoretical use since so much of the discussion is based on technologically determinist concepts. The assumption that the definition of the knowledge economy is constituted by innovation and technological change can therefore be seen as problematic (Sokol 2004).

Consequently, the central identifying feature of the knowledge economy concept is the role innovation plays in economic performance at a firm level and the role of innovative firms in economic performance at a geographic scale (Cooke 2002c; Simmie 2003; Asheim and Gertler 2005; Fagerberg 2005). Innovation can be characterised in a number of ways, as outlined below:

- Schumpeter (1942) argues it is "new commodities, new technologies, new sources of supply and new types of organisation" (quoted in Simmie 2001: 14).
- European Commission (1996) defines it as "the commercially successful exploitation of new technologies, ideas or methods through the introduction of new products or processes, or through the improvement of existing ones." (quoted in Simmie 2005: 790).

- Fagerberg (2005: 6-7) writes of "new products, new methods of production, new sources of supply, the exploitation of new markets, and new ways to organize business."
- Gordon and McCann (2005) suggest it covers "the successful implementation of a new product, service, or process, which for most activities entails their commercial success."

Distinctions are also made between product and process innovation (Malecki 1997) and between radical and incremental innovation that highlights the importance of diffusion (Freeman 1982). It is therefore evident that there are a number of different ways to conceptualise innovation, but that they all contain similar themes, such as an emphasis on 'newness' and consequently uncertainty as well as learning (Malecki 2000; Cooke 2002c; Fagerberg 2005; Gordon and McCann 2005). However, this conceptual emphasis reinforces the perception that technological change directs economic change and reinforces the emphasis placed on innovation.

Innovation is seen as central to the knowledge economy in that it represents the end point of economic development because it can be seen as "the transformation of knowledge into novel wealth-creating technologies, products and services through processes of learning and searching" (Asheim and Coenen 2006: 149). Thus innovation is distinct from knowledge in that it concerns the production of economic value (e.g. wealth), whereas knowledge represents the capacity for and organisation of understandings about the world (see Nonaka and Takeuchi 1995). Thus, although the definition of the

knowledge economy is ambiguous, it can be usefully defined as the commercialisation of 'new' understandings as a resource through the capture of existing and expected future knowledge by the adaptation of institutional systems like intellectual property (IP) (see Drahos and Braithewaite 2002, 2004). It therefore entails the production of both commodities (intangible and tangible) and markets through investments in R&D, organisational change, marketing etc. In this sense, technological change and innovation do not necessarily represent Schumpeterian 'creative destruction', but rather the daily operation of the knowledge economy simultaneously across sectors rather than in the linear model of one sector superseding another. It is therefore too simple to argue that one set of structures produces advantages for some and disadvantages for others since innovation occurs across sectors and structures (Cooke 2002c). Thus technological change and innovation are continual processes (Nelson and Winter 1974, 1982; Dosi 1988; Tödtling 1994). Alongside other sectors like IT, telecommunications and new media, the '*modern* biotechnology' industry is one in which innovation is constant. For this and other reasons it lends itself well to the study of the relationship between knowledge and space.

1.3 THE KNOWLEDGE 'BIO'-ECONOMY

In discussions of the knowledge economy and innovation there are a number of sectors that are repeatedly cited as examples. One such example is the biotechnology industry. In the last few years, the industry has gradually been redefined as the 'bioscience' industry and now 'life science' industry as researchers and policy-makers have sought to

encompass a broader range of economic activity within it. Despite the greater breadth in these later definitions, the focus of attention is still on the scientific and technological derivatives of post-1953 research in genetics, molecular biology, biochemistry and more recent disciplines like bioinformatics, genomics and proteomics. These depend on discoveries in recombinant DNA, cell fusion, protein engineering, recombinatorial chemistry and other such technologies (House of Lords 1993; Woiceshyn 1995). In the UK the biotech industry was originally defined in terms of the application of the biological sciences to industrial production (see ACARD et al 1980) with later definitions conceptualised in "enabling" terms that have persisted (House of Lords 1993). In two important Department of Trade and Industry (DTI) reports, *Biotechnology Clusters* (1999a) and *Genome Valley* (DTI 1999b), biotechnology was similarly defined as "the application of knowledge about living organisms, and their components, to make new products and to develop new industrial processes" (DTI 1999a: 1).

As an industry, biotechnology presents a useful example of the knowledge economy for two primary reasons; first, it relies on high levels of sophisticated scientific knowledge and, second, it relies on a highly educated workforce (Audretsch and Stephan 1996, 1999; Bartholomew 1997; Prevezer 1997; McKelvey et al 2004). It has always been unevenly distributed with major sites of activity in particular places like California and Massachusetts in the USA and Cambridgeshire in Europe, which have persisted as the industry has matured (Prevezer 2003; Cooke 2004a). Several authors have suggested that such concentrations persist because of the nature of the knowledge being used in the biotech industry; it is dependent upon people, especially 'star' scientists (Zucker et al

1998) and relies upon a specific set of intellectual property rights (IPR) (Fuller 2001; Drahos and Braithwaite 2002). Without these aspects the knowledge used in biotechnology innovation would be available to every interested party, so innovators have to ensure that biotech knowledge is appropriable (Zucker et al 1998; Audretsch and Stephan 1999). Consequently the importance of scientists and IPR means that biotechnology can be commercialised, providing an incentive for private capital to invest in innovative activity (MacKenzie et al 1990; Heller and Eisenberg 1998; Hughes 2001).

Although there has been a great deal of enthusiasm and expectation surrounding the biotechnology industry in the 1990s (e.g. DTI 1999a) and the early 2000s (e.g. Boulnois 2000; BIGT 2003), more recent analyses have questioned the innovative and economic performance of the sector (see Arundel and Mintzes 2004; FDA 2004; Nightingale and Martin 2004; Joppi et al 2005). The innovativeness of biotech is therefore neither uncontested nor the simple technological progression of knowledge and its application. Rather there are a number of material and institutional features of the biotech innovation process that impact on and constitute the biotech industry producing both positive and negative effects on the direction of technology (see Arthur 1989, 1999; Cooke 2002c). Considering these systemic effects in dynamic terms through concepts drawn from evolutionary economics necessitates a consideration of path dependency and technological lock-in (Nelson and Winter 1974, 1982; Dosi 1988). However, in order to consider the role of knowledge we must add a spatial dimension to these systemic and dynamic features and this is something that evolutionary economics does not contain, although some authors have tried to theorise it (e.g. Boschma and Lambooy 1999;

Boschma 2004). Therefore it is important to consider the geographical basis of the knowledge economy, especially in terms that seek to explain how and why certain locations dominate certain sectors.

1.4 THE GEOGRAPHY OF THE KNOWLEDGE ECONOMY

The knowledge economy consists of organisations that need the capability to acquire, absorb, learn from, utilise and then unlearn knowledge (see Cohen and Levinthal 1990; Morgan 1997). These provide the means for organisations, particularly companies, to dynamically change and adapt as necessary with the 'environmental' pressures (see Nelson and Winter 1974, 1982). However, such firms are also spatially embedded and this necessitates the consideration of the geography of organisational capabilities, particularly the inter-organisational linkages between different organisation types (e.g. firms, public research bodies). Without such capabilities and linkages these organisations would not be able to function because innovative activity relies upon (1) access to a diverse range of knowledge, (2) access to new knowledge in order to maintain continuous innovation, and (3) iterative interaction between knowledge sites or nodes (von Hippel 1988, 1994; Scott 1998b). It is therefore possible to argue that the knowledge economy is spatially constituted because people in organisations rely upon access to and interaction with these different sites of knowledge. This necessitates an approach to knowledge that incorporates an understanding of the role of external organisations, institutions and agglomerations in providing people with the means to benefit from systemic relationships

that cut across different organisational types and geographical scales (Gibbons et al 1994; Audretsch and Stephan 1996).

At a local level, organisations can gain access to other organisational knowledge through positive externalities such as 'knowledge spillovers' whereby knowledge produced and used in one organisation escapes organisational boundaries through labour mobility and market interaction. Other organisations can then acquire and adapt this knowledge to their own organisational needs, but they need to be 'open' to new knowledge (see Chesborough 2003) and therefore subject to knowledge escape themselves. Patent citations have been used as a means to track the geography of such spillovers with Jaffe and Tratjenberg (2002) showing that there is a distinct time and location lag between patent publication and citation by another patent. Other research in endogenous growth theory has also placed an emphasis on the importance of knowledge spillovers (e.g. Romer 1990, 1994; Grossman and Helpman 1994), although Acs et al (1991) have argued that spillovers cannot explain the process of knowledge transfer from universities to firms (see also Acs et al 1999). However, Krugman (1991) argued that spillovers are not the only factor that makes certain locations attractive meaning that they do not offer a full explanation for the geography of the knowledge economy.

Instead of focusing on the organisational level, other authors have emphasised the importance of the institutional features of locations, whether at a global, national or regional scale. In the first case, the creation of specific global IPR regimes, such as TRIPS at the WTO (Drahos and Braithewaite 2002), and regulatory systems, such as

pharmaceutical regulations in the EU which are designed to enhance competitiveness (Abraham and Reed 2002, 2003), produce 'institutional thickness' that promotes innovation (Amin and Thrift 1992, 1994; Keeble et al 1999). The national case has been explored in relation to both the 'varieties of capitalism' (Hall and Soskice 2003) and national systems of innovation perspectives (Lundvall 1992). In the latter theory the importance of different national features to innovation is explored in reference to innovation with 'social market' countries like Germany pursuing incremental innovation whilst 'liberal market' countries like the USA pursue radical innovation (Gertler 1997, 2001). At the local scale these analyses focus on the embeddedness of organisations in local institutions that promote the development of trust and social capital through the increasing probability and encouragement of interaction between co-located organisations (Amin and Thrift 1992; Amin 1999). Such embeddedness does not mean that organisations operate at an isolated scale, but rather that the local is constituted by its relationship to the global (Amin and Thrift 1994).

The final set of theories emphasise the geographical basis of organisational activity in terms of concepts like agglomeration, which originated in the work of Alfred Marshall and Alfred Weber in the nineteenth century. Here specific activity is located in specific locations because of the benefits that accrue to those organisations in those places through economies of scope and scale. These can include shared local resources, shared local services and labour markets, as well as knowledge spillovers (Simmie 2001). Later theoretical work in agglomeration economies distinguished among internal returns to scale, as well as localisation and urbanisation economies (Hoover 1937). Thus on the one

hand, organisations that locate near similar organisations benefit from shared inputs, whilst organisations that locate near different organisations benefit from the diversity of inputs. There are numerous possible explanations of the benefits that accrue from co-location that cut across material and relational factors. In terms of innovation and knowledge these could consist of the importance of 'learning through interaction' through the difficulty of transferring knowledge across distance to the importance of face-to-face relationships in transferring knowledge and developing trust (Asheim and Gertler 2005). Several authors have built on the national systems theories to suggest that there are regional innovation systems (e.g. Cooke 2004d) or learning regions (Florida 1995; Morgan 1997). Perhaps the most famous example is the work of Porter (1990, 2000, 2003; Porter and Solvell 1998) on 'clusters' of industrial activity, which emphasises the importance of local linkages both along the 'value chain' and across local organisations. All these theories have been applied to the biotech industry in one form or another, although they have, in turn, raised a number of further issues and problems in explaining satisfactorily the spatial embedding of biotech innovation processes.

1.5 CENTRAL THEORETICAL AND EMPIRICAL PROBLEMS

Social science research on the biotechnology industry can be broadly split into a series of phases stretching from early work on management strategy through innovation systems to the more recent emphasis on knowledge spillovers (see Senker 2005). Throughout these phases there has been continuing interest in the political economy of biotechnology (e.g. Kettler and Casper 2000; Loeppky 2004, 2005; Lofgren and Benner 2005). Both strategic

management and innovation systems approaches focus on the acquisition and use of biotech knowledge by biotech and pharmaceutical firms. They also focus on the differential impact of internal firm capabilities and the complementarities of external firm collaborations (e.g. Deeds and Hill 1996; Prevezer and Toker 1996; Sharp 1996; Saviotti 1998). Such analyses are not concerned with geographical aspects except at the broadest national scale. The more recent spillovers approach is oriented towards the regional scale, although because it adheres to a systems perspective it does not adequately address the relationship between different scales. The ongoing approach drawn from political economy obviously concentrates on national differences, although it also considers the important role of supranational and increasingly international governance as well (e.g. Loeppky 2004, 2005).

In the strategic management literature, there is a focus on the importance and role of networks, collaboration and alliances to firms (see della Valle and Gambardella 1993; Powell et al 1996; Powell 1998; Chiesa and Toletti 2004; Powell et al 2004). Such interactions provide the means to access capabilities that firms and other organisations do not have like marketing and manufacturing particularly in the case of dedicated biotech firms (DBFs) (Woiceshyn 1995). They also mean that DBFs can avoid some of the uncertainty and offset their risks during innovation (Chakrabarti and Weisenfeld 1991). Furthermore they necessitate that firms remain 'open' to external knowledge which helps to prevent lock-in (Cooke 2005a, 2005b, 2006) but may also entail a loss of proprietary knowledge. Ironically this means that knowledge excludability is particularly important

to DBFs in the form of either strong IP protection (May 2000) or tacit knowledge from scientists (Zucker et al 1998).

Despite the range of the strategic management literature, there are a number of important gaps in the research. First, they concentrate on social networks rather than spatial networks, which downplays the importance of space in social interactions. A second gap results from the atomistic approach to understanding organisational activity in that there is little consideration of how innovation occurs systematically through the interaction among a range of organisations and not just those involved in a direct relationship. Finally, the understanding of innovation and knowledge is largely static consisting of an analysis of a single time-dependent relationship. In this thesis these issues are addressed with the first hypothesis, which is:

> H1: There are 'knowledge economy' concentrations because successful innovation depends on dynamic (i.e. across time) and systemic (i.e. across organisations) processes embedded in and across specific places.

The innovation studies literature presents a systemic approach to understanding innovation that draws upon work in evolutionary economics and science studies (Fagerberg 2005). Several authors argue that different national or supra-national scales entail specific innovation systems that benefit biotech firms operating within them. This provides a competitive advantage for certain locations such as the characterisation of the USA as a beneficial biotech environment compared with Europe (e.g. Senker et al 1996;

Sharp 1996; Acharya et al 1998; Saviotti et al 1998; Sharp and Senker 1999). One distinctive theory in this field is Etzowitz and Leydesdorff's (2000) *Triple Helix* model in which university, industry and government combine to produce a particular innovation system for biotechnology. Again there are a number of difficulties with this literature. First, such innovation systems remain loosely defined and when they are applied to specific locations they remain a 'fuzzy' concept (Markusen 2003) that ignores national or global scale actors (Lovering 1999) and presents analytical explanations as descriptions that normalise local policy prescriptions (Lovering 1999, 2001). Second, the tendency to normalise explanations also leads to the reversal of causality in that the location of the system is argued to be the reason for innovative activity (Malmberg and Maskell 2002). At a regional scale, according to Frank Moulaert and Farid Sekia, this is because:

> "The conceptual superficiality of the TIM [territorial innovation model] literature is a consequence of several factors such as the immediate links with regional economic competition policy (many TIM were written to legitimize it)" (Moulaert and Sekia 2003: 295).

Finally, the concentration on a system as the source of innovation leads to a supply-side focus that treats sources of demand as external or less significant than the endogenous qualities of the system or particular location. In this thesis these issues are addressed with the second hypothesis, which is:

H2: Successful innovation in the knowledge economy depends on place-specific dynamic and systemic processes because different types of knowledge originate in different places and at different scales necessitating interaction both within and beyond concentrations.

The final set of literature on biotechnology concerns industrial clusters. Porter (1990: 41) defines clusters as a "a network of activities, connected by linkages" that combine different activities within the firm and with external organisations (e.g. suppliers, customers). In his later work, Porter (2000) concentrates more on spatial clusters in contrast to his early focus on sectoral ones (see Malmberg 2003), which has been liberally applied as an explanation for the location of the biotech industry. Within this literature there is an emphasis on several common characteristics that derived from the importance of localised, informal and tacit knowledge exchange between cognate firms, supply/service firms, public sector and other organisations (see Ryan and Phillips 2004). Some common features include:

- Concentrations of dedicated biotech firms (DBFs); usually small or medium sized enterprises (SMEs)
- Concentrations of 'upstream' and 'downstream' competencies (e.g. universities, large pharmaceutical firms)
- Local linkages between the organisations as well as with local service providers (e.g. lawyers, accountants, consultants)

- Local identity fostered by local government or through trade associations and networks
- Local government involvement in the promotion of a 'cluster' approach to economic development.

These features are stylised representations of a number of different theories. Many of these also emphasise the importance of extra-local linkages, in contrast to Porter's cluster argument, in acquiring knowledge and knowledge workers (Lawton-Smith et al 2000; Cooke 2004b; Leibovitz 2004; McKelvey et al 2004). There are once again a number of problems with this approach. First, the focus on a particular location tends to not only limit the analysis of extra-local linkages, but also leads to a loss of comparative perspectives as research concentrates on one location to the exclusion of others. Second, the concentration on one location leads to the conceptualisation of that location as an agent in regional economic performance; i.e. local assets lead to successful outcomes. Finally then, the treatment of a location as an actor tends to produce descriptive research that concentrates on what happens in that location and not how processes function in that location (i.e. explanatory research). In this thesis these issues are addressed with the third hypothesis, which is:

H3: The knowledge economy depends on different locations and scales of knowledge because different places have different locational assets that contribute to successful innovation in different ways and therefore necessitate linkages between locations.

1.6 CONCLUSION AND THESIS SUMMARY

The overall aim of this thesis is to explore the relationship between knowledge and space using the British biotechnology industry as a case study of the knowledge economy. The main reason to do this is to synthesise different approaches in order to avoid a number of theoretical and empirical issues that existing research has encountered in understanding both knowledge and space and the relationship between them. In the next seven chapters I will develop and apply an approach that combines theories of knowledge and theories of space into a conceptual perspective that can be applied to understanding the *knowledge-space* dynamic in terms that address existing theoretical and empirical concerns. This new conceptual approach will combine elements of existing *functional*, *relational* and *associational* theories drawn from a range of disciplines including economics, economic geography, regional studies, management studies, and economic sociology. The three core hypotheses raise questions about whether the biotech industry is concentrated in particular places and asks if so what are the specific features of these places. They also concern the nature of the relationship between different types of knowledge and different places. Finally they consider why different types of knowledge and places impact on innovation in different ways and how the relationship between places may affect this.

The thesis explores how and why the knowledge economy is positioned and embedded in different places. This is achieved uniquely by focusing on the knowledge and spatial processes of biotechnology innovation, rather than by assuming that such concentrations

by necessity entail such processes. Consequently it highlights the processes that are traditionally accepted to underpin the concentration of 'knowledge' industries like biotechnology. Furthermore, the thesis uses a new theoretical approach called the *knowledge-space* dynamic drawing from a diverse number of disciplines (Chapter 2). This directly impacts on the research design and methodological framework (Chapter 3). Using this theoretical and methodological approach, the thesis contains a set of background (Chapter 4), secondary data (Chapter 5) and primary data (Chapter 6) that have not been gathered toegther in one project before.

The first section of the thesis (Part I) concerns the theoretical and methodological grounding of the research approach. The former is fully laid out in Chapter 2 bringing together theories of knowledge and space into a new conceptual approach that can address the *knowledge-space* dynamic inherent to the knowledge economy. This will draw on previous work in economics, economic geography and economic sociology as well as cognate disciplines. Chapter 3 follows directly on from this by outlining a methodological approach that incorporates secondary and primary data collection along biotechnology value chains. The core of the thesis (Part II) consists of background and data analysis chapters. Chapter 4 provides historical background and well as the global and institutional context of the British biotech industry. In Chapter 5 the data analysis concentrates on secondary data concerning the location of the British biotech industry, which includes a number of different variables that impact on innovation processes. Finally, Chapter 6 concerns the results of the primary research from a survey of actors drawn from biotech value chains. In the final section (Part III), the main findings and

conclusions are summarised in Chapter 7 before these are used to consider a number of policy implications.

The major findings of the research show that the biotech industry is not as significant an industrial sector as many policy and popular discourses would suggest. For a start, the global industry has never been profitable (Ernst & Young 2003c; Lahteenmaki and Lawrence 2006) and the latest figures show global net losses of $4.39 billion (Lawrence 2006: 603). Its impact on employment is also relatively small with less than 45,000 total employees and around 10,000 'knowledge workers' (i.e. those in R&D) in the UK. Since the UK only has around 430 firms no UK region, even at the relatively large NUTS1 scale,[i] has more than 105 firms; this implies that biotech 'clustering' is limited. However, four regions (South East, East England, London and Scotland) have more than the average number of firms, university departments, public research organisations and service providers, and as such it could be argued that they represent clusters. Their significance for regional economic performance is another issue. In terms of the relationship between knowledge and space, there was little to indicate that innovators drew exclusively upon localised sources of either tacit or explicit knowledge, nor that they necessarily combined local sources with international ones. Overall the research showed that there was not a localised concentration of biotechnology knowledge, but rather that innovators and firms drew upon a variety of knowledge sources and types from a variety of places.

PART I

Theory and Methodology

This section of the thesis concerns the development of the theoretical and methodological approach used to construct the three hypotheses already outlined in Chapter 1 and how these have been addressed in the research design. The theoretical approach provided in Chapter 2 is centred on the concept of the *knowledge-space* dynamic, which concerns the spatial specificity of different types and forms of knowledge and how the spatial and scalar positioning and embedding of these knowledges impact on the innovation process. The methodological approach detailed in Chapter 3 builds on this theory in a framework that incorporates a number of features from different theories and concepts including a value chains, innovation systems and biotechnology innovation approaches. These all contribute to the research design that is discussed in the rest of the chapter. The framework is built upon a case study that uses biotech values chains (i.e. biotechnology products) as an example of the knowledge economy and enables the exploration of how knowledge and space relate to one another in the innovation process.

CHAPTER 2

DEVELOPING THE *KNOWLEDGE-SPACE* DYNAMIC: THEORETICAL DISCUSSION

2.1 INTRODUCTION

As economic theories have developed throughout the twentieth century the role of knowledge has been positioned as an increasingly prominent driver of economic growth and development. Such emphasis is not a uniquely modern concern since Adam Smith (1723-1790) in the *Wealth of Nations* highlighted the importance of specialisation that:

> "…increases the competition of the producers, who, in order to undersell one another, have recourse to new divisions of labour and new improvements of art" (quoted in Best 2001: 61).

Furthermore, Alfred Marshall (1842-1924), writing over a century later, emphasised the importance of knowledge as a driver of economic growth and the 'fourth factor of production' that attracts producers to particular places (Freeman 1982; Best 2001). Despite such concerns with knowledge and especially Marshall's interest with its interdependence with place, knowledge has only really become a particular policy concern more recently and especially after World War II with the onset of industrial restructuring and globalising markets (see Howells 1997). Such policy interest has

developed through a number of different theoretical phases to the current focus on the 'knowledge-based', 'knowledge-driven' or 'knowledge economy'. Although there are terminological similarities between these concepts they do not necessarily mean the same thing (see Cooke and Leydesdorff 2006).

In recent policy discourse at the national, supranational and international levels the knowledge economy has achieved hegemonic dominance despite a number of problematic concerns with the concept and its policy implications. For example, recent policy discourse (e.g. OECD 1996, 2005; DTI 1998; HM Treasury 2003; House of Commons 2003; Rodrigues 2003; Rosiello 2004; Scottish Enterprise 2004; EC 2005) emphasises the particular role of the public science base with academic research highlighted as crucial, especially in relation to government defence expenditure (Hall 1997) and, more recently, health expenditure (Etzkowitz and Leydesdorff 2000). Implicit within the knowledge economy therefore is the connection between the public and private sectors. For example, in relation to biotechnology the National Health Service (NHS) has been championed as a nationally specific resource for the UK (BIGT 2003; DoH 2003 Vince 2006). Furthermore the knowledge economy has been promoted in policies focused on the role of universities in regional economic development especially by Regional Development Agencies (RDAs) (Goddard and Chatterton 1999; Potts 2002).

This Chapter outlines the analytical foundations for the thesis by developing a theoretical framework that underpins the thesis hypotheses and research questions. The Chapter starts (2.2) with a brief history of 'knowledge economy' theory from the early work by

Machlup (1962) through to the current emphasis on the knowledge-based economy, all of which stress the role that knowledge and information have on economic development generally. Second it outlines (2.3) how innovation contributes to economic growth at the level of the firm. This sets the stage for the consideration of how both knowledge (2.4) and space (2.5) impact on the innovation process. These discussions then feed into the analytical perspective I have called the *knowledge-space* dynamic (2.6) which seeks to combine aspects of both knowledge and spatial theories of innovation. Subsequently this approach is used to develop a conceptual framework (2.7) that raises a number of research questions in pursuit of the central thesis hypothesis:

> Despite being an internationally distributed sector, biotechnology innovation is concentrated in regional nodes because these locations provide advantage through a *knowledge-space dynamic* that encompasses functional, relational and associational features.

Finally, the conclusion will summarise the overall theoretical basis of the thesis before introducing the research design and methodology chapter (Chapter 3).

2.2 THE KNOWELDGE ECONOMY

Although both political economy and classical economics were concerned with the new division of labour in the industrialising society of the eighteenth and nineteenth centuries, they did not focus on it as a particular factor of production. As mentioned both Adam

Smith and Alfred Marshall had considered knowledge to be crucial, but it was first considered seriosuly in the work of Joseph Schumpeter (1883-1950). However, Schumpeter concentrated on the firm level whilst the early discussions on the knowledge economy tended to focus on the broader, societal scale. Schumpeter will therefore be discussed in the next section (2.3). The likes of Robert Solow illustrated the importance of knowledge in work on technical change in the 1950s although he conceptualised technology as exogenous to the market in contrast to Schumpeter who saw it as endogenous (Scherer 1999).[ii] This work by Solow (e.g. Solow 1956) and others built upon earlier economic theories by introducing the concept of technical change as a key factor in economic growth. He argued that labour (L) and capital (K) could not sufficiently explain economic growth since there was a significant 'residual' that was unaccounted for in the traditional production function (f) (see Nelson and Winter 1982; Coombs et al 1987; Cooke 2002c; Easterley 2002). Such technical change could be incorporated into earlier models of the production function as time (t):

$$Q = f(L, K, t)$$

By treating it as neutral, the production function can be split further between technical change (A) and labour and capital:

$$Q = A(t)f(L, K)$$

However, this 'residual' is problematic because, apart from the assumption of neutrality, it covers a wide range of changes including those to organisations, knowledge and education that could impact on economic development (Coombs et al 1987).

Once the role of knowledge, conceptualised as technological change, was highlighted it opened the way to the conceptualisation of economic development as knowledge-driven or knowledge-based.[iii] This was especially relevant to countries whose relative industrial employment had peaked in the 1950s and 1960s like the USA and UK (Townsend 1997; Sadler 2000). The Organisation for Economic Co-operation and Development (OECD) was itself established in 1961 to help promote science and technology policies across its member countries (Cooke and Leydesdorf 2006) and subsequently played a crucial role in the promotion of the 'knowledge economy' concept (Godin 2006). There have been a welter of concepts and definitions since the 1960s including the 'information(al) economy', 'information age', 'post-industrial society', 'post-Fordism', 'service economy', 'new economy', 'weightless economy', and 'post-capitalist society'. In particular there was a proliferation around the theme of the 'knowledge economy' such as the 'knowledge society', 'knowledge-driven economy', 'knowledge-based economy' and the 'learning economy' (Webster 1995; OECD 1996; Morgan 1997; DTI 1999c; Brint 2001; Johnson and Lundvall 2001; Cooke 2002c; Rodrigues 2002; Sokol 2003, 2004; Thompson 2004; Godin 2006).[iv] This changing debate raises two important points, namely that knowledge has become a 'strategic resource' and that learning is crucial for the 'competitiveness' of different places (Coenen and Asheim 2006).

As mentioned, one of the first people to define the 'knowledge economy' was Machlup (1962) who identified 29% of the US GNP in 1958 as belonging to 'knowledge industries': these were defined as those industries which were information centred and therefore make an impression on people's minds (Brint 2001).[v] As such it was a definition that included a broad range of knowledge sectors that included fields like education, research and development (R&D), media and communications, information services and information technologies (Cooke 2002c; Cooke and Leydesdorff 2006). This rather broad definition was not only inconsistent since it combined numerous diverse sectors (e.g. private and public), but also Machlup's expectations of the spread of the knowledge economy proved overly optimistic. For example, later studies of knowledge industries showed that the growth in proportion of GNP was fairly limited and reached a plateau of 34% during the 1970s (Brint 2001: 106). Despite some optimistic claims that the service sector will account for 80% of the UK economy by 2010 (Leadbeater 1998: 376) – which in itself is an inadequate characterisation of the knowledge economy because it covers a vast array of activities – a number of other commentators are less positive. They suggest instead that the potential of the knowledge economy is and will remain limited – especially in some regions – to around a third of employment (Webster 2001; see also Vallas 1999; Thompson et al 2001; Thompson 2004).

Whilst Machlup sought to highlight specific sectors of the knowledge economy, the American social theorist Daniel Bell (1973) focused on the possible change from industrial to 'post-industrial society'. Here Bell's arguments built directly on the conceptualisation of knowledge as a productive resource by suggesting that societies

become increasingly dependent upon the service sector and science-driven, high technology industries (Brint 2001; Thompson 2004). In particular, Bell emphasised the importance of 'theoretical' knowledge in order to distinguish the post-industrial epoch from earlier periods, which therefore leads to a focus on the university and 'knowledge workers'. This, in turn, leads to the idea that there is a 'knowledge society' based on the application and production of intellectual knowledge such as the management practices promoted by F.W. Taylor (Osborne 1998; Fuller 2000; Rikowski 2000; Sokol 2004). Consequently, universities and academic credentials are considered as crucial prerequisites for the development of the knowledge society and are therefore increasingly capitalised and marketised in pursuit of specific forms of value (Brint 2001; Kleinman and Vallas 2001). The university and especially its relationship with industry therefore become a crucial concern in the knowledge economy (Delanty 2001).

Later discussions in the Regulation School around the shift from Fordism to 'Post-Fordism' (Aglietta 1979; Webster 1995; Vallas 1999; Simmie 2001) follow on from the work of Bell as well as the 'flexible specialisation' arguments of authors like Piore and Sabel (1984) in *The Second Industrial Divide*. In this school of thought a number of shifts can be identified in both the regime of accumulation and mode of regulation in Western, capitalist societies (Webster 1995). This can be characterised as a shift from mass production manufacturing (i.e. Fordism) towards a globalised, service-based society (i.e. Post-Fordism) reminiscent of Bell's earlier arguments (Webster 1995). Technology plays a central role in this movement as it enables increased 'flexibility' or 'flexible accumulation' (Vallas 1999), which was most evident in changing production practices

such as ‘just-in-time’ or batch production (Murray 1985) as well as outsourcing (Webster 1995). Again there are a number of discrepancies and contradictions in this perspective, not least of which is the somewhat optimistic contention of some authors (e.g. Piore and Sabel 1984) that ‘Post-Fordism’ represented enormous opportunities for workers (see Webster 1995; Vallas 1999; Kleinman and Vallas 2001).

Yet another concept developed around these ideas were those of Manual Castells (1996) and others on the ‘information society’. Rather than focusing on shifting regimes of accumulation, Castells concentrates on changes to technologies, especially those that relate to the gathering, production, processing and exchange of information and knowledge (Sokol 2003; Thompson 2004). Centrally then, the information society is characterised by the application of knowledge to the production of knowledge (Cooke 2002c), which means that information technology is positioned at a crucial juncture in economic activity. Others like Jeremy Rifkin (1996) present less uplifting analyses by arguing that the ‘new economy’ represents *The End of Work*. More recent arguments about the ‘weightless economy’ (Rifkin 2001) or ‘living on thin air’ (Leadbeater 1999) were all written before the ‘dotcom crash’ in 2000-2001 and perhaps illustrate the dangers of basing such theories on technologically determinist premises (see Sokol 2004). However, it is useful to take away from this discussion the importance that intangible assets have to modern companies, especially those assets that are embedded or embodied in technical knowledge.

The emphasis on technology and in particular on specific technological regimes or waves is reiterated in the firm-level theories derived from Schumpeter's work on innovation (2.3) discussed in the next section. More crucial to note here is that the preceding debates have led to the current interest in the 'knowledge economy'. It is possible to argue that the knowledge economy, as defined in policy at least (see DTI 1999c),[vi] contains features of all four previous concepts with slight differences. Thus the knowledge economy is characterised by industries dependent upon knowledge, which means that knowledge workers are crucial to economic development. Furthermore, changing patterns of consumption entail changes to productive processes and regulations, which are, in turn, influenced by new technologies. Perhaps the most important difference is the emphasis on the individual knowledge capacities and capabilities of both workers and firms (Sokol 2003), which is considered to be socially and iteratively reproduced rather than constrained by organisational boundaries (Cooke 2002c; Chesborough 2003; Cooke 2006). In these terms, the knowledge economy can be characterised as both knowledge-based and knowledge-driven because of the dual purpose of knowledge as both producer and product (Cooke 2002c).

There has been a particular emphasis placed on both the investment in knowledge and the spread of knowledge industries, which combines the focus on learning in the 'learning economy' (Lundvall 1992; Johnson and Lundvall 2001) with the concern with high technology industries in the 'knowledge economy' (Morgan and Murdoch 2000; Godin 2006). According to Godin (2006) these two concerns were wedded together in the work of the OECD during the 1990s in an updating of the original knowledge economy thesis

put forward by the likes of Machlup in the 1960s. It has since been taken up by a number of authors such as Charles Leadbeater (1999: 52) who in *Living on Thin Air* argues that:

> "…knowledge is not just one among many resources, it is becoming the critical factor in how modern economies compete and how they generate wealth and wellbeing".

Because knowledge work is considered to be inherently 'creative' in that it involves the production, processing and transfer of knowledge (Leadbeater 1998; Thompson 2004), it has been positioned in highly positive terms as both a current social trend and potential outcome (Godin 2006). As such it represents a strongly policy-oriented concept that has been adopted across the current UK government from the Prime Minister downward (see Rikowski 2000).

The vision offered in the knowledge economy thesis of the knowledge worker – independent, creative, innovative, entrepreneurial, learning, wealth producing – has provided a strong policy pull for the New Labour administration in the UK and its devolved regions (Thompson et al 2001). For example, the Prime Minister stated in 1999 that:

> "To succeed in this new, competitive, global economy, Britain's businesses need to be knowledge-driven. That applies not just to high-tech business but to all

> businesses in all sectors…Business must lead the way towards the knowledge economy. But government has a part to play" (quoted in Rikowski 2000: 164).

Furthermore, the departments of Trade and Industry (DTI) and Education and Employment (DfEE) have expressed similar sentiments in documents like *Building the Knowledge Economy* and *Learning Age* respectively (Goddard and Chatterton 1999; see also Rikowski 2000; Thompson et al 2001). The British government's Competitiveness White Paper, drafted by Charles Leadbeater, defined the 'knowledge-driven economy' as:

> "…one in which the generation and the exploitation of knowledge has come to play the predominant part in the creation of wealth. It is not simply about pushing back the frontiers of knowledge; it is also about the more effective use and exploitation of all types of knowledge in all manner of economic activity" (DTI 1998).

This aligns the production, processing and transfer of knowledge with its commercial exploitation and therefore legitimates the expansion of intellectual property (IP) regimes, usually following codification (Jessop 2000; Luque 2001; Roberts 2001). This contrasts somewhat with the promise offered by Leadbeater (1998, 1999) of the empowered knowledge worker.

More widely the knowledge economy has come to dominate supranational and international policy-makers, especially the European Commission (EC 2000; Rodrigues

2003) and OECD (1996, 1999b). The knowledge economy's most recent incarnation originated in the latter and was especially focused on Europe rather than the USA (Godin 2006). The importance of this agenda in Europe is most evident in relation to the 2000 Lisbon Agenda (2000; also EC Enterprise DG 2002) and 2002 Sapir Commission (The Sapir Group 2005) although it also impacts directly on bioscience policy in relation to the more recent 'knowledge-based bio-economy' project (EC 2004, 2005; see also Rosamond 2002). For the OECD, the knowledge economy concerns both investments in knowledge and their distribution through networks and is conceptually related to both 'new growth theory' and 'national systems of innovation' (OECD 1996; Godin 2006). Knowledge codification is particularly highlighted as crucial to the knowledge economy enabling knowledge to acquire "more of the properties of a commodity" (OECD 1996: 13). Learning and tacit knowledge (see below), however, are still considered important, especially in relation to the 'interactive learning' between firms and institutions, which is a key element to measure in dynamic systems (see Godin 2006). The EC has taken on board the OECD recommendations that governments need to adapt to this 'paradigm shift' with an aim "To establish an inclusive, dynamic and knowledge based economy", not only in terms of knowledge investment but also institutional 'adjustment' (EC 2000: 11; see also Rodrigues 2002).

2.3 INNOVATION AND ECONOMIC DEVELOPMENT

The knowledge economy theory focuses on broad economic trends and therefore it does not adequately address the processes through which knowledge impacts on economic

development. In order to consider the specific processes that impact on economic development it is useful to consider the studies of innovation inspired by Schumpeter and others. This research provides the means to explore the role that innovation plays in the knowledge economy and how this then impacts on economic change at the regional (Cooke 2004d), national (Lundvall 1992) and even international (Gereffi 1994) scale. Here innovation can be described as the "novel application of economically valuable knowledge" in relation to products, processes or organisations (Feldman 2000: 371), which, in the context of the knowledge economy, refers to the application of knowledge to itself as Peter Drucker emphasised in the 1960s (see Brint 2001). However, this conceptualisation implies that innovation represents both the means and ends of the knowledge economy and economic development.

It is important therefore to distinguish between the knowledge economy and innovation in order to explore the role of the latter in the former. Perhaps the simplest way to do this is by first turning to the work of the Russian economist Nikolai Kondratieff (1892-1938) before considering Schumpeterian theories. In his work, Kondratieff outlined how capitalist economies progressed through long-term booms covering 40 to 60 years that were then followed by depressions (Hall 1981, 1985; Malecki 1997). Each boom represented a wave of technological change that revolutionised the economy. The first of these consisted of the power loom and steam power in the Industrial Revolution, whilst later waves included railways and steel, and electricity and chemicals (Malecki 1997). The eventual economic downturn stimulated the discovery of new inventions that then spread throughout the economy leading to the next upturn (see **Figure 2.1**). In the 1970s

Gerhard Mensch used the ideas of Kondratieff and Schumpeter to show that innovation, as opposed to invention, occurred in clusters over a short period of time that produced new processes, products and sectors (see Hall 1981).

Figure 2.1: Kondratieff Waves

Source: http://www.angelfire.com/or/truthfinder/index22.html

The knowledge economy, as currently conceived, could be considered as the fifth Kondratieff wave representing innovative developments in areas like biotechnology, new materials and nanotechnology amongst other technologies. Such innovations represent potential contributions to economic development in the long-term, rather than assured outcomes, since they necessitate a range of complementary institutions and organisations that embed increasing returns to adoption (see Fagerberg 2005). This is why Schumpeter (1939, 1942) could refer to the 'creative destruction' inherent in the innovation process as well as stress the importance of business cycles and long waves of innovation. Innovation not only leads to decline in some industrial sectors and the rise of other sectors, all of

which drives economic development (see Simmie 2001), but also to changes in surrounding institutions that relate to declining or rising sectors. Consequently, learning is a crucial aspect of the innovation process because it enables adjustment and adaptation to new circumstances through the interaction between institutions and organisations that stimulates innovation (Godin 2006).

This work on innovation by Schumpeter can be split between two periods; Schumpeter I and Schumpeter II. The first consisted of his studies before World War I when he focused on the role of entrepreneurship marked by the separation of invention and innovation, whilst the second concentrated on innovation processes in large, oligopolistic firms (Simmie 2001; Cantwell 2002). In Mark I, Schumpeter emphasised the exogenous nature of invention and its appropriation by small firms that then drove economic development through 'swarming' during new periods of technological change (Simmie 2001). Because there is no assurance of profit in a period of fluctuation or disturbance, innovation occurs in tranquil periods of the economic cycle precipitating booms and then slumps. Schumpeter argued that such innovations "tend to cluster" since they are not "distributed over the whole economic system at random, but tend to concentrate in certain sectors and their surroundings" (1939: 100-101). However, others have stressed the importance of diffusion in this process and the mutual interaction and co-ordination between firms and complementary organisations and institutions (Freeman 1982; Metcalfe 1994).

In Schumpeter Mark II innovation was characterised by routinised innovation within large, oligopolistic firms with established industrial research programmes that combine

invention and innovation in one organisation (Malecki 1997). As Alfred Chandler (1977) identified some years later, the expansion of these large firms had a profound effect on the innovation process through the positive feedback produced by self-reinforcing and therefore path dependent cycles of change (see Simmie 2005). Schumpeter emphasised the dynamic processes surrounding innovation as an evolutionary system derived from profit-seeking rather than profit-maximisation (see Cantwell 2002). Of crucial importance, according to John Cantwell (2005: 561), is that the "capabilities created through innovation" can lead to a situation in which "a range of different actors may improve their competitiveness together". Research in evolutionary economics provides a modern updating of Schumpeter's work with the likes of Nelson and Winter (1974, 1982) and Dosi (1988) providing the means to understand how different technological paradigms and trajectories are embedded in specific collective arrangements, rather than individual firms or organisations (see von Hippel 1988, 1994; Nonaka and Takeuchi 1995).

The resulting emphasis on 'systems of innovation' has proved influential in debates around the knowledge economy in both policy and academic circles (see Godin 2006). There are a number of factors that influence innovation (and therefore economic development) in such systems, which Rosenberg (1976) splits between 'inducement mechanisms' – as described by Albert Hirschman (b.1915) – and 'focusing devices'. These factors constitute the innovation system in terms of inter-related and self-reinforcing features of the technological paradigm (see Dosi 1988). For example, Paul Nightingale (2000, 2003) argues that new gene sequencing technologies have led to a

shift from the original focus on single gene mutations to polygenetic diseases. Innovation diffusion is a central feature of such systems because they increase complexity and the professionalisation of R&D at the same time that they produce co-ordination issues between system actors (Freeman 1982). Thus the system is dependent upon the interaction between system actors that diffuses both commodities and demand throughout the system as the example of electrification illustrates (see Hughes 1983). The systems of innovation approach has proved highly influential across academic discourses, particularly with some of the more recent geographical theories as will be shown later (2.6).

However, there are a number of issues with the systems perspective that necessitate a degree of caution. It is argued that the innovation process can 'lock-in' to specific technological trajectories through 'cumulative causation' or the "mutual reinforcement (a positive feedback) between a certain pattern of learning and a pattern of allocation of resources into innovative activities" (Dosi 1988: 1148). As a consequence, alternative trajectories become increasingly costly to undertake. Furthermore, as Arthur (1989, 1999) argues, returns to adoption can lead to the uptake of technologies that are not necessarily 'superior' to other technologies because it is expensive to break such 'path dependency'. More importantly perhaps, we could argue that such lock-in and path dependence could affect technological paradigms as well as trajectories, embedding specific technological paradigms across networks, societies and cultures. Because the innovation process is collective, the consequence of this lock-in could be potentially ruinous as resources are

invested in particular technologies and people learn and adapt to their existence in a form of 'groupthink' (Fagerberg 2005; see also Janis 1972).

The last issue to address in relation to the innovation process is how knowledge is transferred across different actors in the overall system. One important argument highlights the role of knowledge spillovers. Such spillovers occur not just through direct collaboration, but also, and more crucially, as a consequence of learning from the interaction itself (von Hippel 1988, 1994). This means that knowledge is not unproblematically incorporated into innovation but entails distinct processes for its transfer and absorption. Patent citation studies have shown that there is a distinct time lag between publication and citation that peaks around 6-7 years after publication (Jaffe, Tratjenberg and Henderson 2002). Similar research has shown that there is 'bi-directional' knowledge transfer between specific countries like the USA and UK (Jaffe and Tratjenberg 2002). However, there are limitations to these studies because they do not show how such knowledge corresponds to innovative performance (Acs and Audretsch 1988) or how knowledge transfer actually occurs between different organisations (Acs et al 1991; Acs et al 1999). Research on biotechnology knowledge spillovers emphasises the role of 'star scientists' in providing financial and not just scientific credibility to dedicated biotech firms (DBFs) (Audretsch and Feldman 1996; Audretsch and Stephan 1996; Zucker et al 1998, 2002). The interaction between such DBFs and university science remains ambiguous (Acs and Audretsch 1988) with a number of concerns about the appropriation and codification of biotech knowledge as

well as the impact of commercial considerations on academic research (Blumenthal et al 1986; Krimsky et al 1991; Krimsky and Rothenberg 2001; Krimsky 2003).[vii]

2.4 KNOWLEDGE AND INNOVATION

In the knowledge economy discourse, innovation has been characterised as the driver of economic development where this consists of knowledge produced and exchanged through the interactions between organisations and institutions. The role of knowledge in the innovation process is fundamental to understanding how innovation can be considered as both systemic and dynamic. However, the definition of knowledge, even its distinction from information, is also central for understanding how it impacts on innovation processes and subsequently how such processes are embedded in space (2.5). For example, the knowledge necessary for 'incremental' and 'radical' innovation is dissimilar, as it is for 'process' and 'product' innovations, because different types and forms of knowledge are used in different circumstances (see Malecki 1997; Feldman 2000). In the knowledge economy it is therefore possible to argue, as Lundvall (1992) and others from the 'national systems of innovation' literature do, that innovation is dependent upon the 'distribution' and 'use' of knowledge (see Godin 2006). Or, as will be outlined later, that there is a need to distinguish between the 'knowledge base' and 'knowledge drive' of innovation, which entails further consideration of where different knowledge types and forms are located and embedded.

It is important to define and distinguish between information and knowledge so that they are not confused. One definition of information drawn from the mid-twentieth century is that information represents "messages possessing *meaning* for sender and recipient" (Cooke 2004d: xiv). It is also possible to argue that information is "the process of gathering and organizing data" (Rikowski 2000: 162), although this definition would seem to merely exchange 'information' for 'data' in the terminology and therefore appears somewhat tautological. Perhaps since Burton-Jones (1999: 5) defines 'knowledge' as "the cumulative stock of information", it is possible to define information as specific stocks of existing data, although this precludes its collection. However, arguably the collection of data is fraught with difficulties that arise around the subjective process of selection, collection and storage that make the 'gathering' of data as problematic as its interpretation. Thus the clearest definition of information might be that information represents distinct tangible and intangible artefacts (e.g. posters, leaflets, statistics) that exist at any discrete point in time. Furthermore, information both conveys interpreted details and invites further interpretation.

In contrast, knowledge has been defined as the process of interpretation, understanding and learning. These all present a number of issues in the clarification of its meaning because they are broad and amorphous descriptions. In relation to the knowledge economy concept, knowledge shifted from the information and technology fundamental to the 'information society' thesis to focus instead on people and their embodied understandings and context (DTI 1999c; Rikowski 2000; Sokol 2003). Thus knowledge has been defined in a number of ways by different knowledge economy theorists; as

"impression-making information" by Machlup, as "the organization of understanding" by Drucker and Nonaka and as "economically-relevant systems of thought" by Bell (see Brint 2001: 110). Knowledge can be considered therefore as the means through which people collect, sort, absorb, interpret, and organise information, or "all cognitions and abilities that individuals use to solve problems, make decisions and understand incoming information" (Doring and Schnellenbach 2006: 377). However, it also entails the definition and identification of problems, although this means that it represents a 'system of thought' in which particular concerns, agendas and interests are embedded or 'architectural knowledge' as outlined by Pinch et al (2003). It is important to make this point because knowledge does not just represent the skills or learning of individual people, it is broader than that since it involves continuous accumulation that outlasts individual lives (Doring and Schnellenbach 2006).

Broadly speaking and for ease it is useful to consider knowledge as "a dynamic framework or structure from which information can be stored, processed and understood" (Howells 2002: 872). There are many types and forms of such knowledge relevant to innovation, some of which overlap with definitions of information, whilst others are more difficult to codify or turn into information (Johnson and Lundvall 2001). One definition splits these between 'know-what', 'know-why', 'know-how' and 'know-who'. The first represents information or facts; the second represents analytical principles; the third represents skill; and the fourth represents knowledge about people (OECD 1996: 12; also Morgan and Murdoch 2000). We can distinguish further between a number of these knowledge types; for example, know-what and know-why can be split between

'analytical', 'synthetic' and 'symbolic' kinds that refer to science, technical and creative knowledge respectively (Cooke and Leydesdorff 2006: 11; see also Faulkner 1994; Asheim and Gertler 2005). A more frequent distinction has been made between *explicit* and *tacit* forms of knowledge. Both forms feature strongly in the knowledge economy debate and are presented as crucial parts of the innovation process entailing an emphasis on 'learning' as another characteristic of knowledge. The numerous types of learning have been usefully outlined by (Malecki 1997) (see **Table 2.1**).

Table 2.1: Types of Learning

LEARNING	**AUTHOR**
Learning by doing	Arrow 1960s
Learning by using	Rosenberg 1980s
Learning by operating, changing, feedback, training, hiring, searching	Bell 1980s
Learning by trying	Rosenbloom and Cusumano 1980s; Fleck 1990s
Learning by interacting	Lundvall 1980s
Learning by selling	Thomson 1980s
Learning from inter-industry spillover	Malerba 1990s
Learning to borrow	David 1990s
Learning by failing	Bahrami and Evans 1990s

Source: Adapted from Malecki (1997: 59).

Because knowledge is so dependent upon learning, it is important to distinguish between 'explicit' and 'tacit' forms of knowledge. This was most famously explored by Michael Polanyi (1967, 1973) who identified explicit and tacit knowledge by the degree of fromalisation and articulation, which combines with the process of learning as well (Howells 1996, 2000, 2002). Rather than represent these two knowledge forms as dichotomous categories, Polanyi emphasised the continuum between explicit and tacit knowledge so that one could not be used without the other (Senker and Faulkner 1996; Maskell and Malmberg 1999; Howells 2000; Simmie 2002b). In the innovation process it is possible to argue that tacit knowledge is more closely aligned with know-how (OECD 1996) and 'synthetic' or technical knowledge (Cooke and Leydesdorff 2006) because they are both reliant on the application of practices rather than analytical principles (see Faulkner 1994; Howells 1996). However, others have argued that in certain industrial sectors, biotechnology in particular, the tacit dimension of 'analytical' knowledge is just as important because there is a strong reliance on scientific knowledge held by certain 'star scientists' (Zucker et al 1998, 2002; Asheim and Gertler 2005). Thus it would appear as though the tacit dimension of knowledge is not necessarily dependent upon the information content because different types of knowledge (what, why, how, who) all combine tacit and explicit forms. It is therefore possible to argue that tacit knowledge is actually highly context dependent, which distinguishes it from other forms of knowledge (Pinch et al 2003) and would help to explain why neoclassical economics "fails to account for the uneven distribution of knowledge" (Morgan and Murdoch 2000: 160).

However, it is important to note that Polanyi did not originally conceive of tacit knowledge as contextual, but rather experiential and cognitive (see Gertler 2003).

The spatial dimensions of knowledge will be addressed later (2.7), but first tacit knowledge has to be clearly defined. It can be seen as a form of 'direct experience' that impacts on the use of explicit knowledge so that it represents the skills necessary to use explicit or codified knowledge; i.e. it is individual and particular (OECD 1996; Howells 2002; Simmie 2003). This means that it is implicated in a range of knowledge activities, not just knowledge production. It is necessary for the diffusion, distribution and transfer of knowledge, as well as its absorption, use and adaptation, along with forms of relearning or 'unlearning' (Hassink 2005). This challenges the linear model of innovation, where basic research is seen to lead to technical development and then market demand (Howells 2002; Lever 2002). Instead, it can be argued that innovation is an iterative and interactive process in which explicit and tacit knowledge is cycled through different actors producing feedback on particular strategies, reinforcing certain activities and generally providing the means for learning and therefore more knowledge production (von Hippel 1988, 1994; Nonaka and Takeuchi 1995; Senker and Faulkner 1996; Bathelt et al 2004). Consequently the institutional environment can be seen as a crucial element in the innovation process since it ensures that tacit knowledge can cross organisational borders (Gertler 2003).

More recently, Phil Cooke (2005a, 2005b, 2006) has argued that such 'open innovation' entails a further type of knowledge, namely the 'complicit' or 'translational' knowledge

of intermediaries who can convey tacit knowledge across epistemic boundaries (e.g. between scientists and investors) (see also Chesborough 2003). This chimes with earlier work by Gibbons et al (1994) distinguishing between the transition from Mode 1 to Mode 2 knowledge production (see also Harloe and Perry 2004). The latter is characterised by its transdisciplinariity and social distribution, in that knowledge is diffused across multiple sites and contexts because it is embodied in people who organise themselves differently depending on where they are located (Gibbons et al 1994: 17). Consequently the elements in knowledge production consist of arrangements, interactions and relationships that are embedded in different spaces, different organisational forms and different institutional structures. Thus the role played by intermediaries can be seen as crucial. Even the relaxing of boundaries between different organisations and institutions can be seen as important as the *Triple Helix* model of innovation in the biosciences contends (Etzkowitz and Leydesdorff 2000). The Triple Helix model critiques Giddons et al (1994) by arguing that Mode 1 and Mode 2 knowledge are not distinct phases, but rather intimately tied to one another in the close relationships between government, industry and academia (Etzkowitz and Leydesdorff 2000).

As shown above, the definition of knowledge in the innovation process is fraught with difficulty. It is easiest to distinguish explicit and tacit knowledge as elements on a continuum of knowledge that specifies explicit knowledge as codified intangible artefacts (e.g. information) (Howells 1996) and tacit knowledge as the processing, interpretation and use of codified knowledge. They are therefore 'hybrid knowledges' that not only depend upon the cognitive understanding of knowledge, but also the social understanding

of the cultural context (e.g. norms, trust etc.) that facilitates knowledge production (Goddard and Chatterton 1999; Fagerberg 2005). Explicit and tacit forms are continually converted from one to the other and back again through the interaction of individuals, organisations and institutions (Nonaka and Takeuchi 1995; Morgan 2004). It is useful to consider the conceptualisation of these conversions by Ernst and Kim (2002) as outlined in **Table 2.2**.

Table 2.2: Knowledge Conversion

KNOWLEDGE CONVERSION	TERM
Tacit-to-tacit	Socialisation
Explicit-to-explicit	Combination
Tacit-to-explicit	Externalisation
Explicit-to-tacit	Internalisation

Source: Adapted from Ernst and Kim (2002: 1424-1425).

Thus tacit knowledge can been externalised when it is articulated in the form of information or codified as an artefact, whilst explicit knowledge can, in turn, be internalised when it is absorbed into a particular system of thought (Ernst and Kim 2002). Overall then, tacit knowledge can be defined as the way individuals understand the world, which is highly contingent upon their context because they derive a significant proportion of their cognitive abilities and skills from people around them and their organisational and institutional base. In this way we can identify the role of knowledge in

the innovation process by distinguishing between the knowledge base and the knowledge driver of innovation. Since 'knowledge' in the broadest sense is used in all economic activities, Cooke (2002c: 3-5) characterises the knowledge economy as dependent upon (1) new knowledge, (2) high value (i.e. scientific) knowledge, and therefore (3) new knowledge that is used to produce more new knowledge. Thus the knowledge base is central because it enables the production of new knowledge through the support provided by existing technological paradigms and trajectories (see Dosi 1988). In turn, the knowledge driver provides the impetus to produce new knowledge through collaboration and interaction with other individuals from diverse and dispersed sources. Without both the knowledge base and driver there would be little to stimulate the knowledge economy.

2.5 SPACE AND INNOVATION

The discussion above on the relationships between innovation, economic development and knowledge (2.3 and 2.4) illustrates the importance of spatial considerations to understanding the innovation process and consequently economic development. In particular it is evident that innovation and knowledge are unevenly spread across and within different countries for a variety of reasons, but all of which have a direct impact on the capacity of different locations to pursue economic development (Feldman 1999, 2000; Fagerberg 2005). Consequently a central issue in economic geography, regional and urban studies and other cognate fields is to understand how and why this uneven development occurs across different places. Such differences are not static either, but rather dynamic changing over time as the uneven spread of industries leads to contingent

processes of adjustment and adaptation (Hassink 2005; Hudson 2005). This interest with uneven development has a long history in the field, starting with academics concerned about de-industrialisation such as the seminal work of Doreen Massey (1995[1984]) and David Harvey (1999[1982]). However, the more recent interest has particularly focused on the territorial processes of innovation and knowledge. A number of reviews of so-called 'territorial innovation models' (TIMs) as Moulaert and Sekia (2003) term them have been undertaken in the last 10 years particularly as the 'knowledge economy' has been promoted in policy circles (Malmberg 1997; Yeung 2000; MacKinnon et al 2002; Malmberg and Maskell 2002; Moulaert and Sekia 2003; Lagendijk 2006). A number of reviews have also raised a series of questions and problems with this types of research, not least of which is its orientation around policy concerns to the detriment of 'critical' distance (Lovering 1999, 2001; although also see MacLeod 2001).

The numerous TIMs that seek to explain spatial innovation processes have proliferated throughout this time as they have drawn in a broader range of theories from the work of the French Regulation School (e.g. Aglietta 1979) through to the economic sociology of Granovetter (1985) on 'embeddedness'. In his review, Lagendijk (2006) argues that there are three phases to the development of these conceptual approaches starting with 'structuralist-organisational' phase (e.g. the California School) moving through 'social-institutional' (e.g. 'institutional thickness') before ending with a 'cognitive' model (e.g. 'buzz and pipelines'). These three phases crudely correspond to functional, relational and associational emphases in the various theories where functional concepts are more concerned with the material linkages in space, relational ones with the social and

institutional linkages and associational ones with individual and collective knowledge practices (MacKinnon et al 2002; Lagendijk 2006).[viii] All such theories provide some useful analyses of the spatial embedding of the innovation process and contribute useful insights that all need to be taken into account.

Firstly, the more *functional* models build upon work in economics on transaction costs and the evolution of technological paradigms and trajectories as well as Regulation theory. The early work of the California School in the 1980s is one example of this research agenda, focusing on the importance of transaction costs and flexible production enabled by a lack of existing Fordist production systems (Scott 1989; Storper and Walker 1989). Such 'new industrial spaces' (NIS) included areas like Silicon Valley in California (Scott 1998a, 1998b) where production was distributed across numerous firms so that external economies and economies of scope provide advantages to particular regions (Lagendijk 2006). In particular there was a focus on the region as a site of economic and social activity in a Post-Fordist world (see Storper 1995; Storper and Scott 1995), which placed greater emphasis on agglomeration economies and the work of Alfred Marshall (1890) on 'industrial districts'. Such agglomeration or concentration of industrial production produced "a widening of the social division of labor" meaning that knowledge and innovation were also distributed more widely as well (Scott 1998b: 387).[ix] There are strong links and overlaps between the NIS concept and that of 'flexible specialisation' propounded by Piore and Sabel (1984) and the work on 'industrial districts' (ID) carried out in Italy by Bagnasco, Becattini and others. The ID approach again emphasised local production by small firms which each specialised in different parts of the production

process (Moulaert and Sekia 2003). However, increasingly, both the NIS and ID approaches stressed the importance of 'untraded interdependencies' (Storper 1995) and the institutional structures in different regions especially in relation to the social embedding of networks in Piore and Sabel's (1984) work. Consequently they moved towards a more 'relational' model.

Secondly, the *relational* models build upon the growing interest in the social and institutional features of regional economies and particularly the impact these have on innovation processes. As such they build on work in economic sociology and institutional economics,[x] as well as the institutional concepts from Regulation theory (see Kratke 1999; Lagendijk 2006). The greater emphasis on the collective and therefore institutional basis of innovation and knowledge production helped to stimulate this approach. In particular, the interest in learning through interaction – whether at an individual or collective scale – provides an impetus for understanding how and why such processes occur (Nonaka and Takeuchi 1995; Malecki 2000; Asheim and Gertler 2005). Each location has different institutional frameworks that affect innovation, which then helps to explain the different and uneven development of regional (and national) economies. Thus it is possible to argue that certain regions embed knowledge and therefore innovation more successfully than others leading to 'sticky places' (Markusen 1996) that attract and retain different, particularly tacit, forms of knowledge (see von Hippel 1988, 1994; Malecki 2000). Although there are a number of relational theories, they can be split, again crudely perhaps, between institutional and social approaches. The former includes the research of GREMI [xi] in France on the 'innovative milieu' (e.g. Camagni 1995; also

Keeble et al 1999; Crevoisier 2004) as well as Amin and Thrift's work on 'institutional thickness' in Neo-Marshallian nodes (e.g. Amin and Thrift 1992, 1994; Amin 1999, 2004).

In the innovative milieu approach, innovation and learning are considered as collective processes in a specific territorial context that is enabled by local networking and interaction between not only firms, but also supporting organisations (Plummer and Taylor 2001a, 2001b; Simmie 2005; Lagendijk 2006). A recent addition to this approach by Capello and Faggian (2005) has introduced the concept of 'relational capital' representing a set of relationships that produces strong local culture. The Neo-Marshallian approach stresses the region as a 'relational' concept that is constituted by its relationship to the global; in these regions actors interact in pursuit of collective success, which leads to the development of a collective culture (Amin and Thrift 1994). In the more social models – e.g. 'learning region' (Florida 1995; Morgan 1997) and 'regional innovation system' (Cooke 1998, 2001a, 2004d; Cooke et al 1998; Park 2001) – there is a greater emphasis on the systemic, as opposed to institutional, basis of innovation and knowledge. Again, collective learning is central, but instead of it representing a 'cultural' perspective, the social approach places the emphasis on the relationships between organisations or system members (Moulaert and Sekia 2003). Both are concerned with the effects of the knowledge economy on regional development and how 'less favoured regions' (LFRs) can adjust to the changing economic climate (Morgan 1997). As such they can be considered evolutionary theories (Cooke et al 1998; Morgan 2004), but ones which place more emphasis on the interaction between system members than other

theories concerned with the importance of internal knowledge do, especially regarding tacit knowledge (e.g. Faulkner 1994).

Finally then, *associational* models can be aligned with what Lagendijk (2006) calls 'cognitive' TIMs and includes 'knowledge communities', 'clusters' and 'buzz'. The general emphasis in such approaches is on the 'associational capacity' that different firms have within a particular place to not only encourage co-operation within their organisation, but also across different organisations (Cooke and Morgan 1998). As such it may preclude the functional pursuit of market considerations (e.g. price) or the relational pursuit of social considerations (e.g. trust) for a concern with processes of knowledge collection, absorption and interpretation across organisations (Lagendijk 2006). Thus several authors have argued that regional innovation is constituted by knowledge communities or 'communities of practice' representing a group of actors who co-operate across organisations and institutions (Henry and Pinch 2000; Pinch et al 2003). As such there can be entire systems of knowledge or 'knowing' to which different actors adhere across a number of organisational boundaries, but embedded and bounded in particular places (Pinch et al 2003).[xii] Such locations can be considered as 'clusters' in that they incorporate a number of complementary and associated organisations in a particular geographical location (Porter 2000). They need to be distinguished from Porter's (1990) earliest conceptualisation of clusters as functional (e.g. sectoral) and instead be seen as spatial phenomena (see Malmberg 2003). Even though the cluster concept has proved popular amongst policy and some academic circles, it has also been widely criticised for

its simplicity and lack of empirical support (Malmberg 2003; Martin and Sunley 2003; Cumbers and MacKinnon 2004; Simmie 2004; Malmberg and Power 2005).

In many cases such critiques have pointed out that local linkages and relationships are actually weaker than extra-local ones, which has led to the last associational concept of 'local buzz and global pipelines' (Bathelt et al 2004). This approach acknowledges that both explicit and tacit knowledge are spatially embedded because both entail search and acquisition costs, and explicit knowledge, even though it is supposedly 'ubiquitous' (Maskell and Malmberg 1999), still requires the existence (or production) of tacit knowledge (Bathelt et al 2004). The first feature is the 'buzz' from local interaction, which is crucial in producing group trust and solidarity and thereby enabling both the access to new knowledge and knowledge of how to access such knowledge (see Pinch et al 2003; Storper 2003). However, buzz originates and is perpetuated by particular knowledge communities, rather then by individuals, firms or regions. Consequently it is dependent upon the 'ecology of communication' produced through personal, face-to-face contact and therefore the co-location of people in similar places (Grabher 2001; Lagendijk 2006). The second feature is the 'global pipelines' consisting of the extra-local linkages, specifically global ones, connecting different places to one another (Bathelt et al 2004). Again they can consist of global communities of practice (Asheim and Gertler 2005), although this would not necessarily entail the same type or level of interaction as the local level, and therefore a similar approach to knowledge search, acquisition and absorption (see Bathelt and Gluckler 2005). However they are constituted, they provide

an analytical approach that addresses a number of concerns highlighted around the cluster concept (see Malmberg and Power 2005).

There are a number of conceptual and methodological issues with all the TIMs outlined above, particularly because there is a tendency in each to define the particular processes – functional, relational or associational – as the dominant factor in regional innovation processes. In contrast it is worth arguing that spatially-bounded innovation entails a combination of all three processes to a varying degree depending upon the specific location. There is no reason why regional innovation across the world need be constituted by exactly the same set of processes; rather, it would seem logically to assume that they are not because each region will have different knowledge bases and drivers. Thus one region may have a public-funded university that encourages collaboration between its academics and regionally-based firms, whereas another regional university (privately or publicly funded) may encourage global collaborations in pursuit of global status. The impact of this simple policy pursued by one organisation could significantly impact upon regional innovation. More importantly perhaps, it could have no impact at all for regions in particular circumstances. Such spatial specificity of the innovation process and, in particular the importance (or not) of knowledge, is considered in the next section by outlining a theory called the *knowledge-space dynamic*.

2.6 THE *KNOWLEDGE-SPACE* DYNAMIC

The theory of the *knowledge-space* dynamic hinges on a number of propositions drawn from the preceding literature review of the knowledge economy (2.2), innovation and economic development (2.3), innovation and knowledge (2.4), and innovation and space (2.5). The central proposition is that regional economic development and performance in the 'knowledge economy' – whether we accept that knowledge drives wealth creation or vice versa (Sokol 2003, 2004) – depends upon innovation (Malecki 1997, 2000; Asheim and Gertler 2005; Fagerberg 2005; Simmie 2005).[xiii] Secondly, it is premised on the idea that every spatial context is unique and consequently every concentration of economic activity – whether industrial, service-based or otherwise – entails a geographical specificity regarding the spatial positioning and embedding of knowledge production, search, acquisition and absorption in the innovation process (Cohen and Levinthal 1990; Howells 2002; Gertler 2003; Asheim and Gertler 2005; Cooke and Leydesdorff 2006). Thirdly, it is crucial to acknowledge the cross-scalar relationships and interaction that further embed these knowledge and innovation processes by strengthening the position of certain regions at the expense of others (Malmberg 2003; Bathelt et al 2004; Phelps 2004; Wolfe and Gertler 2004; Malmberg and Power 2005). However, in this framing of innovation and knowledge it is important to acknowledge that neither these inputs to regional development, nor technological change more generally, are necessarily 'progressive' in that they automatically change to 'superior' forms over time. Instead the returns to adoption (Arthur 1989, 1999) engendered by embedding knowledge and innovation processes in particular institutional frameworks – at the regional, national or any spatial scale – may lead to path dependency and lock-in to particular paradigms and trajectories (Dosi 1988; Hassink 2005; Hudson 2005).

The innovation process itself is dependent upon many different types of knowledge drawn from numerous sources, both internal and external to a firm, and involving a collective interaction and engagement in learning and knowledge production that iteratively crosses organisations in a feedback processs (von Hippel 1988, 1994; Nonaka and Takeuchi 1995; Bartholomew 1997; Chesborough 2003; Cooke 2006). This necessitates the combination of diverse knowledge 'inputs' such as problem-setting to acquire funding in the first place (whether externally or internally), research and development, market-making and so on. Consequently the concept of innovation as an atomistic activity is problematic, especially the portrayal of entrepreneurs and investors as 'heroic' individuals (Smelser and Swedberg 1994). Instead the systemic characteristics of innovation means that knowledge is derived from functional, relational *and* associational processes that cover a range of organisational and institutional capabilities. Such knowledge could come from specific commodities and products, industrial or production processes and inputs, marketing and market-making activities, organisational techniques and arrangements etc. (Fagerberg 2005). However, these knowledges are bounded by and embedded in specific sets of conventions and institutional rules that are social produced and sustained by individuals, organisations and other actors working within and across a particular system (Nelson and Winter 1982; Morgan 2004). Consequently such knowledges are constituted by the positioning and embedding of the system in a particular place because the geographical location of a system – i.e. its regional, national and global relations – produces particular social associations (see Whitley 1996, 2004 on national business systems for example).

A central feature of this spatial positioning and embedding of knowledge is the role of individual people as 'knowledge workers' (Brint 2001), although more broadly conceived than an emphasis on 'high technology' knowledge producers. Although knowledge is a central feature of innovation, it has to be produced, transferred and absorbed by individual people within the process who can then contribute to the collective system. This entails a number of important considerations. For example, it would seem evident that the positions of each person within the innovation process – i.e. their organisational, institutional, spatial etc. context – bears closer examination. Furthermore, there is a possibility that the greater the diversity and variation of people in the innovation process would lead to more diverse and varied knowledge that could provide the impetus for conflict that then stimulates innovation (Grabher and Stark 1997). Crucially then, because it is people who produce, exchange and absorb knowledge – whether or not it is then added to organisational memory (Nelson and Winter 1982) – their actions and interactions are important foci for studies of the knowledge economy (Cohen and Levinthal 1990).

Even though people produce, transfer and absorb knowledge, they may be doing so unconsciously or through tacit avenues of learning. As such they are transferring the knowledge of a capability in the Penrosian sense (Penrose 1995[1959]; Ravix 2002; Richardson 2002), or *how* to do something, rather than know-what or know-why (Johnson and Lundvall 2001). Such knowledge transfer is therefore bound up with the issue of how easy it is to access the knowledge in question in the first place and

subsequently how easy it is to absorb and incorporate such knowledge in an existing collective system of thought. As Michael Polanyi argued, it is the tacit dimension itself that:

> "…decide[s] our adherence to a particular culture and sustains our intellectual, artistic, civic and religious deployment within its framework" (Polanyi 1973: 264-5).

So tacit knowledge is both the means of 'knowing' and a crucial form of knowledge for innovation. It is more difficult to transfer because it cannot be 'articulated', which also means it is more difficult to absorb (Senker and Faulkner 1996). Thus the closer someone is to another person's system of thought (i.e. way of knowing) the easier it will be to not only transfer and absorb tacit knowledge, but also exploit explicit knowledge from similar sources. Consequently, the spatial proximity between people may make it easier to access such 'sticky' knowledge especially in face-to-face contact (von Hippel 1994; also see Boschma 2005).

The specific system of thought within which people operate can be seen as an effect of their organisational and institutional membership in that people work within contexts that have established rules and conventions on how knowledge is acquired, used etc. that are specific to that setting (Nelson and Winter 1982; Johnson and Lundvall 2001). Furthermore, these rules and conventions need not be 'efficient' or 'optimal' (see Meyer and Rowan 2004), but instead represent patterns of capabilities that ensure the co-

operation and trust of other people around them (DiMaggio and Powell 2004). The 'embeddedness' of economic actors within such social relationships and institutions has been a research programme pursued by economic anthropologists, sociologists and others for some time (Polanyi 1957, 2001[1944]; Granovetter 1985; Dobbin 1994; Whitley 1996, 2004; Krippner 2001; Grabher 2004; Peck 2005). Consequently, people will be affected by their context cutting across not only spatial, but also social, cultural, cognitive and organisational proximity (Morgan 2004; Boschma 2005). In particular, knowledge acquisition, production and use depends on a series of similarities to ease transfer as well as differences to ensure it is 'useful' that are constituted by multiple types of proximity.

Despite the suggestion that there are multiple types of proximity that impact on the operation of knowledge within the innovation process, it is important to point out that all forms of proximity entail some geographical basis. For example, people working in similar organisations (i.e. organisationally proximate) are also spatially situated in relation to one another; the same is true for social, cultural and cognitive proximity. Organisations are also socially, culturally and cognitively proximate. The extent of the proximity is crucial in determining the impact it has on knowledge and innovation, since too much proximity in one field may prove detrimental to innovation as would too little in another field (Boschma 2005). However, all such forms of proximity are spatially situated and therefore the spatial dimensions of knowledge and innovation processes are crucial to understanding regional development. Furthermore, although this *knowledge-space* is geographically based, it does not mean that it cannot operate across scales. It is important to emphasise that the different knowledge types, forms and sources are

spatially delineated according to their specific features. Thus because tacit knowledge, for example, is allegedly difficult to transfer over distance it necessitates personal contact in a particular community of practice, which, in turn, will be spatially bounded, whether in certain types of organisations, institutions and locations. Overall this means that innovation dependent on knowledge will be located in specific sites because those locations have certain systemic (i.e. collective) and dynamic (i.e. historical) characteristics (functional, relational *and* associational) that are conducive to a particular innovation process.

2.7 RESEARCH QUESTIONS AND CONCEPTUAL FRAMEWORK

The over-riding aim of this thesis is to understand what is particular to the knowledge and innovation processes in the British biotechnology industry and, specifically, what the spatial dimensions are of such knowledge and innovation processes. There are a number of theoretical issues that need to be considered in order to construct a set of research questions that can adequately address this focus (see for example MacKinnon et al 2002; Malmberg and Maskell 2002; Markusen 2003). First there is the question of spatial scale and the difficulties that a particular focus entails; e.g. a local focus will not be able to address national or international dimensions. Second is the question of causation; e.g. do specific concentrations of industrial sectors indicate that local knowledge is important, or does local knowledge indicate that concentrating is important (Malmberg and Maskell 2002). In the development of the theoretical framework outlined above (2.6) a number of these conceptual and methodological issues were considered in order to produce the

theoretical framework for the research agenda and methodology of the thesis. This draws upon a number of approaches, most specifically the following:

- Value chains model
- Systemic-dynamic (i.e. iterative-collective) innovation model, and
- Biotechnology industry model.

These approaches help to avoid a number of issues around space/scale. In particular the tendency for research on regional dynamics to focus on specific locations and especially 'successful regions' (e.g. Silicon Valley) leads to a number of conceptual and methodological assumptions. First, that the region has some form of agency in that its regional assets or endowments create or cause success. Second, the regional focus encourages an interest in what regional actors *do*, rather that how they *function*. The former ends up being largely descriptive, whilst the latter aims for a more explanatory analysis (Maskell 2001). Finally, the regional emphasis discourages a comparative perspective by downplaying (or ignoring) the inter-connections between different locations and different scales. The first hypothesis seeks to address these issues:

H1: There are 'knowledge economy' concentrations because successful innovation depends on dynamic (i.e. across time) and systemic (i.e. across organisations) processes embedded in and across specific places.

The spatial concerns are reinforced in the conceptualisation of causation also proving problematic. First, Ann Markusen (2003) has questioned the 'fuzziness' of process language because it assigns causative agency to an '-ism' or '-ation', which hides the role and function of individuals and organisations. Second, the focus on 'successful' regions can lead to 'reversing causality' in that there is an assumption that a region is successful because of a certain regional asset or endowment, rather than that a specific asset leads to success (Malmberg and Maskell 2002). Finally, the concern with locational assets or endowments as causes of economic development emphasises supply-side factors and limits the importance given to demand-side ones. The second hypothesis seeks to address these issues:

H2: Successful innovation in the knowledge economy depends on place-specific dynamic and systemic processes because different types of knowledge (including supply and demand) originate in different places and at different scales necessitating interaction both within and beyond concentrations.

Finally, there are a number of broader conceptual and methodological concerns beyond those outlined above. The first of these is the need to avoid the static perspective of much regionally focused research (Malmberg and Maskell 2002). The second is the need to avoid focusing on a single actor (e.g. person, firm) because this ignores the collective and iterative innovation process. Finally, there is a need to identify knowledge exchange as a transfer process in which actors *actively* engage rather than simply being an automatic effect of certain types of proximity. The final hypothesis seeks to address these issues:

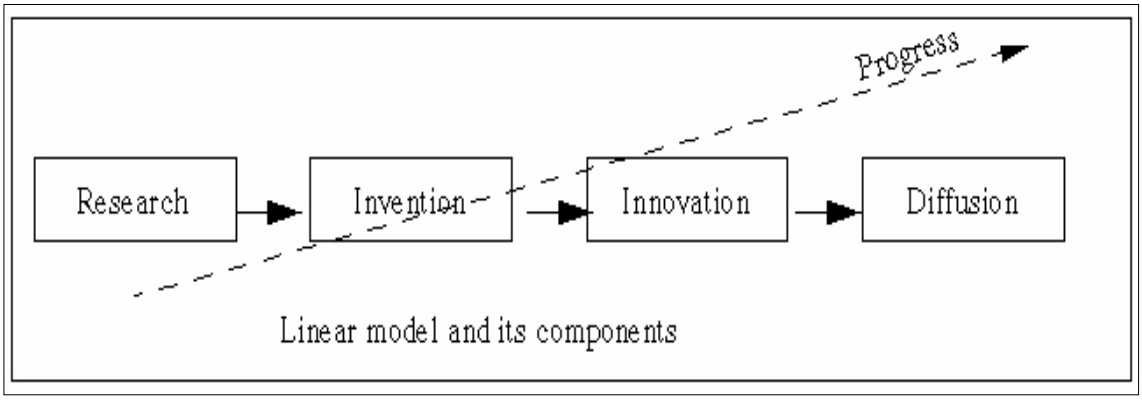
H3: The knowledge economy depends on different locations and scales of knowledge because different places have different locational assets that contribute to successful innovation in different ways and therefore necessitate linkages within and between locations.

To examine and explore these research questions further, this thesis is designed around a conceptual and methodological approach that incorporates three different models for understanding the spatial dimensions of knowledge and innovation processes. The first of these is the value chains model popularised by Porter (1990) in his book *The Competitive Advantage of Nations* and other further research on industrial 'clusters'.[xiv] Without wishing to accede to the hyperbole around the cluster concept, it is still fruitful to utilise the value chain approach because it provides a useful means to avoid a number of the problems outlined above. In particular the value chains model enables the research to consider knowledge and innovation processes across organisations both within a location and with other locations, although the latter point is not a specific feature of Porter's (2000) later concept of the cluster (see Malmberg 2003; Malmberg and Power 2005). However, the emphasis on different and discrete features of the value chain, from logistics through operations to marketing, means that a diverse array of knowledges need to be included in the conceptual approach.

The second approach is the 'systems of innovation' model (Freeman 1982; Fagerberg 2005), which emphasises the collective and iterative features of knowledge and

innovation processes. This avoids two conceptual problems, namely the assumption of linear progression in innovation (see **Figure 2.2**) and that individual people or organisations are the drivers of innovation. Instead the innovation systems approach enables research to consider the collective and iterative aspects of the knowledge and innovation processes.

Figure 2.2: Linear Innovation Model



This is illustrated in the work of von Hippel (1994) and Kline and Rosenberg (1986) who outlined a 'chain-link' model of innovation (see **Figure 2.3**). In these models it is the relationship and interaction between actors (e.g. people, organisations) that represents the locus of innovation. There is an inherent spatial dimension to these innovation models because they position the process within the relationships and interactions between spatially embedded actors (e.g. organisations), which benefit from their location to differing extents (see Moulaert and Sekia 2003 for a summary).

Figure 2.3: Chain-Link Model of Innovation

Source: Kline and Rosenberg (1986).

The final approach is specific to the biotechnology industry and draws on the work on this particular sector. Early analyses drawing on strategic management and innovation studies approaches (see Senker 2005) emphasised a number of features of biotech

innovation that have since been incorporated into more spatial perspectives. To start with there was an emphasis on alliances and collaborations between firms and cognate organisations both 'upstream' (e.g. universities) and 'downstream' (e.g. large pharmaceutical firms) from biotech firms (see Hamilton et al 1990; Chakrabarti and Weisenfeld 1991; Dodgson 1991; Greis et al 1995; Deeds and Hill 1996). Later work drew on research in innovation studies and also highlighted the important role of such external collaborations. This research emphasised the particular advantage held by some firms because of their location in certain countries (e.g. the USA) as opposed to other parts of the world (e.g. Europe) (see Walsh et al 1995; Senker et al 1996; Acharya et al 1998; Saviotti 1998; Saviotti et al 1998; Senker 1998, 2004, 2005; Acharya 1999; Senker et al 2000).

In the more recent geographical analyses, there is a continuing emphasis on the importance of external knowledge, although this time there is a difference between adherents to Krugman's (1991) 'new economic geography' (or more accurately 'geographical economics') and existing economic geography or regional studies. The former largely emphasises the importance of local knowledge spillovers (see Prevezer 1997; Audretsch 2002, 2003; Johnson and Mareva 2002; Fuchs 2003; Fuchs and Krauss 2003). However, the latter tends to also stress importance of extra-local knowledge, sometimes to a greater extent than local knowledge (see Lawton-Smith et al 2000; Zeller 2001, 2004; Coenen et al 2004; Cooke 2003a, 2004a; Leibovitz 2004; Ryan and Phillips 2004). Throughout this literature there is a common set of characteristics that can be used

to represent a stylised biotech concentration (see Ryan and Phillips 2004 for example). These include the following, to varying degrees:

- Concentrations of dedicated biotech firms (DBFs) usually comprising small or medium sized enterprises (SMEs)
- Linkages to 'upstream' (e.g. universities) and 'downstream' (e.g.large pharmaceutical firms) organisations that provide complementary competencies
- Linkages to specialised service organisations like lawyers, business consultants, and accountants
- Local identity that has led to the generation of trade associations or networking organisations
- Local and national government involvement in the promotion and encouragement of a territorial approach to economic development.

Below **Figure 2.4** provides a visual representation of the innovation system that is particular to the biotechnology industry (CRIC 2000). However, one important caveat needs to be made in regards to this representation: it does not include any of the spatial dimensions of the various actors included in the process. Consequently it is important to incorporate the spatial features of the innovation process into a biotech innovation model.

Figure 2.4: CRIC Biotech Innovation Model

Source: CRIC (2000).

2.8 CONCLUSION

The start of this chapter showed how knowledge has become an increasingly important focus in economic analyses and policy-making, especially after the 1950s. In part at least, this concern has led to the discussion of the 'knowledge economy' as first conceived by the likes of Fritz Machlup and others. Although such concepts have been through a number of transformations as Godin (2006) and Sokol (2003) both illustrate, they retain the central concern with how a society based on industry has gradually – or rapidly in some cases – shifted to one based on services, knowledge and creativity (Florida 2002).

The role played by innovation in this economic change is argued to be pronounced as firms have adapted to changes in society by competing on 'quality' as opposed to 'price' (Cantwell 2002). This has, in turn, led to an interest in the systemic nature of innovation since individual firms and organisations find it increasingly difficult to acquire and retain all the necessary knowledge and skills needed to successfully innovate. Such 'open innovation', as it has been called, cuts across organisations and embeds innovation in networks of actors who all benefit from the deliberate and often accidental transfers of knowledge between organisations and people (Chesborough 2003; Cooke 2006). Thus learning has become a crucial factor in the pursuit of innovation, as has the ability to convert different types of knowledge between different organisational and network settings.

Throughout such debates the importance of space is illustrated in relation to the enduring concentration of knowledge and innovation processes in specific locations. The number of 'territorial innovation models' (see Moulaert and Sekia 2003; Lagendijk 2006) that seek to explain the relationship between these concepts has proliferated throughout the last three decades. Broadly speaking, such models can be split between 'functional', 'relational' and 'associational' theories, all with their own set of characteristics highlighted as the determinative factor in explaining innovation. However, this chapter outlined an approach that seeks to incorporate aspects of all these types of theories into one concept called the *knowledge-space* dynamic. As outlined above it seeks to explain knowledge and innovation processes in terms of their spatial and scalar specificity that entails the acknowledgement of the impact of cross-spatial and cross-scalar connections

as well as functional, relational *and* associational features of particular places. Thus the positioning and embedding of different types and forms of knowledge in different forms of proximity represent particular sites of knowledge and innovation. As a consequence of this approach, the research process and methodology outlined in Chapter 3 have been designed to address these conceptual issues.

CHAPTER 3

STUDYING THE KNOWLEDGE ECONOMY: RESEARCH DESIGN AND METHODOLOGY

3.1 INTRODUCTION

The last chapter (Chapter 2) outlined the theoretical framework that drives the thesis and its research design. In brief it shows how the knowledge economy is premised on the concept of economic development through the pursuit of innovation, which, in turn, depends on the inter-relationship between knowledge and space that produces a *knowledge-space* dynamic. This dynamic consists of functional, relational and associational features that are positioned and embedded in particular places and across different scales. Consequently, it is important to ask research questions that address these concerns and design the research and its methodologies around it (3.2.1). In particular there are a number of issues with the designation of space and scale as well as with causation that entail the adoption of a particular research framework (3.2.2).

Initially the research was designed to explore these questions using case studies of specific products, akin to the work on global commodity chains or global production networks (Gereffi 1994, 1996; Coe et al 2002; Hess and Yeung 2006), but this approach proved unfeasible for three reasons. First and foremost, there are very few clearly identifiable 'biotechnology' products that have been developed by UK firms, especially pharmaceutical products. Second, it would have necessitated an in-depth approach focused on only a few products that would have limited its explanatory

power. Third, because of the limited number of products it would have depended upon a few key informants who may not have been willing to take part. Consequently, the research design was broadened to incorporate a range products that had been developed at a number of different sites around the UK and that drew upon a range of diverse knowledge inputs.

The approach taken in this thesis is therefore designed to use the biotech industry as a case study of the knowledge economy drawing on particular informants to explore the relationship between space and knowledge. It especially focuses on what types and forms of knowledge that informants drew upon during the development of successful innovations (i.e. those that have been marketed or near market). This chapter explains this research design (3.2) and in particular the data collection (3.4) phase. First it returns to the research hypothesis and outlines a number of research questions that were raised by the three main hypotheses and details the overall research design (3.2), before briefly addressing some of the ethical issues involved (3.3). Next it outlines the main methodological approach (3.4) covering secondary and primary data collection before concluding with a summary of Part I.

3.2 RESEARCH DESIGN

3.2.1 Research Questions and Hypotheses

The overall hypothesis of the research was derived from the literature review outlined in Chapter 2. It was particularly concerned with how and why certain locations produce successful innovation in the knowledge economy. The positioning and

embedding of innovation in processes of *knowledge-space* is considered to be the main defining feature of the theoretical approach. This can be broadly laid out as follows:

- Regional development in the knowledge economy depends on innovation
- Innovation comes from knowledge
- People produce knowledge
- People consciously and unconsciously transfer knowledge
- People work within organisations
- Organisations and people are spatially situated.

This brief outline underpins the overall thesis hypothesis. The central aim of this hypothesis is the exploration of the particular knowledge and innovation processes in the UK biotechnology industry, especially in relation to the spatial dimensions of these processes. The main hypothesis is therefore:

> Despite being an internationally distributed sector, biotechnology innovation is concentrated in regional nodes because these locations provide advantage through a *knowledge-space* dynamic that encompasses functional, relational and associational features.

The dynamic between these three aspects of *knowledge-space* leads to innovation outcomes, some of which succeed and some of which fail. It is therefore important to remember that the tolerance of uncertainty and possible failure is a significant part of the innovation process.

The central hypothesis is itself split between three hypotheses that entail specific methodological concerns themselves. In each case the hypothesis is derived from the theoretical and methodological frameworks. The first (H1) of these concerns the dynamic and systemic features of innovation and how such aspects of innovation are spatially embedded. This hypothesis is largely addressed using secondary data collected on the UK biotech industry (Chapter 5).

H1: There are 'knowledge economy' concentrations because successful innovation depends on dynamic (i.e. across time) and systemic (i.e. across organisations) processes embedded in and across specific places.

The second hypothesis (H2) concerns the particular knowledge processes involved in innovation that originate in and across different spaces and scales thereby necessitating interaction both within and across different locations. This hypothesis is largely addressed using primary data collected on the role of different types and forms of knowledge in the innovation process (Chapter 6).

H2: Successful innovation in the knowledge economy depends on place-specific dynamic and systemic processes because different types of knowledge originate in different places and at different scales necessitating interaction both within and beyond concentrations.

The final hypothesis (H3) relates to the specific features of different spaces and how these impact on the innovation process. This draws on a theoretical position that

emphasises the importance of geographical, organisational and institutional influences on the innovation process. It has been largely addressed throughout Part II from the discussion of the historical background and global context of the UK biotech industry (Chapter 4) through the secondary data analysis (Chapter 5) to the primary data analysis (Chapter 6).

H3: The knowledge economy depends on different locations and scales of knowledge because different places have different locational assets that contribute to successful innovation in different ways and therefore necessitate linkages between locations.

Ourlined below is the research and methodological framework derived from the theoretical discussion developed in Chapter 2 and incorporating a number of the concerns with existing research on innovation processes and their spatial dimensions.

3.2.2 Research and Methodological Framework

In the last chapter (Chapter 2) a number of concerns were raised regarding existing research in economics, economic geography, regional studies and other fields that focus on innovation. In particular, nine main issues were raised that need to be addressed in the thesis' methodological approach. These are outlined in **Table 3.1** below, which consists of the particular research 'pitfalls' that the thesis seeks to avoid as well the methodological model used to avoid this problem and the theoretical basis of this methodological choice.

Table 3.1: Methodological Framework

RESEARCH PITFALL	METHODOLOGICAL MODEL	THEORETICAL BASIS
Assigning agency to location (i.e. it causes success)	Focuses on a chain (or sector) and not a region	People produce knowledge
Focus on what actor's doing, not how they function	Value chain concerns interaction over action	People rely on interaction
Limits comparative analysis in the understanding of space	Value chain represents an industrial sector and therefore has a comparative basis.	People work with different knowledge
'Fuzziness' of process language	Innovation is conceived in neutral terms – i.e. it is neither an advantage nor disadvantage	Knowledge has no value by itself
'Reversing' causality (i.e. something is important because a region is successful)	Innovation is considered as dependent upon knowledge; i.e. a product of people in place	Knowledge is produced in place
Supply-side focus	Knowledge conceived in terms of explicit and tacit continuum, therefore not supply-side focused	Knowledge comes from all aspects of production
Static research design	Unit of analysis is a biotech product or technology and the process of innovation over time	Locations inter-relate across different space, time and scale
Singular actor focus	'Systems' approach avoids reliance on a singular actor.	Locations have multiple actors
Relational emphasis	Knowledge focus means that relational perspective was not emphasised	Locations have endogenous features

With caveats, the value chains model used in Porter's (1990) earlier work proves a useful conceptual perspective because it enables the research design to focus not just on 'successful regions', but also on other regions whose innovation processes may be more difficult to identify. Because the research design focuses on a value chain and not a region and because the value chain concentrates on interaction over action, the

research design also emphasises the functioning of actors over a description of their actions. Finally, because the value chain represents an industrial sector rather than particular location it provides the means to develop a comparative perspective.

The conceptualisation of innovation as an iterative and collective process means that knowledge can be both the main focus of research and conceived as a product of different organisational environments. Successful innovation can therefore be seen as dependent upon interaction between such organisations. This conceptualisation means that the 'causation' problem can be avoided. First, because innovation is conceived in neutral terms – i.e. it is neither an advantage nor disadvantage – it is not considered in 'fuzzy' or normative terms. Second, because innovation is considered as dependent upon knowledge, which is, in turn, seen as a product of people – who interact within and through their organisational environment – there is a specific causative direction. Third, because knowledge is conceived in terms of Polanyi's (1967, 1973) explicit and tacit continuum the research did not only focus on the supply-side of the process.

Finally then, the biotech innovation model means that the research incorporates the value chain and innovation models above in a specific sectoral model that avoids the final three methodological 'pitfalls'. First, by focusing on value chains the framework establishes the relevant unit of analysis as a biotech product or technology and the process of innovation. It therefore avoids a static research design. Second, by emphasising a 'systems' approach in focusing on a process the research avoids emphasising a singular actor. Finally, because the research focuses on knowledge – in all its forms – it does not emphasise a particular relational perspective, but rather

takes account of the possible spatial characteristics inherent in knowledge production and transfer.

3.2.3 The Case Study Approach

The research design uses a case study approach because the research field – the biotech industry – covers a range of analytical units – e.g. product value chains. Each value chain is therefore an element of the case study, which seeks to represent the biotech industry as an example of the 'knowledge economy'. The case study approach suits the methodological framework because it seeks to be explanatory, which Yin (2003: 6) argues leads to "operational links needing to be traced over time", rather than the more traditional focus of case studies on an 'instance' (see Blaikie 2000: 215). Each value chain is conceived as temporally as well as spatially contextual and thus each chain covers the whole of the innovation process from, crudely speaking, the initial 'discovery' stages to product sales.

Case studies are inherently dynamic because they concern more than a single point in time. Thus they can incorporate the dynamic elements of the methodological framework outlined above. However, because it needs to cover a specific context (Bryman 1996: 100) – which in this case is the UK biotech industry identified – and spatial research needs to avoid a location emphasis, the case study needs to be focused on an industrial sector. Furthermore, by focusing on value chains – constituting the overall case study – the research avoids the static, spatial focus on 'what' organisations do and, in contrast, focuses on the more dynamic, organisational aspects of 'how' they do it (i.e. function) (Maskell 2001).

In summary the theoretical and methodological concerns raised in Chapter 2 and in this chapter above encourage the adoption of a case study approach because a regional focus could not be used. The conceptualisation of innovation as systemic and dynamic also means that the biotech value chains are designated as the units of analysis and therefore necessitate a non-static and organisational perspective. The case study approach also enables the research to avoid one major issue with a focus on value chains. There is a possible issue here with the need for specific informants (i.e. people involved in a value chain) that may lead to problems with access to informants (Arksey and Knight 1999) and commercially sensitive data (O'Neill 2003). However, the case study approach sufficiently broadens the research area and thereby alleviates the possible threat of low response rates and inaccessible informants.

3.2.4 Initial and Revised Research Designs

After choosing the case study approach it is important to consider how a sample population is to be identified for each unit of analysis (i.e. biotech value chain). The initial research design centred on a 'product history' approach akin to the global commodity chains (see Gereffi 1994, 1996) or global production network (Coe et al 2004) perspectives. This would have centred on a small number of products and analysed their historical development in depth. However, there were some crucial weaknesses with this approach. First, there were only a small number of clearly UK origin biotechnology products, which could have meant that data availability would be very low. Second, and following on from the last point, the small number of products would have meant that any research would have been highly reliant on

access to certain informants and data. This was a special concern with biotech because of the importance of commercially sensitive and confidential product data. Therefore informants may have been reluctant to take part. Third, the popularity of the biotech sector as a research site may also have been an issue because of the time and energy needed using a product history approach; interview or survey 'fatigue' was therefore a particular concern (Healey 1991). Thus to broaden the sample size it was necessary to expand beyond a product history approach.

The research design therefore focuses on the role and use of knowledge in the biotech industry using value chains as a means to identify the sites of innovation and knowledge processes, especially the transfer and acquisition of different types and forms of knowledge. The research design is oriented towards quantitative research techniques and in particular it uses a mixed survey methodology comprising standardised questions administered via structured telephone interview or as a questionnaire. Informants are identified through their involvement in a biotech value chain, which are, in turn, identified using secondary data. Thus the value chains themselves are part of the methodological framework rather than the point of the methodology itself. There is still an issue with access to secondary data – especially because of commercial confidentiality – and primary data – especially in access to 'elite' groups – but these concerns are lessened using this approach (Stewart and Kamins 1993). However, both issues are still central concerns in the research ethics and design of the mixed method survey, which needed to ensure confidentiality and anonymity as well as reassure elite informants that taking part will not require excessive time or effort.

3.3 RESEARCH ETHICS

3.3.1 Research Ethics

During the research process, ethical approval was sought and received from the research ethics officer of the Department of Planning at Oxford Brookes University. Final approval was received on form SOPE1 in September 2003. Where relevant, the research design complies with the Oxford Brookes *Code of Practice* regarding the 'Ethical Standards for Research involving Human Participants'. At the same time I attended a University training session on the 'Principles of Ethical Research for Studies involving Human Participants'.

The mixed methods survey had been based on informed consent with details on the project, its aims and initial motivations provided to informants when they were approached. Perhaps the most significant issue that has already been highlighted above is how to maintain and assure confidentiality, particularly commercial confidentiality, whilst administering the survey. During administration by either email or telephone each informant had been assured of anonymity and confidentiality. This is maintained in two ways. First, the standardised survey questions are worded in such a way as to avoid the need for a specific, self-identifying answer (see **Appendix 3.1** for the coding frame), whilst informants' responses to the open questions are anonymised. Secondly, during analytical coding of the survey responses the survey title page, containing personal information on the respondent, had been removed.

Where relevant potentially revealing comments recorded in the survey itself are also erased or deleted on electronic copies. The front pages have been disposed of, but an electronic record of the identities of respondents has been kept by the researcher and updated regularly. Once the final response had been completed the electronic files were deleted from the university computer although an electronic backup was kept in a secure location. All hardcopy survey responses have been kept in a locked desk draw until the analysis stage when the standardised questions were input into an SPSS data format and the open question responses were transcribed. Once this had been done, these survey hardcopies were disposed of.

3.3.2 Researching Elites

A secondary element that had to be taken into account during the research design is the special circumstances surrounding research on 'elite' groups. Whilst the term itself is certainly ambiguous (see Woods 1998), the conceptualisation of an 'elite' informants plays an important role in methodological design. There are several things that need to be taken into account in terms of a research design based on accessing biotech firm managers, academics and service provider personnel. First, approaching elite informants requires short, concise requests and administration because of time constraints (Kincaid and Bright 1957). Second, preparation is vital because informants are willing to argue, sometimes forcefully, their own point of view, especially where they do not see the point of the research emphasis. Therefore it is necessary to be prepared to defend this focus. Third, informants are not necessarily restricted to a clear set of organisational boundaries or locations (Cochrane 1998). Some informants move around frequently, both within and across organisations, whilst others spend a

considerable amount of time moving between locations, in meetings or tied up in their work. For example, over about eight months I attempted repeatedly, and in the end unsuccessfully, to interview one informant, who was a venture capital investor, even after they had agreed to participate.

3.4 RESEARCH METHODOLOGY

3.4.1 Sampling

The sampling process was two phased. In the first phase a series of value chains were identified through the collection of secondary data on biotech products and processes. Although there had been several problems during this phase, usually concerning the difficulty identifying relevant value chains, eventually enough value chains were identified. The second phase consisted of the identification of individual informants drawn from value chains identified in the previous phase.

3.4.1.1 Value Chain Identification

The value chain sample was constructed from both biotechnology products and biotechnology processes in order to broaden the sample and account for technologies that are intangible (e.g. bioinformatics platforms) or designed for intermediate markets (e.g. drug delivery platforms). For ease these are all referred to as ‘products’ throughout the thesis. In each case the product had the following four characteristics:

- It had to be marketed, have been marketed or be near market (i.e. be successful)

- Its sale had to benefit a UK company (i.e. contribute to the UK economy)
- Its R&D had to occur at least partially in the UK (i.e. derive from UK knowledge)
- It had to involve biological science or be produced by a biotech company (i.e. be part of the 'biotech industry').

A sample population was created through the collection of secondary data on biotech products. This started with regulatory agencies like the FDA, EMEA, Canadian drug agency, and MCA (now MHRA). However, because the number of products identified this way was limited, covering pharmaceutical products only, it was necessary to broaden the approach. Consequently, biotech databases and consultancy reports were used to identify other products because they referred to the products / technologies of firms. Furthermore, after a database of firms had been created (3.5.1) it was possible to check their websites and identify any relevant products through such internet sources. Using these methods it was possible to identify around 250 biotech firms (over half the total number) which sold some sort of product, although in most cases these were limited to research tools and techniques, components, and technology platforms.

All biopharmaceutical products identified by the FDA and EMEA were included in the sample because these tend to be the products that are most often analysed in existing research. No agricultural crop products were included because of the moratorium on crop growing in the UK until 2004. There were other agricultural products, but these refer to products like feed enzymes or pest control products. A significant number of products were tools or techniques for use in the biological sciences (e.g. platform technologies) rather than products for general sale. It was

necessary to include these types of products because of the limited number of products in the therapeutic and agriculture sectors.

In order to identify the relevant informant for the mixed methods survey it was necessary to collect secondary data on the biotech products covering a number of characteristics. In particular it was important to identify where development had taken place and who had been involved in development. The exact information collected includes the following:

- Type of product
- Product sector: e.g. therapeutic, agricultural
- Product launch or approval date
- Product's marketer
- Product's developer
- Development collaborators.

It is difficult to acquire this secondary data on biotech products, especially where the aim is to create an adequate sample population, because the number of marketed products is limited (as with therapeutics) or information is scarce (as with platform technologies). Despite claims to the contrary in the BIGT (2003) report on the UK biotechnology industry, there are few biopharmaceutical products that have been developed by UK firms. For example, BIGT (2003) provides a list of around 40 UK 'biotech' products, which includes both chemical substances and products developed outside of the UK. However, the number is really nearer 10 biopharmaceuticals and even some of those are loosely defined, no longer marketed, or jointly developed with

non-UK firms. Furthermore, the secondary data on other types of biotech products was also limited meaning that only brief details for 107 biotech products could be acquired covering the 250 identified companies with products (see above). These products therefore do not represent a random sample per se, but rather a sample based on data availability that enables the identification of individual informants involved in the product's value chain (see **Appendix 3.2** for a list and **Appendix 3.3** for an analysis).

3.4.1.2 Informant Identification

The identification of biotech value chains enables the identification of informants who have been involved in the development of the particular product. These informants were initially separated into three distinct populations to cover the biotech innovation system: (1) company informants, (2) science base informants, and (3) service provider informants. These had been defined in terms of their organisational position within the value chain:

- A company informant was someone in a company carrying out R&D on biotechnology
- A science base informant was someone connected to a biotech company whether through their research or position (e.g. Science Advisory Board (SAB) member)
- A 'service provider' was a person in a non-biotech organisation that provided non-R&D services during development. It is a broad category that covers a

range of services, from the usual legal or consultancy services through to technology transfer offices to regional development agencies and regulators.

However, this original three-way distinction had to be abandoned because of the poor response rate from science base informants. Instead, two categories were used:

- Innovator: covering anyone involved in R&D anywhere throughout the value chain.
- Service provider: covering anyone involved in a non-R&D function anywhere throughout the value chain, although still outside the firm.

The reason for distinguishing between informant populations is to see whether there are any major differences in their responses in the mixed survey. Since all respondents are considered as members of the value chain, conceived in systemic terms, it is interesting to consider the differences between 'innovators' and 'service providers' to explore whether the innovation process can actually be conceived in such a systemic fashion. Any differences between the informants would also be useful in illustrating the different position of different actors with the innovation process and the particular knowledge that these different actors draw upon based on their role and function.

Both sample populations were identified using the biotech value chains, defined as a particular product. The innovator informants were identified using two main methods. First, from a patent search for a relevant product and then an internet search of the company website for the relevant person. This proved to be a surprisingly successful method for a number of products, but usually only for smaller firms and therefore

another method proved necessary as well. Secondly, informants were chosen from firms themselves, either (initially, but later dropped) from SABs (for science base informants) or from management teams. The usual informant chosen was either the Chief Scientific Officer (CSO) or Chief Technology Officer (CTO), although where a manager's biography mentioned a specific product then they were chosen.

The service provider sample was slightly more difficult to identify. They were chosen because of their position within an organisation that had some sort of connection to a particular value chain. For example, where a value chain firm was located on a science park then the science park manager might be approached, or if the firm had a particular investor then one of investment managers might be approached. More generic informants were also approached where they are part of organisations like Regional Development Agencies (RDAs) or government departments (e.g. the DTI Bioscience Unit). Because of the way that the methodological framework was constructed the experiences and perceptions of these 'service provider' informants are treated the same as 'innovator' informants.

The main problems with this sampling process derives from the reliance upon identifying specific biotech value chains and then associated individual informants who played a part in it. Knowing whom to focus on is a problem in research, particularly with business informants whose 'status' may prove ambiguous (see Cochrane 1998). In order to avoid this issue, the research design concentrates on specific individuals involved in the value chain. In a majority of cases these can be identified in the innovator sample population with over two-thirds (39 out of 58) directly associated (i.e. worked on research and/or development) with a particular

product. The other third (19 out of 58) were chosen according to job title and, where possible, relevance to R&D (see Markusen 1994 for problems with using occupational titles). A secondary problem is the low response rates from specific population types, in particular university academics. The initial three-way sample approach had to be adjusted because so few academics were willing to participate; usually for time reasons, but also because they did not associate themselves with a particular value chain. The use of SABs did not solve this problem because most SAB members are there to reflect financial credibility, rather than provide direct scientific and technical input (see Audretsch and Stephan 1996). Finally, the original approach to service providers had to be adjusted because of confusion over the questions in the mixed methods survey as identified during the pilot study phase as outlined below.

3.5 DATA COLLECTION AND RESEARCH METHODOLOGIES

A number of issues helped to influence the choice of methodologies. For example, the initial research design focused on 'product histories' and had led to the collection of secondary data on biotech products (see **Appendix 3.2**, **3.3**) and firms (see Chapter 5). This data proved useful in the subsequent research framework. The research also largely followed a 'realist' approach – in that it is concerned with the existence of a material world understood through particular social descriptions (Williams and May 1996: 81-82) – and therefore focuses on causation rather than 'refining' or questioning material descriptions. Consequently the research methodologies are concerned with the 'representativeness' and 'reliability' of the phenomenon under consideration (i.e. *knowledge-space* processes in innovation) over and above 'validity' (Bryman 1996). This means that data collection has been split between the

collection of secondary data from primary sources (e.g. databases, websites) and primary data using a mixed methods survey administered through structured phone interview or as an email questionnaire.

The first stage of the research had been the collection of secondary data on biotech products and firms. There were two main reasons for collecting data on biotech firms; the first was to generate a database on the UK biotech industry and the second was to identify a sample population for the primary data collection. Since the latter has already been discussed above, we will deal with the former here. The purpose of the secondary data on firms was to address the first hypothesis and thereby complement the primary data generated through the mixed methods survey that addressed the sedond hypothesis (Markusen 1994). Thus the secondary data provides the grounding for the primary data analysis through describing the UK biotech industry, especially in relation to the analysis of the spatial distribution and connections between different scales.

3.5.1 Secondary Data Collection

The secondary data on the biotech sector came from a number of primary sources (see **Tables 3.2**, **3.3**, **3.4** and **3.5** below) and was used to construct a database in a number of electronic formats depending on the analytical use to which it was put. The database covers the whole UK biotech industry and details a number of firm-level indicators chosen because of their relevance to the theoretical and methodological framework. It also covers other organisations like public research organisations (PROs) and universities. The data is analysed on a territorial basis using software such

as Microsoft Excel and SPSS. In particular, the data is split between three scales based on Eurostat regional designations:

- NUTS1 (equivalent to RDA designations)
- NUTS2 (equivalent to two or three counties)
- NUTS3 (equivalent to one county or city).

These Eurostat designations were used because they are scalable in that one scale leads to another and the data is therefore easier to compare across scales. Second, it enabled the use of secondary data derived from Eurostat itself. Third, the data collected during the research would also be relevant beyond the confines of the UK. Finally, such scales are based on population, rather than administrative, boundaries which means they are relevant for population specific indicators.

The first stage of secondary data collection involved identifying biotech firms, which necessitated a definition of 'biotechnology' that could be applied to firm activities, especially their research activities. This definition follows previous ones used in policy circles (e.g. ACARD et al 1980; House of Lords 1993; DTI 1999a, 1999b) in order to make the research policy relevant. As a consequence it is a broad definition covering firms that primarily use biological production processes and / or produce biological products. However, since the thesis focuses on innovation processes only firms that carry out R&D were included. Overall this means that pharmaceutical companies, major corporations, and other specialist supplier and service firms are not included in the definition. Thus the database may not reflect the whole scope of

biotechnological activity within the UK although studies by the DTI (2005) and Critical I (2006) have used similar approaches.

Firms were identified through regional biotechnology associations such as ERBI, OBN, and Scottish Enterprise, which means that they are largely self-selecting and therefore cover a number of unsuitable firms (e.g. reagent suppliers and service firms). Therefore it was necessary to filter the firms by refining the database according to the above definition particularly in relation to R&D activity. Furthermore, because regional associations are self-selecting it is necessary to search other biotech databases produced by private organisations such as Biospace and the BIA (free access) as well as BioWorld and BioCommerce (subscription service); the latter were accessed either through copyright libraries or on trial periods. This cross-checking of firms between the regional associations and biotech databases helped to filter out unsuitable firms as well as provide information on those firms included in the database.

The collection of data on firm indicators was determined by the theoretical and methodological concerns highlighted above. They primarily cover 'knowledge' factors such as the number of patents a firm has, the size of its R&D employment and the number of alliances it has. Data on the basic characteristics – e.g. location, foundation date, employee numbers etc. – was derived from two sources, either a biotech database or the FAME internet database of all UK firms, [xv] depending on which was most up-to-date. Data on the knowledge indicators came from a range of other electronic sources. For example, patent data came from searches of patent

offices. The sources of the basic secondary data on firms are outlined below in **Table 3.2**, which also highlights the data coverage and type.

Table 3.2: Secondary Data Sources: Firms and Products

DATABASE	ACCESS	COVERAGE	TYPE
Bioworld	Pay (3-week trial)	Industry	Firms, products, alliances, finances
Biocommerce	Pay (OBN copy)	Firms	Firms, statistics,
Biospace	Pay (part free)	Products	Marketed products are free access
BIA	Pay (part free)	Firms	Firms, products
Bioscorpio	Pay (part free)	Industry	Firms, products
Nature Biotechnology directory	Pay (part free)	Firms	Firms, statistics
Genetic Engineering News	Pay (part free)	Products, technologies, science	Products, alliances
BIO	Free	Industry	Firms, products, statistics
Biotech Analytics	Free	Firms	Firms, histories and products
Informagen.com	Free	Firms	Addresses
National Center for Biotechnology Information (NCBI)	Free	Products, technologies, science	Products, histories
Open Directory	Free	Information sources	Databases, webpages
Oxfordshire Bioscience Network (OBN)	Free	Firms	Firms
ERBI	Free	Firms	Firms, products
BioDundee	Free	Firms	Firms
Bio Sci North	Free	Firms	Firms
London Biotechnology Network	Free	Firms	Firms, products
Scottish Enterprise	Free	Firms	Firms

Once a list of products and firms had been compiled, secondary data on firm-level knowledge indicators was collected from the same secondary sources and from

relevant primary sources. Once this data was collected it was input into the database as well. The source of data on firm-level indicators is shown in **Table 3.3** below.

Table 3.3: Secondary Data Sources: Knowledge Indicators

INDICATOR	SOURCE
Location	FAME database, company website, biotech database
Company type (e.g. public, private)	FAME database
Biotech sector (e.g.. therapeutic, agriculture)	Company website
Ownership (foreign)	FAME database, company website
Spin-out	Company website, university technology transfer offices
Foundation Date	FAME database, company website
Turnover 2001-03	FAME database, biotech database
Employment 2001-03	FAME database, biotech database
Employment R&D 2001	Biotech database
Total Alliances 1997-2004	Bioworld database
Total International Alliances 1997-2004	Bioworld database
Total UK Alliances 1997-2004	Bioworld database
R&D Spend $	www.innovation.gov.uk - R&D Scorecard, biotech database
Number of Patents USPTO <2003	USPTO
Number of Patents EPTO <2003	esp@acenet (patent database)
Number of Articles <2003	ISI Web of Science

As well as data on products and firms, secondary data on universities and public research organisations (PRO) was collected. The main secondary source for this data was the university department lists from the 2001 Research Assessment Exercise (RAE), but biotech the databases already used to identify firms were also used to identify PROs. Instead of merely identifying whole universities, separate university departments were identified based upon their relevance to biotechnology. The departments chosen corresponded to those selected in the DTI (1999b) *Genome Valley Report* and are outlined below:

- Agriculture
- Biological Sciences
- Chemistry
- Clinical Laboratory Sciences
- Hospital-based Clinical Subjects
- Other Studies and Professions Allied to Medicine
- Pharmacology
- Pharmacy
- Veterinary Sciences

Table 3.4: University Department Indicators

INDICATOR	SOURCE
Location	Website
Department	RAE 2001
2001 RAE Score	RAE 2001
1996 RAE Score	DTI (1999b)
Staff Numbers 2001	RAE 2001
Total Research Council PhD Studentships	BBSRC, NERC, MRC websites
Wellcome Trust Funding 1980-2002	Wellcome Trust
NERC Funding 2003	NERC
MRC Largest Recipients 2001/02	MRC
BBSRC Top 50 Institutions by Total Approved Funds	BBSRC

PROs were identified from research council (RC) websites (e.g. MRC, NERC, BBSRC), the Wellcome Trust website, two biotech databases (Biocommerce and Nature Biotechnology), and the *Genome Valley Report* (DTI 1999b). Once both university departments and PROs were identified, secondary data was collected on organisational-level indicators covering information related to their knowledge base. These data sources are outlined in **Table 3.4** for university departments and **Table 3.5** for PROs.

Table 3.5: PRO Indicators

INDICATOR	SOURCE
Location	Website, RC websites, biotech databases
Institute Type	Website, RC websites, biotech databases
Foundation Date	Website, RC websites, biotech databases
Total Research Council PhD Studentships	BBSRC, NERC, MRC websites
Staff Numbers 2001	Website, RC websites, biotech databases

3.5.2 Primary Data Collection

A mixed methodology survey was used to collect primary data (see Lavrakas 1993). It covered a series of standardised questions administered via either structured telephone interview or email questionnaire. Around 60% of the surveys was carried out via telephone interview and 40% by questionnaire with three face-to-face interviews carried out during the pilot phase. The choice of telephone or email administration was driven by the location and choice of the respondent – e.g. all international respondents were asked to complete a questionnaire, whilst national respondents were asked for a telephone interview. All the face-to-face interviews were within Oxfordshire (i.e. local).

The mixed method survey took place over a 10-month period starting in December 2003 and was split between a pilot and main phase. During the whole period a total of 302 people were contacted – 174 innovators and 128 service providers – either by email (usually) or phone (where email information is unavailable). Of these people 101 were unavailable or denied their relevance to the particular product value chain (33%), whilst 90 rejected the approach (30%) and 109 accepted (36%).

3.5.2.1 Mixed Method Survey: Pilot Phase

The pilot phase covered December 2003 to January 2004 and consisted of eight structured interviews with six innovators and 2 service providers. It was stopped at this point because of a number of ambiguities with the questions. The pilot phase therefore proved a crucial part of the research process because it enabled the testing of the survey design as well as the questions and their meaning and interpretation by respondents. Such testing of surveys and their questions using a pilot phase is emphasised as crucial throughout the methodological literature (see Schoenberger 1991; Healey and Rawlinson 1993; Arksey and Knight 1999).

The pilot phase revealed an ambiguity within the research design that treated all informants whether 'innovators' or 'service providers' as similar actors in the innovation process. Because the questions focused on specific value chains (i.e. products) service provider respondents found the questions irrelevant to their roles in the innovation system because they did not see their role as directly impacting on innovation per se. The research design therefore contained a conceptual slippage between sampling and question rationale, which needed to be removed. For example, when service providers were asked about their role in value chains they denied involvement, but when asked about generic innovation systems (without reference to a product) the sampling frame lost its rationale and their answers became irrelevant.

As a consequence of the pilot phase a choice had to be made between three possibilities. First, to not sample service providers at all; second, to use generic

questions for all respondents; or third, to use generic questions for service providers and specific questions for innovators. The first of these would limit the sample size, making the survey even more dependent on one sample population and skewing the methodological approach (i.e. that multiple organisation are involved in innovation providing different inputs that are all valid and important to success). However, the second choice would have meant that the sampling frame lost its relevance altogether. Therefore, the sampling frame was not changed (i.e. informants were still identified in relation to a value chain), but rather the questions service providers were asked were changed to make them generic. Thus, for example, instead of being asked:

'Please rate how often you read information from the following sources during development?'

They were asked:

'Please rate how often you read information from the following sources?'

Innovators were still asked the specific questions. The pilot process not only provided the means to address this design fault, it also meant that several other elements in survey administration could be practised. Thus it provided the opportunity to improve the precision of questions (Healey 1991); it helped to develop the interpretative advice given to respondents (Frey and Oishi); it improved the initial request techniques (in emails and phone calls); and finally it revealed the questions that informants found particularly problematic (Arksey and Knight 1999).

3.5.2.2 Mixed Method Survey: Question Choice and Design

The pilot survey included a total of 109 standardised questions and five open questions with a general comment at the end. All the questions were developed in relation to the theoretical and methodological framework that draws on the existing literature on knowledge and innovation processes and their relationship to space. A number of people also provided advice on refining the questions as well as the layout and the design of the survey itself.

The decision to use standardised questions was primarily to reduce the time needed for completion of the survey and thereby increase the response rate. The questions were designed around the Likert-scale (1 to 5) where 1 always represented the 'lowest' response (e.g. very unimportant) and 5 the 'highest' (e.g. very important). The inclusion of open questions was designed to avoid restricting the respondents' 'voice' (Arksey and Knight 1999) and reduce any possible frustration at being limited to a certain set of responses; a particular concern with elite respondents (Schoenberger 1991).

The questions themselves were split between three sections (*Relationships*, *Location*, and *External Influences*) each of which was designed to cover an aspect of the methodological framework and the subsequent research questions. The sections covered the following issues:

- Relationships: these questions focused on the main interactions of each respondent and the source and types of explicit and tacit knowledge they access
- Location: these questions focused on the location of each respondent in terms of the regional 'assets' and importance of different labour markets
- External Influences: these questions focused on the importance of external influences on the biotech industry, such as location of demand or government interventions.

After the pilot phase the number of questions was reduced for two reasons. First, some of them were considered superfluous, whilst second the length of the telephone interview was considered to be too long by some respondents. Consequently, the number of questions was reduced to 79 standardised questions, three open questions and the general comment. The actual form of the questions was not changed except for the service provider sample population so the responses received during the survey phase could be used in the primary data analysis. The coding frame for the survey is contained in **Appendix 3.1**.

3.5.2.3 Mixed Method Survey: Main Phase

During the main phase of the survey the national-based informants were sent a prior request via email asking for an interview with the attached survey in Microsoft Word format. The survey included an introduction outlining the aims of the research as well as an Oxford Brookes logo and contact details to provide credibility. Because the introduction is an important tool for raising response rates, it was designed to identify

myself and my university affiliation as well as explaining my research purpose and assuring confidentiality and anonymity (see Lavrakas 1993). In particular and taking Healey's (1991) suggestion into account the introduction also included information on the usefulness of the research by referring to the benefits it might have in relation to '*regional economic growth strategies*'. The emailing of the survey questions prior to interview also proved useful because they then acted as a 'flashcard' during the interview itself, which proved particularly useful with the standardised, Likert-scale questions (see Frey and Oishi 1995: 74-5). It also enabled respondents to raise preliminary issues.

The email interview request included a comment stating that it would be followed up with a telephone call in the next two weeks to allow for time delays caused by holidays or other events and so that informants did not simply ignore the request. This also meant that the sample members could forward the email to another person within their organisational hierarchy, which happened several times during the research process (see Healey and Rawlinson 1993). Those informants with no identifiable email address were contacted directly by telephone to ask for an interview or to complete a questionnaire, but were given a similar introduction as that in the email (Lavrakas 1993). All internationally based informants were sent an email although in these cases they were only asked to complete the attached survey. Instead of emails or telephone calles large firms were sent letters addressed to either the 'director of research' or 'company secretary' asking if they would allow interviews of personnel involved in a particular product's development. This was usually necessary because of the added difficulty identifying a relevant sample member from such large organisations since they restrict the amount of published information on employees

and have complex hierarchies (O'Neill 2003). Consequently it was a less successful than email approaches and more difficult to follow-up because of access difficulties.

Only a limited number of informants chose to respond immediately to emails, which meant that most were also contacted by telephone. This was expected and the email pre-warning was designed to increase response rates (Healey 1991). The initial approaches were directed towards asking for an interview rather than administering the interview at that time as were the 'cold-calls' to informants with no identifiable email address. This meant that interviews could be properly prepared and structured before administration. It also made it more convenient for the informant and hoepfully increased their response rate, especially because business informants may not wish to answer questions during work hours (Gilham 2000).

On several occasions informants were willing to complete the interview at the approach stage, which necessitated a degree of preparedness before cold-calling. However, it was more usual for informants to either reject the request (for a variety of reasons) or accept and agree to arrange a time for the interview. Some also agreed to complete the questions and return them via email. The number of phone calls necessary to *reach* each informant was usually between one and six, although in some cases it was as high as 10. Where possible messages were left with each unanswered call stipulating the next time they would be contacted (e.g. tomorrow).

3.5.2.4 Telephone Interviewing

The usual reason for choosing to use telephone interviewing is that it reduces the incidence of interviewer bias because the administration of questions can be tightly controlled thereby limiting any 'interviewer effects' because an interviewer can be trained and supervised before and during interviewing (Fowler and Mangione 1990; Frey and Oishi 1995). Telephone interviewing is also seen as "well-suited to random and structured sampling" (Arksey and Knight 1999: 79) because there are electronic means to select respondents, such as 'computer-assisted telephone interviewing' (CATI) and 'random-digital dialling' (Lavrakas 1993; Frey and Oishi 1995). However, these concerns were not as important during the thesis' research process because each informant was individually selected in relation to their specific role or duties, which meant that each informant had to be treated differently.

According to Lavrakas (1993) little is lost between face-to-face and telephone interviews, meaning that the former is not necessarily more relevant than the latter. However, it was hard to test this claim during the research because there were so few face-to-face interviews. Those that I did undertake invariably took longer, taking between 30 and 60 minutes, and the standardised format was less suitable than during telephone interviews. This aside, telephone interviewing had the following benefits:

- It took less time than face-to-face interviewing (Frey and Oishi 1995)
- It was cheaper than either face-to-face interviewing or a postal survey (Gilham 2000)
- There was a quicker response than a postal survey (Arksey and Knight 1999)
- The social etiquette of telephone usage meant that termination was less likely (Lavrakas 1993).

Despite these benefits there were still several problematic aspects to telephone interviewing. First, they still took a lot of time because of the need to make multiple calls to initiate the request, the callback and then the interview (Arksey and Knight 1999). The usual number of phone calls to conduct the interview was between two and 10, which was fairly reasonable in comparison to other studies ranging between five and 20 calls (see Frey and Oishi 1995). Second, because the sample population consisted of elites they were more difficult to tie down to a single location during the initial approach (Cochrane 1998). It was therefore necessary to call mobile phones as well as landlines, which could have interferred with the concentration of respondents. Third, although the short length of the interview was beneficial, it also meant that there was limited time to collect data. The suggested length of a telephone interview ranges between 10 minutes (Healey 1991) through 20-30 minutes (Lavrakas 1993), to a high of 50 minutes (Frey and Oishi 1995). During the initial approach informants were told that it would take around 15 minutes to do the interview, which was designed to encourage participation. Overall, the average (mean) time taken was 18 minutes. Finally, the interviews were surprisingly tiring despite their short length because they required considerable concentration and sometimes detailed explanations. Overall, these issues meant that the complexity of the interview questions had to be limited, which in some ways created its own problems in that respondents often required interpretative advice (Lavrakas 1993; Arksey and Knight 1999).

3.5.2.5 Standardised Questions

As with telephone interviewing, the use of standardised questions is meant to avoid interviewer bias. However, the thesis' research design entailed a focus on the experience of informants rather than 'factual' information about their organisation (Healey 1991; Healey and Rawlinson 1993). Therefore during the administration of the survey I played an important role interpreting the questions for respondents. Because I was the sole interviewer this did not affect the interpretative advice given to respondents and therefore avoided some aspects of 'interviewer bias'. It was apparent that interpretative assistance was almost a necessity with standardised questions because respondents often have very different understandings of terms or apply different meanings to concepts from the interviewer (Schoenberger 1991: 180-1).

The main reasons to use standardised questions was to enable quality control of data collection through the easier construction of questions in relation to specific research aims (Lavrakas 1993). Second, because they increase time efficiency by taking 10-20% less time (Groves 1989 in Arksey and Knight 1999), standardised questions enabled a larger respondent sample. During the thesis the average time per interview was 18 minutes, which was three more that claimed at the email or telephone requests stage (i.e. 15 minutes). Overall 83% of the telephone interviews took less than 20 minutes. Third and most importantly, standardised questions improve response rates (Healey 1993), which Healey (1991) argues can vary considerably between methodologies. Frey and Oishi (1995) argue that a 70% response rate is reasonable for standardised questions for the general population, although this is lower for specialist populations. During the primary data collection phase a total of 174 innovators and 128 service providers were approached over a 10-month period. After discarding those informants who were 'not relevant' – e.g. they had no involvement with the

product in question or could not be contacted after repeated callbacks – the final response rate was 53% across the whole sample. There was little difference between the two main sample groups (innovators and service providers) and it would appear that the use of standardised questions with a mixed methodology helped to ensure the reasonable response rate.

3.6 CONCLUSION

The research design and methodological approach outlined in this chapter are meant to address the thesis hypotheses presented earlier in the chapter (3.2.1). The approach has been built upon a conceptualisation of the innovation process that incorporates three conceptual models identified in the last chapter (Chapter 2). These are the value chains model, the systems of innovation model and the biotech innovation model. All three represent crucial elements in the methodological framework (3.2.2). They are designed to address the central questions and issues that the *knowledge-space* dynamic raises regarding innovation processes in the knowledge economy and particularly in the biotech industry.

First, the secondary data collected (3.5.1) during the research is meant to address the first hypothesis covering the question of whether knowledge economy concentrations are dynamic systems embedded in space. This is detailed in Chapter 5, which explores these issues by identifying a number of possible biotech concentrations in the UK and their particular characteristics that distinguish them from other concentrations. It then considers what types of proximity can explain such concentrations and how exactly the *knowledge-space* dynamic operates across different scales.

Second, the collection of primary data (3.5.2) is designed to address the second hypothesis on how the place-specific dynamic and systemic processes can be seen as originating in a number of different places, both within and across concentrations. This is explored in Chapter 6, which considers what different types, forms and sources of knowledge actors in the innovation process access. From this it is possible to argue that knowledge is positioned and embedded across different spaces and scales that are all necessary for successful innovation to occur.

Finally, the collection of primary and secondary data alongside the exploration of the changing global and institutional context of the UK biotech industry is meant to enable the analysis of how different locational assets provide different advantages during the innovation process that therefore necessitate the formation of linkages within and across different locations. This analysis runs throughout Part II being incorporated in the next chapter on the background and context of the biotech industry (Chapter 4) as well as the secondary data analysis (Chapter 5) and primary data analysis (Chapter 6) in later chapters.

Overall the research design and methodology adopts two distinct features. It reverses the causality of previous research by considering the knowledges – in all types, forms and sources – that actors use in the innovation process. It also adopts a specific spatial dimension, in that it considers each location as distinct from each other and therefore the site of geographical specificities. Consequently, the analysis of the biotech industry portrayed here concerns how different and distinct spaces of knowledge

position and embed different types and forms of knowledge that are then accessed by actors across and within different spatial scales.

PART I

SUMMARY

This section deals with the theoretical and methodological basis of the thesis, in particular outlining the core issues and problems that the thesis seeks to address. In particular these concern the spatial positioning and embedding of knowledge and innovation processes in the knowledge economy using the UK biotechnology industry as a case study. Chapter 2 provided a theoretical analysis of existing literature on the knowledge economy as well as theories addressing the importance of innovation to economic development and both knowledge and space to innovation. In so doing it provided the basis for a new approach called the *knowledge-space* dynamic that led directly to the construction of the methodological framework and research design outlined in Chapter 3. This entailed a case study approach using biotech value chains to produce an informant sample who were then questioned about the knowledge processes during the development of successful biotech innovations. As such the theory and methodology enabled the avoidance of reversing causality by addressing the importance of spatially-situated knowledge processes rather than assuming that such processes are important simply because of the success of particular locations.

PART II

Background and Data Analysis

The term ‘biotechnology’ was first coined by the Hungarian Karl Ereky in 1917 to describe his work on the industrial fattening of pigs for the Austro-Hungarian war effort (Bud 1998: 7). Since then it has been defined in terms of three historical periods covering early biological processes like those undertaken by Ereky as well the industrial fermentation of the nineteenth and early twentieth century. More recently this definition has included ‘modern biotechnology’ following the work of Crick and Watson on the double helix of DNA and later work in recombinant DNA techniques. It is during the modern period that biotechnology has assumed commercial importance and consequently come to represent a distinctive and perhaps even paradigmatic example of the knowledge economy. In this section the thesis outlines the historical development of biotechnology in the UK and the world as well as the global context of the current UK sector (Chapter 4). Subsequently the section consists of analyses of the secondary (Chapter 5) and primary (Chapter 6) data collected during the research process in response to the hypotheses developed in the last section of the thesis (Part I). In each of these chapters the primary focus of analysis is on understanding what the particular knowledge processes in the spatially embedded innovation system are and how these contribute to successful innovation.

CHAPTER 4

PLACING THE BIOECONOMY: HISTORICAL BACKGROUND AND GLOBAL CONTEXT OF THE UK BIOTECHNOLOGY INDUSTRY

4.1 INTRODUCTION

As the discussion of *knowledge-space* dynamic in Part I shows, it is as important to ground any research on the knowledge economy in an analysis of the institutional environment and historical change as to focus on specific innovation processes. This is particularly important for the biotech industry because of the crucial role that institutions (e.g. intellectual property rights) play in promoting and encouraging the sector as well as the high expectations that are perceived to be necessary for its success (May 2000; Walsh 2002; Drahos and Braithewaite 2002, 2004). Such expectations can actually be seen as a constitutive element of the sector itself (Rajan 2006) because of the important role they play in encouraging investment (Walsh 2002). Thus it is possible to argue that the biotech industry is 'socially constructed' through very deliberate legal, policy and legislative changes made by a number of governments in their pursuit of competitiveness in biotechnology over a number of years (Wright 1993; Loeppky 2004; Birch 2007). Overall the chapter concerns the particular institutional characteristics of the UK biotech industry in the wider global context in order to ground the later analyses in Chapters 5 and 6 as well as illustrate and address the third hypothesis that:

H3: The knowledge economy depends on different locations and scales of knowledge because different places have different locational assets that contribute to successful innovation in different ways and therefore necessitate linkages between locations.

To do so this chapter provides an historical background for the discussion and analyses as well as positioning Britain within the global context. Although there are several thorough histories of developments in molecular biology and biotechnology, there are no histories of the biotechnology industry from its inception in the mid-1970s until the present. Three examples of the former include:

- Daniel Kevles' (1995 [1985]) *In the Name of Eugenics* which concerns the development of genetics from its origins in eugenics to the subsequent shift to molecular biology in the 1930s.
- Robert Bud's (1993) *The Uses of Life* which is subtitled *A history of biotechnology* and concerns the development of biotechnology specifically from 'zymotechnology' (i.e. fermentation) in the nineteenth century through chemical engineering to modern biotechnology.
- Herbert Gottweis' (1998a) *Governing Molecules* which focuses on changes in the regulatory environment, particularly in Europe, covering modern biotechnology and how its subsequent development.

However, these histories are limited and therefore it is necessary to provide at least a brief history of both modern biotechnology and the early development of the biotech

industry in the UK. This provides the historical background to the discussion of the global context in which the thesis has been undertaken. This is presented later in the chapter and covers two main issues. The first is the global context of the biotech industry, its comparative strength in different countries and especially the dominance of the USA. The second issue is the institutional environment in which biotechnology has developed both globally and in the UK, especially the changes in intellectual property rights (IPR). This discussion will ground the analysis of the secondary and primary data collected during the thesis in broader issues focused on the institutional changes particular to the biotech industry and how they have contributed to the development of the sector.

4.2 HISTORICAL BACKGROUND

4.2.1 Biotechnology Definition

Biotechnology tends to be defined in terms of the application of the biological sciences to industrial production. In 1980 the *Spinks Report* used a definition of 'modern' biotechnology (see later on difference between old and new) as "the application of organisms, systems or processes to manufacturing and service industries" (ACARD et al 1980: 7). The European Federation of Biotechnology (EFB) – founded in 1978 with the goal of promoting the development of biotechnology in Europe (Dibner 1986) – defined biotechnology in 1981 as the:

> "…integrated use of biochemistry, microbiology, and engineering sciences in order to achieve the technological application of the capacities of micro-organisms, cultured tissue cells and parts thereof" (quoted in Bud 1998: 9).

Over a decade later in 1993, the definition of biotechnology remained broadly equivalent with the House of Lords Select Committee on Science and Technology defining it in "enabling" terms, which has persisted in later UK policy discourse. The Select Committee defined biotechnology as "the use of biological processes to make useful products (organisms, substances and devices)" (House of Lords 1993: 12). They argued that biotechnology is "not a single discipline", but rather "it is a collection of quite different enabling technologies" such as recombinant DNA, cell fusion techniques, micro-infections, 'biolistics', viruses and fermentation of cell cultures (ibid.: 14-15). The 'enabling' concept was again emphasised in both the *Biotechnology Clusters* (DTI 1999a) and *Genome Valley* (DTI 1999b) reports which defined biotechnology as the "the application of knowledge about living organisms, and their components, to make new products and to develop new industrial processes" (DTI 1999a: 1). Interestingly, the latest government-sponsored report produced by the Bioscience Innovation and Growth Team (BIGT) in 2003 failed to provide a definition of biotechnology in its executive summary.

The use of an 'enabling' definition means that biotechnology is very broad covering many biological processes and not just those that occurred after the advent of either recombinant genetic engineering (1973) or cell fusion (1975). Consequently biotechnology has also been characterised in generational terms, such as "old biotechnology" – based on brewing and fermentation – and "new biotechnology" –

based on post-1973 or even 1953 developments (Bud 1993: 200). Another generational typology splits biotechnology between "first", "second" and "third" generations. The first generation was characterised by the experimental application of biological processes in foodstuffs (e.g. brewing) and animal breeding. It can be traced back thousands of years to the beginnings of agriculture in the Fertile Crescent, which explains why biotechnology is often characterised as both old and new. Second generation biotechnology involved the industrialisation of biological production processes derived from greater scientific understanding and largely originated in the late nineteenth and early twentieth century. Finally, third generation (or 'modern' biotechnology) dates from the 1953 discovery of the double helix structure of DNA and the subsequent breakthroughs in molecular biology and genetic engineering that followed this event (Acharya 1999; Brink et al 2004). Since 1953 there have been numerous 'discoveries' and 'inventions' that have led many commentators to proclaim a future 'biotech age' (Oliver 2000) or 'biotech century' (Rifkin 1999), even though there have also been a number false new dawns during this period (Glassman and Sun 2004).

4.2.2 History of Biotechnology

Whilst biotechnology, defined as the application of biology in technical form, has existed for millennia, modern techniques have their roots in the late nineteenth and early twentieth century, especially in genetics and eugenics (see Kevles 1995, 1997). A new "age of biology" was even proclaimed by the US geologist Clarence King as early as 1892, whilst the term "biotechnology" itself was fist coined in 1917 by the Hungarian Karl Ereky (Bud 1993). Later in 1936 Julian Huxley claimed that

"biotechnology will in the long run be more important than mechanical and chemical engineering" (quoted in Bud 1998: 6). Despite such early support, modern biotechnology was derived from molecular biology, which was at least partially a response to the decline of eugenics as a discipline, if not a movement. Eugenics had been a dominant approach across many developed countries from the nineteenth through to the twentieth century, but was increasingly sidelined from the mid-1930s as molecular biology superseded it (see Kevles 1995; Gottweis 1998a, 1998b).

Molecular biology research was initially funded by private and charitable organisations like the Rockefeller Foundation and Volkswagen Foundation, but after World War II the state became increasingly involved as science policy was aligned with national goals (see Yoxen 1981; Gottweis 1998a). The USA government in particular supported 'big science' projects with Vannevar Bush, head of the Office of Science Research and Development, contributing to the rise of the National Institutes of Health (NIH). In Europe equivalent changes took place with the European Molecular Biology Organization (EMBO) originating in the 1950s (Yoxen 1981; Gottweis 1998a). The role of private foundations has not declined in importance since then. Today they still contribute significantly to the research effort as illustrated by the role played by the Wellcome Trust in the UK science base where its annual expenditure of $1 billion contributes enormously to basic research (Cooke 2004b). However, state investment remains a central plank in the development of basic science and its application as the recently completed Human Genome Project (HGP) shows (Loeppky 2005).

The first major break with the molecular biology focus was the development by James Watson and Francis Crick of the 'double helix' model of DNA in 1953 at the Medical Research Council (MRC) funded Laboratory of Molecular Biology in Cambridge (Bud 1993). Prior to this, in 1944, researchers at the Rockefeller Institute in New York had established that it was DNA and not proteins that bore genetic information thereby encouraging the subsequent mapping of DNA (Dutfield 2003). However, the research by Crick and Watson as well as later work on both DNA and proteins in the 1950s and 1960s did not lead to major commercial developments. There was a thirty-year gap before modern biotechnology produced its first major commercial commodity.

In 1973 Stanley Cohen, Herbert Boyer and their colleagues at Stanford University and the University of California developed a recombinant DNA (rDNA) technique which provided the means to insert foreign genes into microorganisms (Rifkin 1999; Dutfield 2003). The commercial application of rDNA and, shortly afterwards, the development in 1975 of hybridoma techniques by Georges Köhler and Cesar Milstein, who both worked at the MRC Laboratory of Molecular Biology (Cambridge), heralded the start of the 'biotech industry' proper. The latter technique enabled the fusion and multiplication of monoclonal antibodies (Sharp and Senker 1999). Several subsequent discoveries have also proved to be important elements in the expansion of commercial applications, or at least were presented as such. For example, Kary Mullis, working for Cetus Corporation, developed the means to amplify (i.e. replicate) large quantities of DNA through polymerase chain reaction (PCR) technology (Dutfield 2003; Bergeron and Chan 2004). Throughout the 1980s such genetic engineering techniques were expanded beyond microorganisms to other living

organisms; initially with plants where the first cross-plant species gene insertion occurred in 1983, then animals where a cancer-causing gene was inserted into a mouse, patented in 1988 (Dutfield 2003).

Whilst genetic techniques were expanding, a new focus in biotechnology arose around genomic research. In 1990 the multi-national Human Genome Project (HGP) was instigated, largely funded from public sources such as the NIH and Department of Energy in the USA, but also with funding from private foundations like the Wellcome Trust in the UK (Bud 1993; Dutfield 2003). The HGP relied upon the earlier discoveries and inventions in DNA sequencing by Frederick Sanger and others at Cambridge in the 1970s and automated sequencing machines of Leroy Hood and others at the California Institute of Technology in the early 1980s (Dutfield 2003). Subsequently, several living organism genomes have been sequenced such as *H. Influenzae* (1985), *C. elegans* (1988), and *Arabidopsis thaliana* (2000) (Cooke 2001c; Dutfield 2003). Finally, in February 2001 the HGP and the company Celera Genomics, which from its establishement in 1998 had been competing with the HGP, both announced the completion of a draft human genome sequence (Dutfield 2003).

Whilst biotechnology had a range of potential applications – as evident in **Table 4.1** below – the first commercialisation of molecular biology actually involved a firm called Cetus founded in 1971 in California before the discovery of rDNA. Cetus sought to apply new techniques in the engineering of bacteria for therapeutic purposes and had been founded with the support of the venture capital (VC) firm Kleiner Perkins, which had previously been heavily involved in the development of Silicon Valley (Bud 1998; Owen 2001).

Table 4.1: Timeline of Important Biotech 'Discoveries'

DATE	INNOVATION OR DISCOVERY	SCIENTISTS	COUNTRY
1953	DNA structure	Watson/Crick	UK
1968	Chromosome identification	Caspersson/Lech	Sweden
1973	*In vitro* recombinant DNA	Cohen/Boyer	USA
1975	Monoclonal antibodies	Milstein/Kohler	UK
1977	DNA sequencing of a virus	Sanger et al	UK
1981	Automated gene sequencing machine	Hood et al	USA
1983	First plant gene inserted in gene of another species	Various	USA, Belgium
1985	DNA profiling	Jeffreys	UK
1985	Polymerase Chain Reaction amplification	Mullis (Cetus)	USA
1995	Genome of first free-living organism sequenced: *H. Influenzae*	Venter, Smith	USA
1997	Clones and transgenic sheep	Wilmut	UK
1997	Stem cells cultured for first time	(Gerhard)	USA
1998	Nematode worm sequenced: *C. elegans*	Waterston, Sulston	USA/UK
2000	First plant genome: *Arabidopsis thaliana*	Davis, Federspeil	USA
2001	Human genome sequenced in draft	HGP/Celera Genomics	USA/UK/Other

Source: Rifkin (1999); Cooke (2001c); Dutfield (2003); BIO website.

However, after the mid 1970s Cetus faced strong competition from the newly emerging dedicated biotechnology firms (DBF) based on rDNA research. The first of

these was Genentech established in 1976 on the basis of the work of Cohen and Boyer, who had sought to patent their rDNA discovery under advice from Robert Swanson who was a partner at Kleiner Perkins (Hughes 2001).[xvi]

Whilst the rDNA patent was not finalised until after the conclusion of the *Diamond vs. Chakrabarty* case in 1980 (dealt with later), Genentech still managed to gain credibility through a 1978 contract with the pharmaceutical multinational Eli Lilly for the production of recombinant human insulin (Bud 1993; Owen 2001). Recombinant human insulin subsequently became the first widely commercialised modern biotechnology product; it was launched in 1982 and reached annual sales of $5,340 million by 2002/03 (Acharya 1999; Nightingale and Martin 2004). Following Genentech two other firms were founded in the 1970s – Biogen and Genex – before a burst of activity in 1980 led to the foundation of 26 new firms (Bud 1993: 193). In the same year Genentech had floated on the NASDAQ exchange and raised $35 million by doubling its market value in one day (Owen 2001; Dutfield 2003). Genentech was also the first biotech firm to market a new biotech pharmaceutical product (rDNA human growth hormone), which was approved in 1985 in record time (McKelvey 1996; Dutfield 2003). Despite achieving these milestones, Genentech was subsequently acquired by Hoffman-La Roche in 1989, although it retains a significant level of independence (Bud 1993).

4.2.3 History of the UK Biotech Industry

Whilst the biotech industry was starting to develop in the USA, the Labour government in the UK sought to establish an equivalent industrial base and to this end

it commissioned an inquiry into biotechnology in 1978 (Gottweis 1998a, 1998b). Alfred Spinks, an ex-research director at ICI (Imperial Chemicals Industry), headed the commission, and the eventual report produced in 1980 became known as *The Spinks Report* (ACARD et al 1980). The report was the result of a working party set up to assess the "existing and prospective science and technology relevant to industrial opportunities in biotechnology" by the Advisory Council for Applied Research and Development (ACARD), Advisory Board for the Research Councils (ABRC) and The Royal Society (ibid.: foreword). According to Herbert Gottweis (1998a: 196) the composition of the 'Spinks Working Party' indicated a "new orientation for the political coding of the new biology" towards a concern with the commercial applications and benefits of biotechnology as opposed to concerns with health and safety. A dominant theme throughout the report was the fear of lost commercial opportunities, which resurfaces throughout later assessments by UK policy-makers (see House of Lords 1993; BIGT 2003). However, the fear of lost advantage was not new, but had been evident much earlier in relation to molecular biology. For example, a 1962 Royal Society ad hoc committee argued that the UK would lose its "place in international research" without "major changes in the organisation of biology departments" (quoted in Yoxen 1981: 98). Even earlier, in the aftermath of World War I, the UK had established research councils, such as the Medical Research Council (MRC) (established in 1920), in response to a perceived "scientific and technological crisis" (Yoxen 1981: 84).

After the publication of *The Spinks Report* in 1980, the new Conservative government in the UK produced a White Paper (1981) response that broadly claimed that biotechnology could be left to market forces and did not require government

intervention (Sharp 1985). Despite such claims, several important public initiatives were undertaken between 1980 and 1982 to encourage biotechnology research and commercialisation.[xvii] First, in 1980 the government founded a new firm called Celltech, which had special rights to commercialise research funded by MRC (Bud 1993; Owen 2001). Second, in 1981 the Science and Engineering Research Council (SERC) established a Biotechnology Directorate to support applied research in biotechnology (see Dunnill and Rudd 1984 for an assessment). Finally, in 1982 the DTI set up a Biotechnology Unit to support the commercialisation of research and included staff seconded from industry to help in this endeavour (Sharp 1985; OECD 1988).

Despite these changes Herbert Gottweis (1998a: 203, 205) argues that the new Conservative government "failed" to properly follow up *The Spinks Report*'s recommendations, and took 10 years to "find a suitable organizational structure for funding decisions in biotechnology". In contrast, Margaret Sharp (1985) suggests that the government strongly promoted biotechnology across a range of schemes including the funding of basic and applied science and the encouragement of public-private partnerships. However, there was a move away from a central strategy with a reorganisation of the National Research Development Corporation (NRDC), which had a monopoly over the commercial exploitation of government-funded research. The NRDC was merged with the National Enterprise Board (NEB) in 1981 to form the British Technology Group (BTG), which finally lost its overall monopoly in 1985 (Owen 2001).

Whilst the public sector was reorganising the funding of biotechnology in the UK, the private sector was taking an active role in the establishment of more biotech firms. One such firm was British Biotech, which two scientists from the subsidiary of the US firm Searle founded in 1986; it has since merged with and been renamed Vernalis plc in 2003. Perhaps incidentally, the first research director of Celltech, and several other staff, had also come from Searle (Owen 2001). A new type of science entrepreneur was also evident with the likes of Christopher Evans founding Enzymatix in 1987 after returning from working in the USA at Genzyme. Subsequently, he spun off a number of other companies like Celsis International and Chiroscience (merged with Celltech plc in 1999, which has since been bought by the Belgium firm UCB) (Owen 2001). Evans is now chairman of the biotechnology venture capital firm Merlin Biosciences, which he founded in 1996.[xviii] One major change that benefited the expansion of the private sector was the 1993 decision by the London Stock Exchange (LSE) to alter its listing rules so that firms could raise public investment without requiring revenue, profitability and trading experience (Gottweis 1998a; Owen 2001). There were still specific requirements that firms had to meet, such as £20 million market value and three-year record of R&D operations, but it still enabled UK firms to pursue public investment. As a consequence of such changes, firms began to publicly launch on the stock market so that by 1995 twenty-five firms had gone public (Owen 2001: 14-15).

4.3 GLOBAL CONTEXT OF THE UK BIOTECH INDUSTRY

4.3.1 The Global Biotech Industry

To gain some understanding of the global context in which the UK biotech industry operates it is useful to draw upon secondary data from market and consultancy reports. The most commonly used reports are those produced by Ernst & Young each year. These are particularly popular sources in the academic and policy literature on biotechnology, where they have been used extensively (e.g. DTI 1999b; van Reenen 2002; Casper and Murray 2004). The reason to use these data is that it provides a consistent and comparative view of the global biotech industry. It also means that the data collected during the thesis could be contrasted with a broader view of the biotech industry. A final reason is that even though there are strong reservations about their veracity, the market and consultancy reports also tend to be more conservative than government estimates about biotechnology and therefore less subject to exaggeration.

Table 4.2: Global Biotech Industry 2005

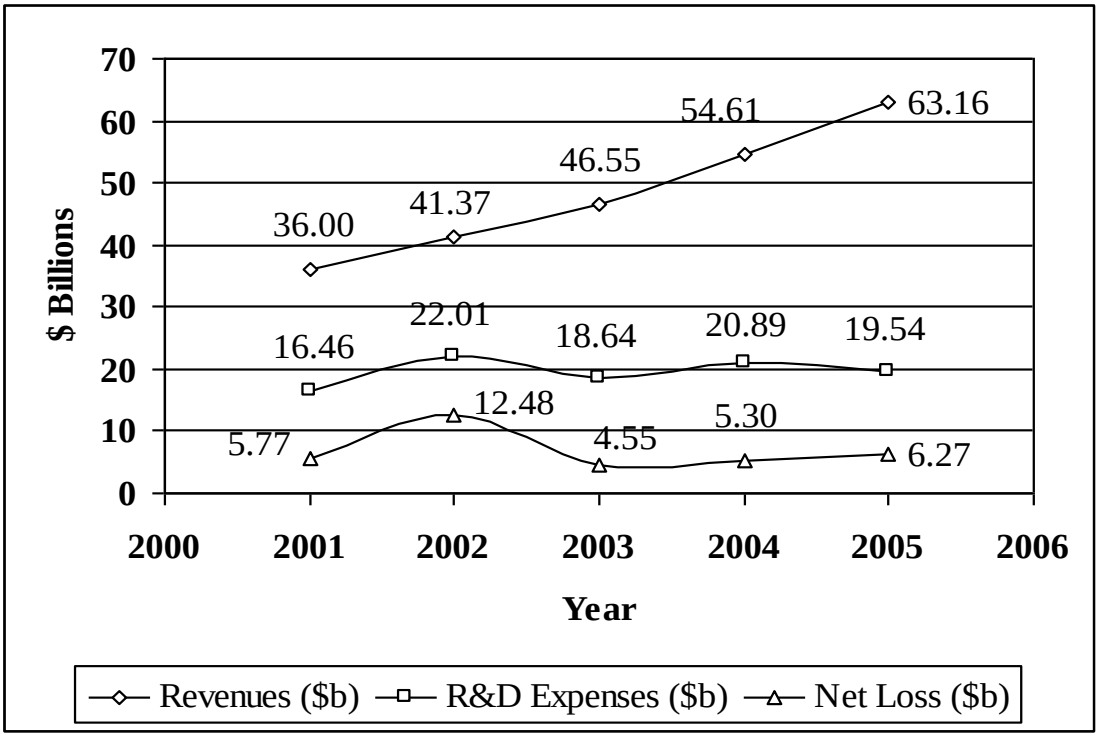
	GLOBAL BIOTECH	**% CHANGE 2004-2005**
Revenues ($b)	63.16	18
R&D Expenses ($b)	19.54	4
Net Loss ($b)	6.27	-30
Public Companies	645	4
Private Companies	3,522	0.3
Total Companies	4,167	1

Source: Adapted from Lawrence (2006).

In 2005 Ernst & Young reported that the global biotech industry had reached revenues of $63.16 billion for public companies (see **Table 4.2**), which is lower than an earlier

DTI forecast for the year 2000 of £70 billion (DTI 1999b). Another forecast, made in 1997 for the European biotechnology trade association EuropaBio, predicted four possible scenarios for 2005 ranging from 'fast' to 'failed' development; the forecasted revenue projections ranged between €250 billion for the former and €25 billion for the latter (see DTI 1999b: 23-4). It is evident that current revenues are considerably closer to the 'failed development' figure, especially when we consider that the EuropaBio figures refer to Europe alone. According to Ernst & Young (2005), the 2004 revenues in Europe were only $7,729 billion. Even though this refers to public companies only, a report by Critical I (2006) showed that the European biotech industry still only had revenues of €21.5 billion in 2004 for the whole sector. It is evident that the size of the biotech industry is well below the expectations of some policy-makers, especially when considering that the global biotech industry has never been profitable.

Figure 4.1: Global Biotech Industry Change between 2001 and 2005



Source: Adapted from Ernst & Young (2003a, 2003b, 2005); Lawrence (2006).

Even public biotech companies have, as yet, to return positive revenue figures (Lahteenmaki and Lawrence 2006). Ernst & Young figures, which are based on data from public companies, show that between 2001 and 2005 revenues in the global biotech industry have increased by 75%, or nearly 15% per year. R&D expenditure also rose between 2001 and 2005, but only by 18.7% (see **Figure 4.1**). The impressive rise in revenues, however, has had only a marginal effect on net losses, which actually rose by 8.7% in the same period. As significant perhaps was the fall in global employees by 21% between 2001 and 2004. The number of firms remained relatively static with a 2% decline between 2001 and 2005.

Table 4.3: Comparing the US and European Biotech Industries 2004

	GLOBAL	**USA**	**EUROPEAN**	**EURO as % of USA**
Revenues ($b)	54.61	42.74	7.73	18.09%
R&D Expenses ($b)	20.89	15.7	4.15	26.43
Net Loss ($b)	5.3	4.14	0.48	11.59
Employee Numbers	183,820	137,400	25,640	18.66
Public Companies	641	330	98	29.70
Private Companies	3,775	1,114	1,717	154.13
Total Companies	4,416	1,444	1,815	125.69

Source: Adapted from Ernst & Young (2005).

Although the global biotech industry provides a useful context in which to position the thesis, it is also helpful to compare the size of the US and European industries to show the difference in size of both and the dominance of the US globally. Again, Ernst & Young provide a useful secondary data source for the reasons outlined earlier. The data here concerns 2004 rather than 2005, primarily because the secondary and primary data collected during the thesis was only up until 2004. Therefore data from 2004 provides a more relevant context for the rest of the thesis, even though the above discussion provides as up-to-date information as possible. The main indicators used by Ernst & Young to portray the biotech industry are revenue, R&D expenditure, net loss, employee numbers, and the number of public, private and total companies (see **Table 4.3**).

Table 4.4: Biotech Industry Change 2003-2004

	GLOBAL	**USA**	**EUROPEAN**
Revenues	17.31 %	19.22 %	3.48 %
R&D Expenses	12.07	15.70	-1.89
Net Loss	16.48	27.78	-12.73
Employee Numbers	-6.13	-5.95	-21.03
Public Companies	4.91	5.10	2.08
Private Companies	-2.20	-3.88	-2.72
Total Companies	-1.23	-1.97	-2.47

Source: Adapted from Ernst & Young (2005).

This data shows how small the European biotech industry is in comparison with the USA. In terms of both revenues and employee numbers, Europe represents around 18% of the US; less than a fifth. For R&D expenditure this is slightly higher at 26% or a quarter and for number of public companies 29%. Net losses are only around 11%, which indicates that Europe may be more sustainable, if significantly smaller. However, Europe does perform well in terms of number of companies with over 50% more private firms and 25% more total firms than the USA. Overall this would suggest that the European industry is made up of much smaller firms with lower revenues and levels of employment, although also significantly lower losses. This analysis is borne out in the change between 2003 and 2004, which show that although the USA is increasing its revenues significantly (and far more than Europe), it has also witnessed large rises in net losses over the same period, higher than revenues (see **Table 4.4**).

Table 4.5: US and European Biotech Industry Growth 1998-2003

	USA	**EUROPE**
Revenues ($m)	115 %	754 %
R&D Expenses ($m)	101	556
Net Loss ($m)	71	58
Employee Numbers	38	184
Public Companies	-1	41
Private Companies	16	59
Total Companies	12	58

Source: Adapted from Ernst & Young (2004a).

There appears to be a growing divergence between the USA and Europe as the former continues to invest heavily in the biotech industry as evident in the 15.7% increase in R&D expenses between 2003 and 2004 compared with a 2% fall in Europe, whereas the European sector stabilises in search of profitability. However, by taking a longer period of data it is possible to show that European biotech is outperforming the USA in relative terms (see **Table 4.5**). Between 1998 and 2003 the growth in European revenues was 754%, over six times higher than for the US during that period. There are similar figures for the growth in R&D expenses where the European change between 1998 and 2003 was over five times the US. There also appears to be a fivefold difference in the growth of companies between Europe and the US, although most significantly perhaps is the huge difference in growth of public companies, 41% growth in Europe and 1% decline the USA. Despite the comparatively strong growth of the European sector, however, it is still obvious that there is a massive difference in economic and technological performance between the two geopolitical regions.

4.3.2 Global Biotech Performance

The difference between the US and European sectors can be split between market and technological performance. The market performance of the US biotech sector can be shown using data on the market capitalisation of US companies. This was $189.5 billion in 2002 for the US – a decline of 34.7% from 2001 – and €21.8 billion for Europe, or a decline of 52% from 2001. However, to put this last indicator in perspective ir is worth noting that in 2001 the market capitalisation of the US company Amgen was $61.5 billion whilst for the whole European sector it was only

$51 billion (all data from Ernst and Young 2003a, 2003b, 2003c). More recent data shows that the market capitalisation of the San Francisco Bay Area – the heartland of biotechnology – was around $162 billion in 2005 (Lawrence 2006). The main reason for these differences is that US companies dominate product development particularly in relation to biopharmaceutical products, which represent the highest earning products in the biotech industry. The difference in technological performance between the US and Europe can be shown in relation the number of biopharmaceutical products each has produced and the strength of their product pipelines. A note of caution must be raised here, however. It is important to acknowledge a number of recent critical analyses of both pharmaceutical and biopharmaceutical development (see Horrobin 2003; NRDD Editorial 2003; FDA 2004; Nightingale and Martin 2004; Joppi et al 2005; Martin et al 2006). These will be dealt with below, but first it is useful to consider the strength of different national product pipelines. The different phases of these pipelines are outlined in **Table 4.6**.

Table 4.6: Clinical Development Phases

PHASE	PROCESS
Pre-clinical	In vitro and animal testing
Phase I	Toxicity testing on healthy volunteers
Phase II	Efficacy testing on patient volunteers
Phase III	Efficacy and statistical significance testing on large number of patient volunteers
Phase IV	Post-marketing surveillance

Source: Eaton (2004).

Product pipelines are useful for illustrating the strength underpinning a country's biotech industry because they represent actual commercial possibilities as opposed to expectations. In **Table 4.7** below there is data on the 2002 pharmaceutical pipelines of a number of countries which details the number of products in various phases of development and testing.

Table 4.7: National Biotech Product Pipelines 2002

	PRECLINICAL	PHASE I	PHASE II	PHASE III	TOTAL
UK	65	50	56	23	194
Switzerland	45	12	11	11	79
Sweden	14	8	10	0	32
France	16	8	6	1	31
Denmark	14	5	5	4	28
Italy	9	0	4	3	16
Israel	2	3	6	4	15
Germany	7	4	3	1	15
Norway	8	2	2	3	15
Netherlands	9	1	1	0	11
Finland	9	1	0	0	10
Ireland	2	0	2	3	7
Belgium	2	0	1	0	3
EUROPE	**202**	**94**	**107**	**53**	**456**
USA	**584**	**96**	**148**	**44**	**872**

Source: Adapted from BIGT (2003).

It is obvious that the USA dominates national pipelines with a total of 872 products in development and 44 in Phase III testing and therefore closest to the market. Phase III testing does not mean that a product will automatically make it to market, but there is a higher possibility than for the previous Phases (see Nightingale 2000; FDA 2004).

Figure 4.2: European Biotech Product Pipelines

Source: Adapted from BIGT (2003).

A comparison of European and US pipelines shows that the USA has a significantly stronger pipeline with almost double the number of products in development than the whole of Europe; 872 and 456 respectively. Out of the European countries, the UK had the strongest pipeline with 23 products in Phase III development alone, a number that is over half the number that the USA has (44). The UK pipeline is obviously very strong, especially in Europe where it represents 43 percent of the European total (see **Figure 4.2**) and 42 percent of Phase III products. The UK and Switzerland accounted for nearly two-thirds of all European Phase III products.

By 2003 the UK proportion of total products had fallen to 41 percent, although the proportion of Phase III products remained the same (Ernst and Young 2004). The overall number of European products in development had also fallen from 456 in 2002 to 392 in 2003, with the most significant fall in Pre-clinical development where numbers fell from 202 to 147. The decline in products in development was not necessarily because products were successfully marketed since the United States Food and Drug Administration (FDA) only approved 25 new biotech products in 2003 (Ernst and Young 2004), most of which had been developed and marketed by US companies.

The first major reason that the US dominates biopharmaceutical development is that North America represents the largest market for both pharmaceuticals – 50% of global sales (Thayer 2004) – and biopharmaceuticals – 60% of global sales (Bibby et al 2003). The current US dominance is evident in a number of recent analyses (e.g. Reichert 2000; Ashton 2001a; Arundel and Mintzes 2004; FDA 2004; Nightingale

and Martin 2004). Such research also shows how dominant the blockbuster model of development remains (Bergeron and Chan 2004), despite scientific and technological discoveries (e.g. pharmacogenomics) that make it possible to target pharmaceuticals to specific subgroups more effectively. The blockbuster model has, however, meant that the US biotech industry receives enormous revenues each year from its marketed products, although a significant proportion accrues to only two firms; Genentech and Amgen with 30% of revenues (Lahteenmaki and Lawrence 2006). Furthermore the top six biotech drugs launched during the 1980s and 1990s were all launched first in the USA (by US companies) where total biopharmaceutical sales represent $19 billion per year or 58% of global sales in 2002 (Bibby et al 2004: 5).

The second major reason for US dominance is that the US has more marketed products and therefore higher revenues than Europe. The US Bio Industry Organisation (BIO) estimated that there were 197 approved 'biotech' products in 2003, although due to definitional ambiguity this figure may be significantly lower. For example, IMS Health estimates that there were only 119 biopharmaceuticals in 2004, whilst Arundel and Mintzes (2004) put this even lower at only 60 biopharmaceuticals. Despite the different claims, there is one uncontentious fact; US firms have more approved products than other firms. For example, data produced by Ashton (2001b: 23-26) shows that of the 66 'biotech' products introduced between 1982 and 1998 exactly half were marketed by US firms compared with around a third by European firms, including one from the UK, and a fifth by Japanese firms.[xix]

Table 4.8: Top 10 Biopharmaceutical Products in 1993 and 2002/03

PRODUCT	**DEVELOPER**	**MARKETER**	**1993 SALES ($ m)**	**2002/03 SALES ($ m)**	**LAUNCH DATE**	**1993 POSITION (top 10)**
Epogen (erythropoeitin)	Amgen	Amgen / Johnson and Johnson	587	8880	1989 (US)	2
Humulin (recombinant human insulin)	Genentech	Eli Lilly	560	5340	1982 (US)	4
Intron A (interferon)	Biogen	Roche and Schering-Plough	572	2700	1986 (US)	3
Neupogen (GCS factor)	Amgen	Amgen	719	2520	1991 (US and EU)	1
Betaferon (interferon B)	Berlex (Schering AG)	Berlex (Schering AG)	-	2200	1993 (US)	-
Protropin (recombinant human growth hormone)	Genentech	Genentech	217	1760	1985 (US)	9
Remicade (infliximab)	Centocor	Centocor	-	1730	1998 (US)	-
Rituxan (rituximab)	Genentech/IDEC	Genentech/IDEC	-	1490	1997 (US)	-
Follicle stimulating hormone	Serono/Organon	Serono/Organon	-	1000	1995 (EU)	-
Synagis (palivizumab)	MedImmune	MedImmune/Abbott	-	850	1998 (US)	-

Source: Sharp and Senker (1999); Ashton (2001a, 2001b); Nightingale and Martin (2004).

As the total number of pharmaceutical product approvals has declined, these biotech products have assumed an increasingly important position in pipeline of multinational pharmaceutical companies. However, the number of biological license applications (BLA) to the FDA has also fallen from 25 in 2000 to 14 in 2003 suggesting that the biotech industry has also suffered from a similar 'productivity crisis' to the pharmaceutical industry (FDA 2004; Martin et al 2006). Furthermore, this trend is global with the FDA reporting in 2004 that since 2000 there has been a marked slowdown in the number of new drug/biologic submissions to all worldwide agencies.

Despite these trends, a number of biological treatments and products have produced enormous returns for their developers and marketers.[xx] For example, the main reason that Amgen has such a high market capitalisation is because it not only developed the 2003 top-selling biotech drug – Epogen – with sales of $8.9 billion, but also the 1993 top-seller – Neupogen [xxi] – which still had sales of $2.5 billion in 2002/03 (Sharp and Senker 1999; Nightingale and Martin 2004). In contrast European companies only had four of the 15 highest selling biotech drugs in 2002/2003, all ranked 9th or below and only two top 10 biotech drugs were originally launched in Europe, one of which was Neupogen produced by Amgen (Nightingale and Martin 2004) (see **Table 4.8**).

4.4 INSTITUTIONAL CONTEXT OF THE UK BIOTECHNOLOGY INDUSTRY

4.4.1 Global Institutional Change

Considering the major differences between the US and European biotech sectors, it is important to explain why, aside from 'first-mover' advantage, the former so thoroughly dominates the biotech industry. In this regards it is useful to explore the different institutional environments in the two geopolitical regions, especially in relation to intellectual property rights (IPR). Some of the most important global changes to intellectual property (IP) are outlined in **Table 4.9** below. These concentrate on the USA and Europe, although they also illustrate the growing importance of international standards such as the development of TRIPS at the World Trade Organisation (WTO).

The main reason that IP is so important is that property rights are necessary for the delineation of new markets, especially in relation to markets based on 'knowledge economy' products exemplified by the biotech industry (Green 1991, 2002). Tait et al (2006) argue that IP is necessary for private investment in biotechnology and that because there was weaker protection in Europe the USA had a competitive advantage. One major difference between Europe and the USA was that in a number of European patent offices awarded patents to inventors and not organisations like universities, which therefore provided few incentives for such organisations to commercialise basic and applied research involving biotech (Senker et al 2000). [xxii] Furthermore, Tait et al (2006) argue that US IP laws enable small and medium-sized enterprises (SMEs) to develop products by undertaking risky research that means large companies can avoid liability for failure, which encourages large firms to fund these SMEs. In turn though, such SMEs remain dependent upon the large companies because SMEs do not have the capabilities or financing to fulfil regulatory requirements (ibid.).

Table 4.9: Intellectual Property (IP) Changes affecting the Global Biotech Industry

YEAR	POLICY/EVENT	DETAILS
1873	Pasteur patent	Pasteur awarded patent claiming yeast as an "article of manufacture".
1911	Parke-David & Co. vs. H.K. Milford & Co.	Purified and slightly modified natural product (adrenaline) considered patentable.
1973	EPO established	European Patent Convention established European Patent Office (EPO) and harmonised patent law.
1980	Diamond vs. Chakrabarty	US Supreme Court ruling on patenting living matter.
1982	CAFC established	Court of Appeals for the Federal Circuit (CAFC) established as final patent appeal court in the USA.
1985	USPTO	Decides that plants, seeds and plant tissue culture are patentable.
1987	USPTO	Decides that non-human living organisms are patentable.
1988	EPO	Grants first plant patent
1994	WTO (TRIPS)	Article 27 relates to biotech, which ensures that patents on genes etc. are covered by all signatories.
1995	In re Brouwer	CAFC rules that 'novelty' is based upon the final product and not the process, therefore allowing process patents.
1995	Biotech Patent Act	Protected process patents in the US.
1995	EPO	Declares that DNA is not life but a chemical and therefore patentable.
1998	EU Parliament	Life Patent Directive adopted.
2001	USPTO	Changed concept of utility to cover theoretical uses.

Source: Maebius (1996); May (2000); Coriat and Orsi (2001); Mowery et al (2001); Drahos and Braithewaite (2002, 2004); Ossorio (2002); Coriat et al (2003); Dutfield (2003); Laurie (2003).

Technology transfer in the USA was also encouraged, facilitated and promoted by successive government policies that shifted ownership of public sector research outcomes, in the form of patents and other IP, to the research organisation rather than central government (see Malinowski 2000: 19). Thus the critical Bayh-Dole Act (1980) reduced restrictions on licensing and allowed universities to retain IP on federally funded research. This policy was subsequently extended to small businesses carrying out federal research in 1983 (Poyago-Theotoky et al 2002). The US government also enacted a number of other pieces of legislation deliberately designed to promote the exploitation of basic and applied research. These included the Stevenson-Wydler Technology Innovation Act (1980), Economic Recovery Tax Act (1981), Small Business Innovation Development Act (1982), Orphan Drug Act (1983), Patent Term Restoration Act (1984), National Cooperative Research Act (1984), Federal Technology Transfer Act (1986), and, more specifically to biotechnology, the Biotechnology Process Patent Act (1995) (Kuhlman 1996; Slaughter and Roades 1996; Loeppky 2004; Birch 2007). The Bayh-Dole Act is seen as particular important with many national governments following suit with their own versions, although often some years later (Howard 2004; Senker 2004).

Aside from this flurry of legislation, IP rights were also changed in the USA as a consequence of the desire to commercialise biotech research, including allowances for the patenting of living material (e.g. microorganisms, animals). Prior to 1980 there had been several patent cases concerning living material (e.g. Pasteur in the nineteenth century and adrenaline in 1911), but it was not until the 1980 *Diamond vs. Chakrabarty* (DvC) ruling by the US Supreme Court that such patent claims were

formalised (see Iwasaka 2000; also Kevles 1998). The ruling upheld a "broad patent" in biotech specifically (Mowery et al 2001: 103) deriving its judgement from a 1952 US Supreme Court judgement that patentable matter could include "anything under the sun made by man" (quoted in Krimsky 1999). After DvC the US Patent and Trademark Office (USPTO) also shifted its position so that by 1987 it was allowing "nonnaturally non-human living organisms, including animals, to be patentable" (Coriat and Orsi 2001: 18). A year later the US Patent and Trademark Office (USPTO) granted Harvard a patent for their Oncomouse.

4.4.2 National Institutional Change in the UK

Whilst other countries changed their institutions, a succession of UK governments sought to counter the (perceived) threat of the USA to UK competitiveness in biotechnology. There has been a continual policy concern with the advantages of the US regulatory environment in UK policy discourse (see ACARD et al 1980; House of Lords 1993; BIGT 2003). There were at least two major reasons for this perception of the US. First, there were "powerful interests emerging in the late 1970s [in the USA] to promote deregulation of industry" (Wright 1993: 81), which cast regulation as an impediment to innovation. Policy-makers in the US quickly moved from concerns about regulation of biotechnology to its commercial exploitation (e.g. US Congress 1981), whereas other countries mostly took their lead from US policies (see Wright 1993; Gottweis 1998a). Second, public acceptance was also cast as an impediment (see Gottweis 1998b), seen as threatening the competitiveness of the emerging biotech industry (House of Lords 1993; US Congress 1981). However, the US government, through the NIH, launched public campaigns early on to persuade the US public that

there were low risks associated with biotechnology (Wright 1998). Thus although the UK had a different initial regulatory framework than the USA, it gradually adjusted to US policy because of the fear that 'stronger' regulation might lead to lower competitiveness (Wright 1993, 1998). Thus the risks involved in the biotechnology industry came to be defined in terms of lost commercial opportunities rather than safety (Wright 1998).

In the UK the 1980 *Spinks Report* heralded an increased concern with biotechnology, characterised by direct government intervention in terms of the foundation of Celltech and the establishment of biotechnology directorates at SERC and the DTI (Gottweis 1998a; Owen 2001). However, alongside these specific policies the government also instigated a series of complementary policies designed to encourage hi-tech innovation generally and biotechnology specifically. These policies are outlined in **Table 4.10** and **Table 4.11** below, which specify the schemes pursued by both Conservative (1979-1997) and Labour (1997-Present) governments respectively.

The broader schemes enacted by the Conservative government like Enterprise Zones, Small Firms Loan Guarantee Scheme and Business Expansion Scheme, were supplemented by policies designed to promote hi-tech growth. These included the 1988 decision to privatise the British Technology Group (BTG) and its earlier emergence from the NRDC and NEB. Furthermore, in the same year universities were given greater scope to exploit their inventions (Robinson 2001) embedding the 1985 decision to end the BTG monopoly on government-funded research, which sought to replicate the impact of the 1980 Bayh-Dole Act in the USA (Casper and Kettler 2001; Owen 2001).

Table 4.10: UK Government (Conservative) Policy 1979-97

YEAR	POLICY/EVENT	DETAILS
1979 – 1997	General government schemes	Enterprise Zones: firms exempt from local tax and some planning controls are relaxed. Business Expansion Scheme: tax incentives for people investing in small firms which allowed investors to claim tax relief on equity investments up to £40,000 and pay no capital gains on sums invested for 5 years or more.
1981	BTG	NEB and NRDC merged to form BTG.
1984	Agricultural Genetics Co.	AGC founded to commercialise results of Agriculture and Food Research Council.
1985	BTG lost monopoly	BTG lost monopoly on government-funded research: reform based on Bayh-Dole Act (1980).
1985	Support for Business Programme	Rationalisation of various schemes that support SMEs by DTI. Includes SMART awards which are competitive system to win awards for product development
1988	BTG privatised	BTG was privatised and universities were allowed to exploit their inventions.
1994	BBSRC	Biotechnology and Biological Sciences Research Council founded.
1995	EMEA	Pan-European medical regulatory agency founded.
1995	Venture Capital Trusts (VCT)	VCTs started to encourage people to invest in higher-risk SMEs that are not on recognised stock exchanges. Income tax relief and Capital gains tax relief on VCT shares
1996	Pharmaceutical Price Regulation Scheme	Companies in the UK allowed to set UK launch price of drugs

Source: Walsh et al (1995); Casper and Kettler (2001); Owen (2001); Robinson (2001); PICTF (2003); Senker (2004).

In 1994 the government also established the Biotechnology and Biological Sciences Research Council (BBSRC) dedicated to funding academic research in the biosciences. A year later the government set up venture capital trusts (VCT) to encourage people to invest in high-risk SMEs that were not on recognised stock markets. Such policies were supported by the early 1990s decision by the London Stock Exchange (LSE) to allow companies to claim their IP as assets during the process of listing on the LSE (Gottweis 1998b).

With the accession of the 'New' Labour government in 1997 the number of policies specifically oriented towards encouraging the biotech industry multiplied considerably. The DTI, for example, established numerous schemes designed to assist biotech firms, such as Biotechnology Exploitation Platforms (BEP), Biotechnology Mentoring and Incubator (BMI) challenge, Biotechnology Finance Advisory Service (BFAS) and the Manufacturing for Biotechnology initiative (DTI 1999b). Furthermore the government introduced a Third Funding Stream for universities in 1999 designed to encourage technology transfer from universities (HM Treasury 2003). There was even a specific policy to encourage the development of business clusters with the 1999 *Planning Policy Guidance (PPG) 11* and *PPG12* requiring support for cluster development at a regional level (ODPM 2004). Corporate venturing, regional venture funds and lower capital gains tax were also all adopted and encouraged (DTI 1999a, 1999b, 2003). Such policies sought to stimulate high-tech sectors, especially the biotech industry, as well as SMEs more generally.

Table 4.11: UK Government (Labour) Policy 1997-present

YEAR	POLICY/EVENT	DETAILS
1997+	DTI schemes	BEP, BMI, BFAS, MBI and Bio-Wise.
1997+	Corporate tax	Lowest in Europe and reduced lower rate from 10% to 0%.
1999	Third funding stream	University funding: Science Enterprise Challenge, Higher Education Innovation Fund (HEIF), University Challenge Funds.
1998	RDA	Regional Development Agencies (RDA) established.
1999	PPG Note 12 and PPG11	Planning guidance issued to encourage planning bodies be more responsive to land-use implications of clusters.
1999	Capital Gains Tax	Taper relief to introduce lower rates.
1999	RVC Funds	Regional Venture Capital (RVC) Funds set up to invest in SMEs.
2000	EMIS	Enterprise Management Incentive Scheme (EMIS): allows tax-privileged share options for key employees of small firms.
2000	Corporate tax	New rate 10% for SMEs.
2000	R&D tax credits	For SMEs, increased from 100% to 150%.
2001	SBRI	Small Business Research Initiative (SBRI): target 2.5% of purchasing for govt departments from SMEs by 2004/05.
2001	Regulatory Reform Act	Allows govt to amend primary legislation such as business regulation.
2001	Health and Social Care Act	Enables inventors to participate in commercialisation of NHS research and allows NHS to take shareholding in spin-out companies.
2001	Criminal Justice and Police Act	Provisions to allow company directors to apply for confidentiality orders so their home address is not publicly available.
2002	R&D tax credits	Extended to all companies of 125%.

Source: DTI (1999a, b; 2002; 2003); Owen (2001); van Reenen (2002); HM Treasury (2003); House of Commons (2003); ODPM (2004).

The general support for SMEs is evident in the lowering of corporate tax for small firms in 2000 and the increase in R&D tax credits from 100% to 150% for SMEs in the same year (DTI 1999b; Owen 2001). Subsequently, in 2002, R&D tax credits were extended to all companies, although at 125% (Owen 2001). In 2001 the government also introduced the Small Business Research Initiative (SBRI) to encourage government departments to dedicate 2.5% of their purchasing from SMEs by 2004/05 (DTI 2003): this copies the Small Business Innovation Development Act (1982) in the USA (Walsh et al 1995). In the same year, the introduction of the Health and Social Care Act (2001) enabled inventors in the NHS to participate in commercialisation and shareholding in spin-out companies from NHS research (House of Commons 2003).

4.5 CONCLUSION

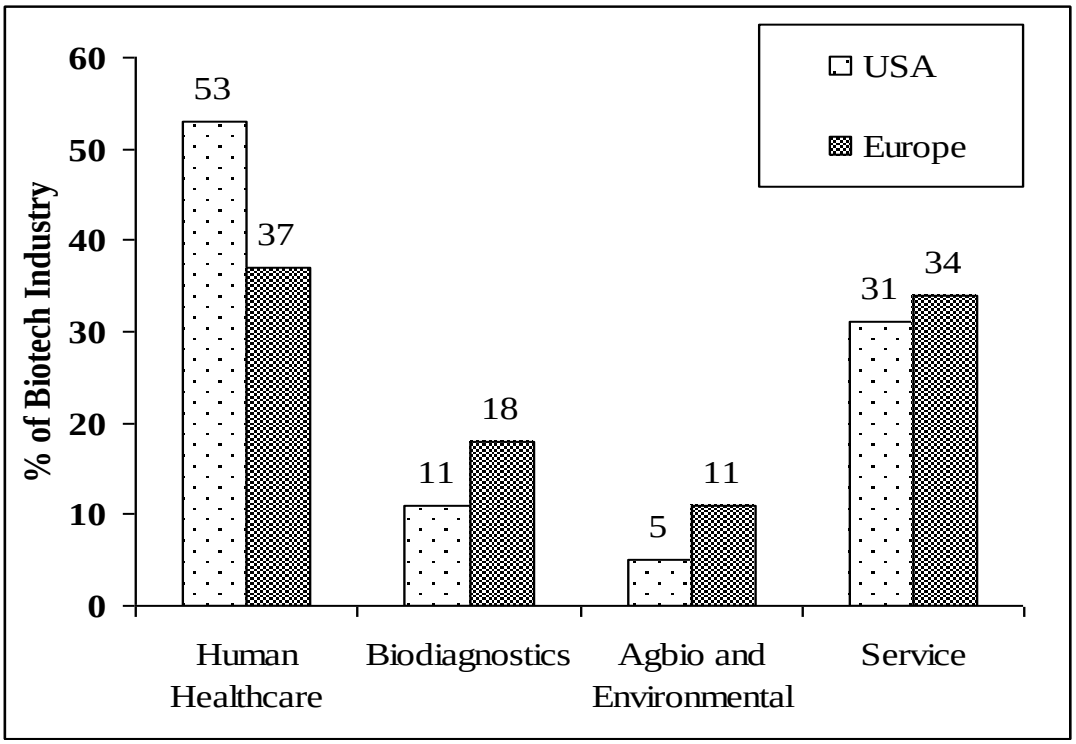
This chapter provides an historical and contextual grounding for the rest of the data analysis in Part II by showing how the development of biotechnology as a commercial endeavour and its current state of the industry has been not been straightforward nor linear. As a country the UK, for example, played a central role in the history of molecular biology and genetics with a number of important early discoveries made here (e.g. DNA structure) as well as more recent contributions to current research (e.g. Human Genome Project). However, whereas the UK has contributed to the 'advancement of science' for a number of years, the lack of commercial exploitation of these ideas has been in marked contrast to the USA. Thus whilst Cohen and Boyer patented rDNA techniques leading to the foundation of the biotech giant Genentech, Milstein and Kohler chose not to do so, which, in its own way, led to the foundation

of Celltech, the UK biotech bellwether that was bought in 2004 by the Belgium phamaceutical firm UCB Pharma.

These two contrasting examples illustrate the dominance of the US in economic terms, if not also in scientific ones. As mentioned above, there are a number of reasons for this dominance. Notably, the US industry has a considerable first-mover advantage as a consequence of early support and encouragement for the biotech industry, both by the US government, but also, more importantly perhaps, by private investment from VC (Bud 1998; Loeppky 2005). Currently the US represents three-quarters of global revenues according to Ernst & Young (2006: 5). Furthermore, US firms dominate both (bio)pharmaceutical product pipelines and markets, although British firms do proportionately well in relation to both of these.

The US dominance is marked in relation to the European sector, although there are possible reasons for this dominance; namely the focus of market and industrial assessments on the healthcare sector. Thus the majority (53%) of US biotech firms operate in the Human healthcare sector as opposed to 37% of European firms (Critical I 2006): see **Figure 4.3**. This means that the US dominance of pharmaceutical pipelines and products ensures that US firms reaped the highest revenues. However, perhaps problematically for US firms there are concerns about the viability of both the 'blockbuster model' of development (Thayer 2004) and the innovativeness of biotech drug products (Arundel and Mintzes 2004; Joppi et al 2005). The UK has the 'strongest' biotech industry in Europe with significantly more pipeline products than any other country and 43% of the European total (BIGT 2003).

Figure 4.3: US and European Biotech Sectors



Source: Adapted from Critical I (2006).

It also has around a fifth all European biotech R&D employees and biotech R&D spend (Critical I 2006: 39). It is important to consider the institutional changes that both the US and UK have instigated over the past three decades to account for the dominance of each country, globally for the US and in Europe for the UK. The US has been especially pro-active in introducing legislation and policies that encourage and support the biotech industry, a trend that the UK has followed as a consequence of the fear of losing competitive advantage to the USA. What this means is that the outline of any analysis of the biotech industry, as will be covered in the next two chapters, has to bring such institutional concerns into this approach. This entails an appreciation of the different scales at which firms and organisations operate, as well as the influence and impact that different institutional structures have on decision-making regarding the acquisition, production, use and commercialisation of

knowledge. Thus the national context, especially in terms of institutional changes, can be seen as central features of the biotech industry. Consequently it is vital to understand how such national (and also global) factors play out in the biotech innovation system, rather than simply assuming that firms operate within countries conceived as market environments. National governments and international actors play a vital role and represent central sources of knowledge for those involved in innovation, which necessitates an external orientation and focus in relation to knowledge acquisition.

CHAPTER 5

EXPLAINING THE BIOECONOMY I: THE CONCENTRATION AND DISPERSAL OF INNOVATION PROCESSES IN THE UK BIOTECHNOLOGY INDUSTRY

5.1 INTRODUCTION

Although institutional change cuts across multiple scales it affects UK regions differently because these changes impact upon particular locations in relation to the existing regional context. For example, changes in public science funding or intellectual property rights (IPR) have different affects on regions because each region has different existing public science infrastructure (e.g. number of universities, public research organisations etc.). This very basic point means that it is important to identify the dynamic (i.e. changes over time) and systemic (i.e. complementarities) features of UK regions in relation to the biotech industry. This includes identifying not only the number of firms and when they were founded, but also the number of relevant university departments, public research organisations (PROs) and service provides such as financiers (Kenney 1998; Powell et al 2002).

Recent literature on the biotech industry emphasises the importance of local sites or 'nodes' of knowledge production that are linked to global knowledge networks (e.g. Wolter 2003; Coenen et al 2004; McKelvey 2004; Ryan and Phillips 2004). This

literature argues that although biotechnology is concentrated in specific sites innovation is not constituted by spatial proximity, but rather through knowledge proximity that may necessitate embedding in a range of external, sometimes global, linkages. This provides a more sophisticated analysis of agglomeration economies than the 'cluster' literature derived from the work of Michael Porter (1990, 2000), which has encoutered criticism for the lack of empirical support (see Malmberg 2003; Malmberg and Power 2005). The more recent literature is built into the first hypothesis:

H1: There are 'knowledge economy' concentrations because successful innovation depends on dynamic (i.e. across time) and systemic (i.e. across organisations) processes embedded in and across specific places.

This chapter concentrates on this hypothesis by first analysing the organisational concentrations of the biotech organisations and their knowledge components in particular places. Although four distinct locations can be identified as concentrations of biotechnology, it is difficult to characterise a general trend that covers all such places. Instead it appears as though each location has a different set of knowledge characteristics – both in terms of bases and drivers – that help to explain the different paths each region has taken. It would also be difficult to support the notion that these UK biotech concentrations reflect similar locations in other countries, especially the USA where, for example, the San Francisco Bay Area alone has twice the revenue of Europe (Lawrence 2006). The next objective of this chapter is therefore to consider what effects different types of proximity – social, spatial and organisational – have on the concentration of the biotech industry (Boschma 2005). Of these three types, only

organisational proximity appears to have an important relationship. Thus the final objective is an exploration of the strength of different scalar relationships between knowledge (bases and drivers) and concentrations to determine the importance of these scales in relation to knowledge and innovation processes.

5.2 UK BIOTECHNOLOGY CONCENTRATIONS

The identification of UK biotech concentrations is mainly based on the number of research-driven firms in each NUTS2 region. This provides the means to identify both the commercial exploitation and creation of modern biotech knowledge, the two central features of knowledge economies identified by Phil Cooke (2002c: 3-5), that can be used to identify the specific characteristics of each concentration. However, because biotech knowledge is also derived from extra-company sources, such as universities, and successful exploitation is dependent on non-science knowledge, such as financing, it is necessary to consider a wider array of organisations. Therefore the organisations included are:

- Biotech firms
- Service providers
- University departments
- Public research organisations (PROs).

Alongside the consideration of the organisational characteristics of regional concentrations, it is also necessary to consider what types of knowledge exist in particular places, how this knowledge is manifested and transferred, and the linkages

both within and across different locations (McKelvey et al 2004). Amongst others, these knowledge indicators include:

- Public science investment
- Intangible knowledge (e.g. patents, articles)
- Employment levels
- Firm sizes and types.

These indicators provide the means to consider some of the complexity of knowledge economies, especially in terms of exploring the importance of inter-regional relations and different knowledge types (Cooke 2003a; Wolter 2003). They also help to situate each biotech concentration within a series of regional, national and international relationships and therefore cut across different spatial scales.

All these data were collected using the European Union NUTS2 region as the main spatial designation. There are 37 NUTS2 regions in the UK, most of which cover an area of approximately three counties or one large city. This means that, first, administrative boundaries are not used as arbitrary sites of research because NUTS2 regions crossed several borders. Second, it provides a means to compare different spatial levels using a consistent scale that could be expanded upwards to NUTS1 or downwards to NUTS3 scales. Finally, it also means that the research is relevant at a European rather than just national level should anyone wish to pursue further comparative research.

5.2.1 Organisational Concentrations

Four major concentrations of the biotech industry can be identified in the UK from available secondary sources; 'major' means that they represent double the average (mean) number of all four types of organisation outlined above (except Eastern Scotland for service providers and East Anglia for university departments). These four main concentrations were, using NUTS2 categories:

- East Anglia: consists of Peterborough, Cambridgeshire CC, Norfolk and Suffolk.
- Berkshire, Buckinghamshire and Oxfordshire: consists of Berkshire, Milton Keynes, Buckinghamshire CC and Oxfordshire.
- Inner London: consists of Inner London West and Inner London East.
- Eastern Scotland: consists of Angus and Dundee City, Clackmannanshire and Fife, East Lothian and Midlothian, The Scottish Borders, City of Edinburgh, Falkirk, Perth and Kinross and Stirling, and West Lothian.

There were also three regions with above average concentrations of all four organisations; Greater Manchester, Surrey, East and West Sussex, and South Western Scotland. However, considering that Surrey, even though it had the most, had only 22 biotech firms, these regions were not considered to be concentrations. No other region in the UK had more than the average (mean) number of all four organisations and, more importantly, no other region had more than the average (mean) number of biotech firms (11.8 firms). So, out of 37 regions only seven contained any significant biotech presence (see **Appendix 5.1** for full list of regional biotech).

5.2.1.1 Biotech Firms

The main variable used to identify British biotech concentrations was the number of research-driven biotech firms in a region. As explained in Chapter 3, these were firms engaged in biotech R&D, which means that they are the main producers of new biotech knowledge for commercialisation. In 2003 there were 436 British biotech firms with an average (mean) of 11.78 per NUTS2 region (median of 6). Only seven regions had more than the mean number (**see Table 5.1**).

Table 5.1: Regional Concentrations of Biotech Firms 2003

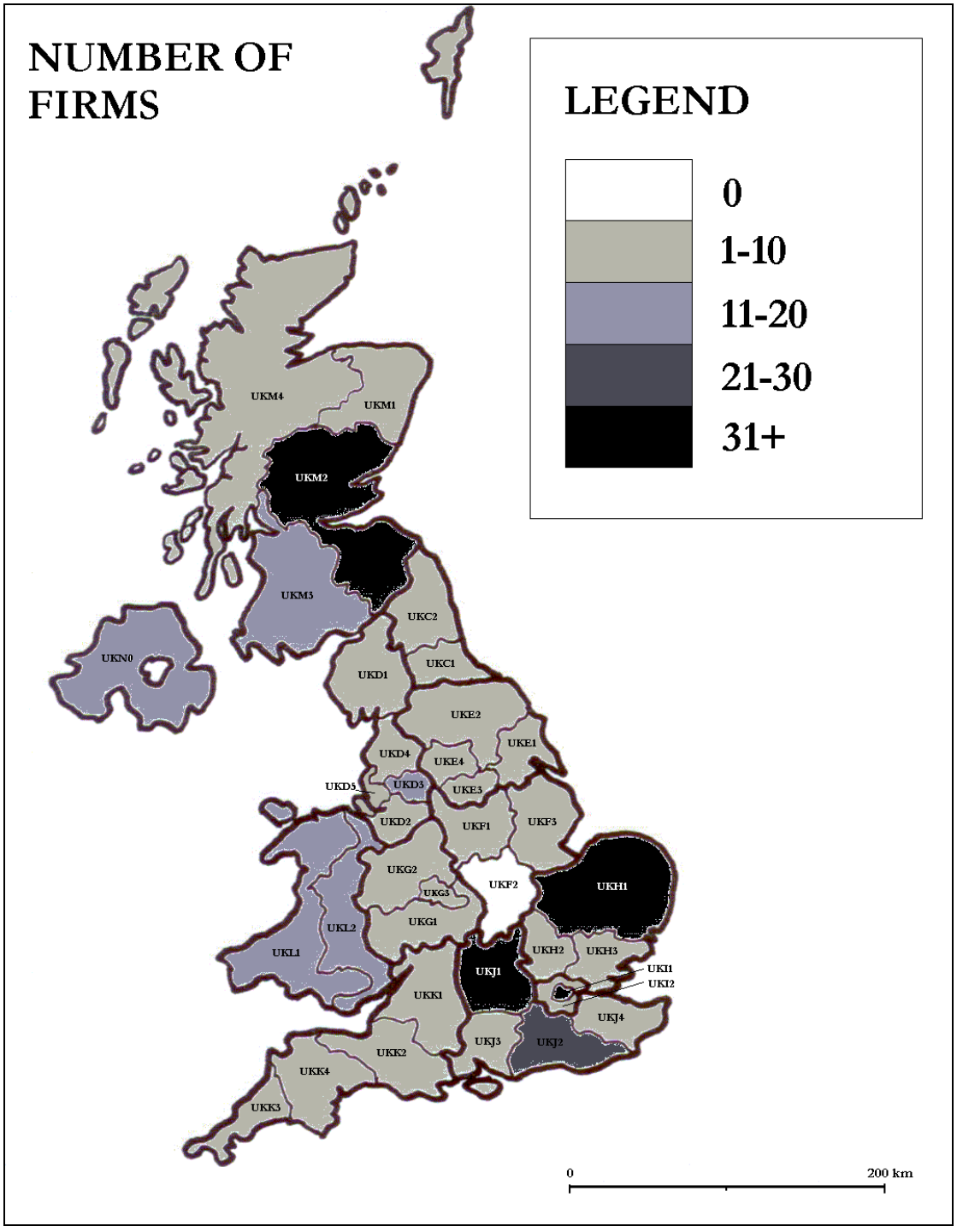
REGION	NUMBER OF BIOTECH FIRMS
Berkshire, Buckinghamshire and Oxfordshire	68
East Anglia	65
Inner London	62
Eastern Scotland	39
Surrey, East and West Sussex	22
South Western Scotland	18
Greater Manchester	14

Source: Various (see p.97).

Only four of these regions had more than double the mean number (23.66) and these four regions represented over half of all British biotech firms with the two main regions (Berkshire et al and East Anglia) representing around 30% of all biotech firms. Historically these biotech firms have also been concentrated in these two

regions; of the 42 firms in 1983, around a third were concentrated in these two regions.

Figure 5.1: Map of Biotech Firm Concentrations 2003



5.2.1.2 Service Providers

Another important organisational variable is the concentration of service providers, representing complementary knowledge for biotech firms such as legal and financial services, financial investment, networking opportunities and technology transfer (amongst others). Secondary sources for 2001 showed that there were a total of 470 relevant service providers across the UK with an average (mean) of 12.70 per region (median of 5). There were only three regions with twice the mean (see **Table 5.2**).

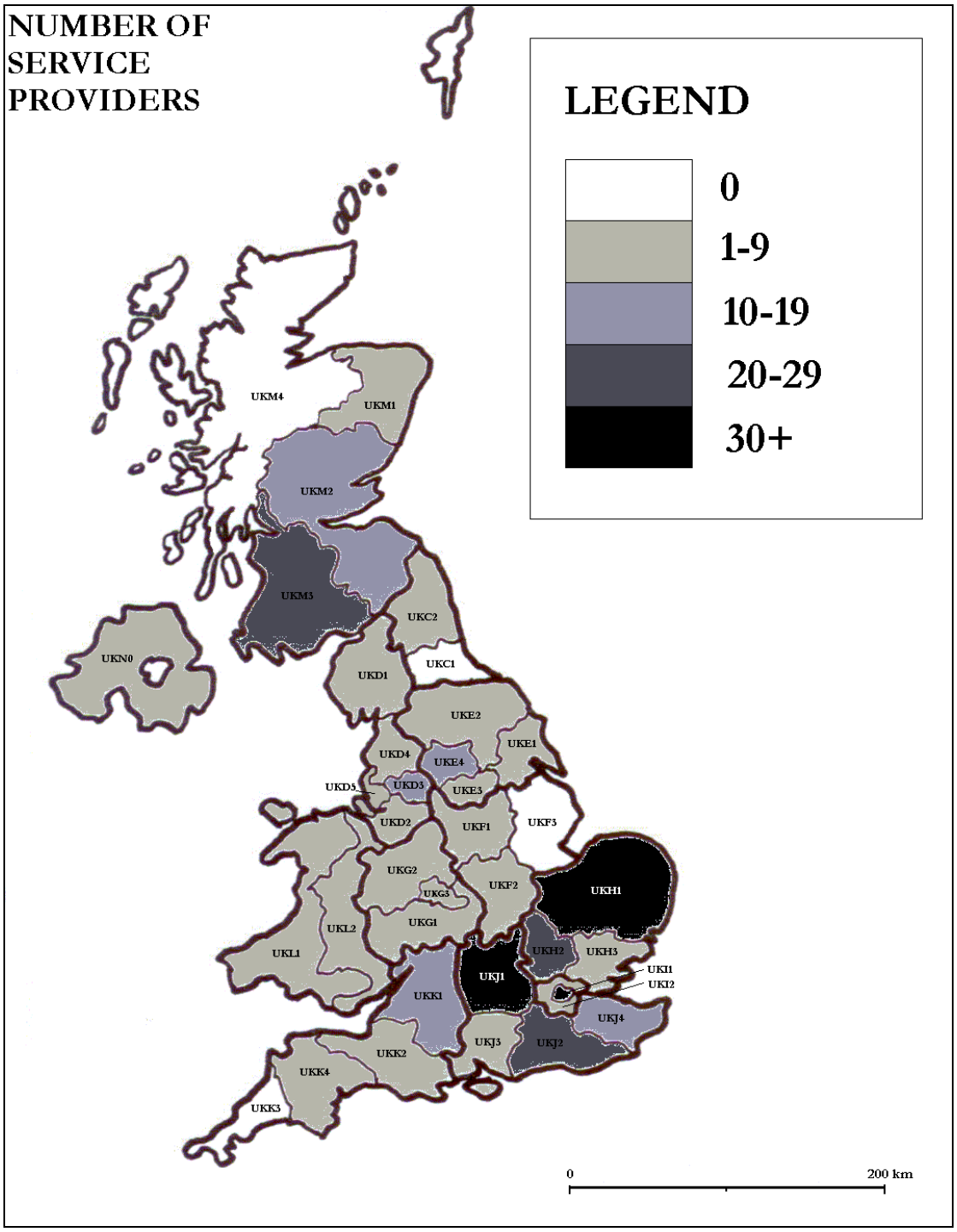
Table 5.2: Regional Concentrations of Service Providers 2001

REGIONS	**NUMBER OF SERVICE PROVIDERS**
Inner London	149
Berkshire, Buckinghamshire and Oxfordshire	50
East Anglia	49

Source: Biocommerce (2001).

The highest concentration of service providers was in Inner London where nearly a third of them were located. There were another seven regions with above average (mean) numbers of service providers, but the three main regions represented over half of all these organisations. The dominance of these three was also evident historically with nearly half of the service providers located in Inner London in 1983 (49.6 %).

Figure 5.2: Map of Service Provider Concentrations 2001



5.2.1.3 University Departments

Because of the important role that public science plays in the biotech industry, the next organisational variable considered is the concentration of 'biotech' university departments (e.g. biological sciences, chemistry, pharmacology) in the UK. These totalled 255 departments in 2001 with an average (mean) of 6.89 per region (median of 6). In contrast to the two previous organisational variables, university departments were more evenly distributed across the UK. Consequently there were nine regions with more than 10 departments, although only three with twice the average (i.e. 14). The regions are outlined in **Table 5.3** below.

Table 5.3: Regional Concentrations of University Departments 2001

REGIONS	**NUMBER OF UNIVERSITY DEPARTMENTS**
Inner London	46
Eastern Scotland	14
Berkshire, Buckinghamshire and Oxfordshire	14
East Anglia	13
Greater Manchester	12
Leicestershire, Rutland and Northamptonshire	12
West Midlands	12
Gloucestershire, Wiltshire and North Somerset	12
South Western Scotland	11

Source: RAE 2001 (see p.99).

Inner London alone represented around 18 % of all 'biotech' university departments, whilst all nine regions represented nearly half of the UK total. The historical data on this organisation type is less clear, but it does show that in 1996 there were similar concentrations with Inner London again dominant.

5.2.1.4 Public Research Organisations

The final organisational variable is the concentration of biotech public research organisations (PROs), which represent public investment in applied research. These were the least prevalent with 106 such PROs in 2003; the regional average (mean) was 2.86 per region (median of 1). The spread of these organisations was fairly limited with nearly 50% concentrated in just four regions, each with over 10 PROs. These regions represented extreme concentrations with three-times the average number (**Table 5.4**).

Table 5.4: Regional Concentrations of PROs 2003

REGIONS	**NUMBER OF PROs**
East Anglia	15
Eastern Scotland	13
Inner London	12
Berkshire, Buckinghamshire and Oxfordshire	12

Source: Various (see p.100).

Figure 5.3: Map of University Departments 2001

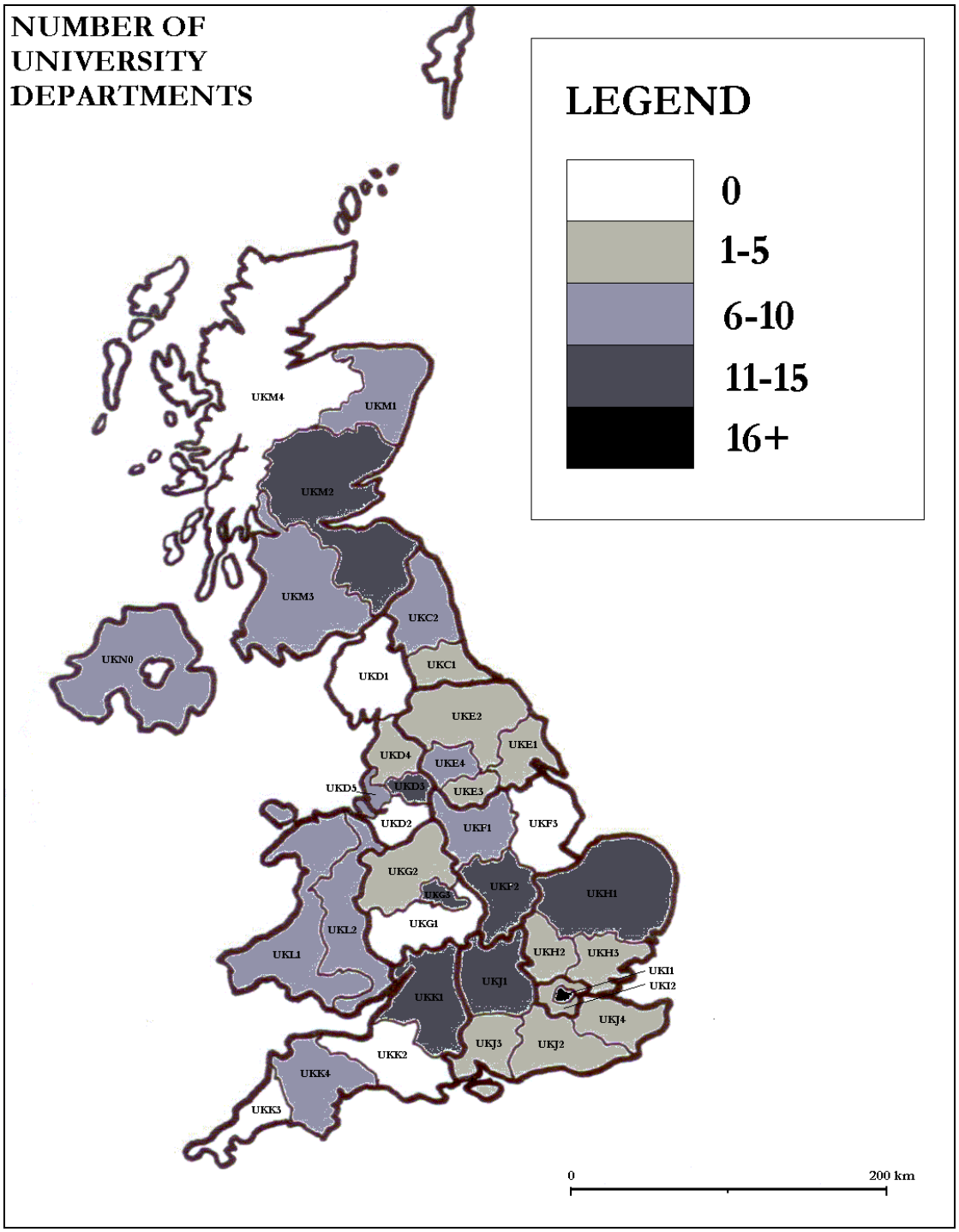
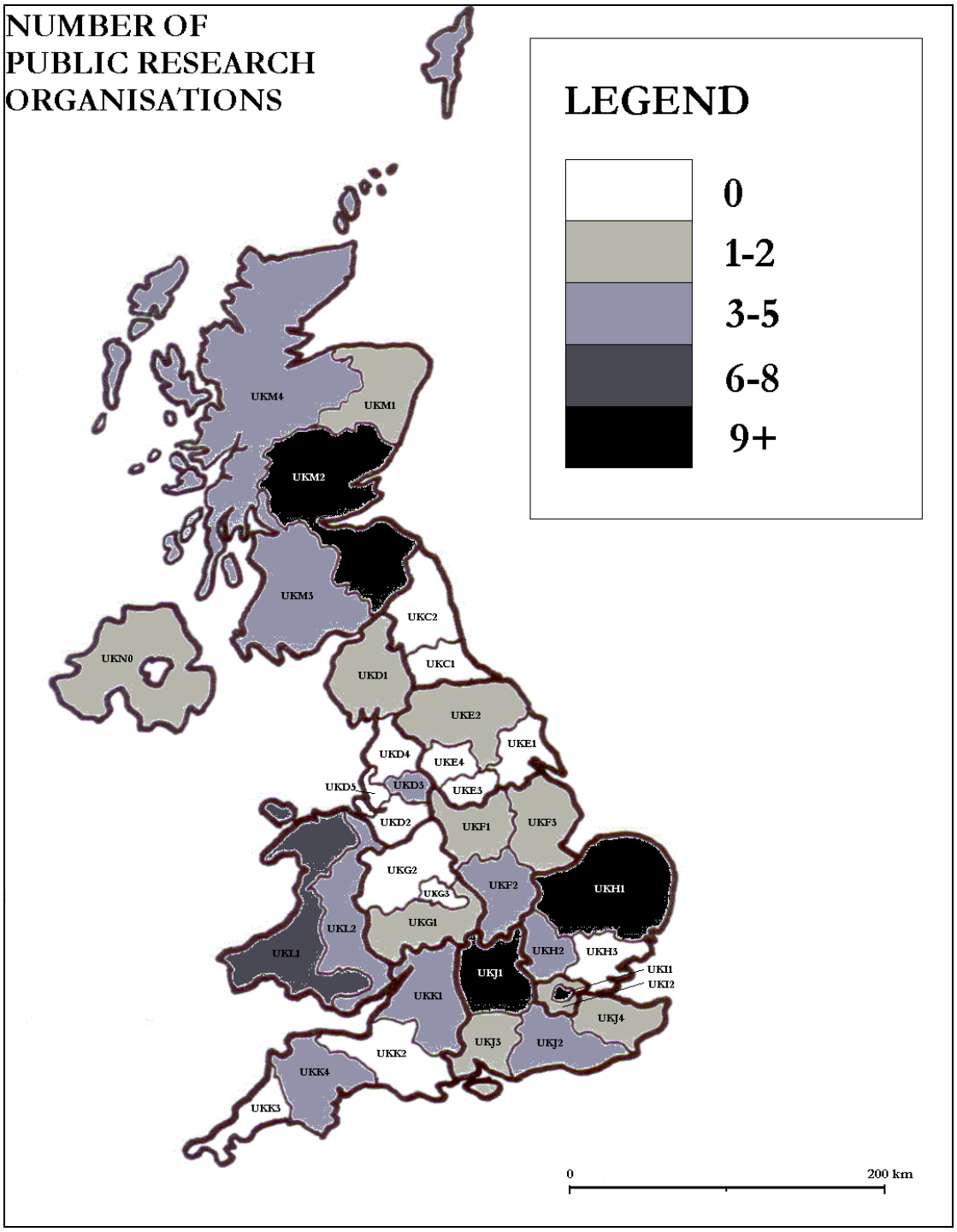


Figure 5.4: Map of PROs 2003



Information on foundation dates showed that in 1983 these PROs were concentrated in Eastern Scotland (8) and Inner London (5), which means the highest proportional investment in applied public research appears to have been in East Anglia (fivefold increase) and Berkshire, Buckinghamshire and Oxfordshire (fourfold). This might indicate that the PROs in these latter two regions were more oriented towards new research projects and programmes, such as biotechnology, whilst the PROs in the former two regions were less so.

5.2.2 Knowledge Concentrations

It is evident from secondary data sources on knowledge indicators that the four main organisational concentrations also represent significant concentrations of knowledge from levels of public science investment through to the number of large and medium enterprises. However, a number of other regions also feature strongly across these indicators, especially in relation to public science, which raises a number of questions about why there were only four main concentrations. These issues will be dealt with in the subsequent section when the specific knowledge bases and drivers are used to differentiate between different types of biotech concentration.

5.2.2.1 Public science investment

Throughout the literature on the biotech industry the role of public investment in basic science is repeatedly emphasised as crucial (Woiceshyn 1995; Senker et al 1996; Acharya et al 1998; Cooke 2003a; Bagchi-Sen et al 2004). Such public investment can be split between research funding and research training. In the UK these can be

represented by the total research council (RC) funding and RC-funded doctoral studentships of the Medical Research Council (MRC), Natural and Environmental Research Council (NERC) and Biotechnology and Biological Sciences Research Council (BBSRC). The latest available data for each council was collected covering 2001/02 for the MRC and 2003 for the NERC and BBSRC. The average annual RC funding per region was around £19 million, although there were a number of major regional concentrations as shown in **Table 5.5**. However, some concentrations have a higher RC spend per university department than others, which suggests that whilst absolute spend may be important, relative spend may also be significant for determining regional knowledge capacity.

Table 5.5: Regional Concentrations of Research Council Spend

REGIONS	RESEARCH COUNCIL SPEND	SPEND PER DEPARTMENT
Inner London	c.£102 million	£2.22 million
East Anglia	c.£85 million	£6.54 million
Berkshire, Buckinghamshire and Oxfordshire	c.£60 million	£4.29 million
Eastern Scotland	c.£58 million	£4.14 million
Greater Manchester	c.£50 million	£4.17 million

Source: MRC; NERC; BBSRC.

The concentration of RC-funded doctoral studentships was similar, although there were two regions with significantly higher proportions than other regions. In total

there were 879 RC-funded doctoral studentships in 2003/04 with an average (mean) of 23.76 per region (median of 15). The main regional concentrations were the same as the top four regions for research council spending (see above) as **Table 5.6** shows. Again, the average number of studentships per university department reveals a different picture since the dominant region (Inner London) in absolute terms was also the weakest in relative terms.

Table 5.6: Regional Concentrations of Research Council Funded Doctoral Studentships

REGIONS	RC-FUNDED DOCTORAL STUDENTSHIPS	STUDENTSHIPS PER DEPARTMENT
Inner London	164	3.57
East Anglia	133	10.23
Eastern Scotland	87	6.21
Berkshire, Buckinghamshire and Oxfordshire	73	5.21

Source: MRC; NERC; BBSRC.

As the data above shows, public knowledge investment is strongly concentrated in a few regions of the UK. These concentrations map onto the earlier organisational concentrations supporting earlier research highlighting the important role that public science investment has in relation to the biotech industry. However, there is not a clear relationship between such investment and the exploitation of biotech knowledge,

characterised as the number of firms in a region since some regions perform better relatively on some indicators (e.g. Greater Manchester and RC funding) than other regions with more firms (e.g. Inner London in relation to RC spend).

5.2.2.2Private Knowledge Investment (i.e. patents, articles)

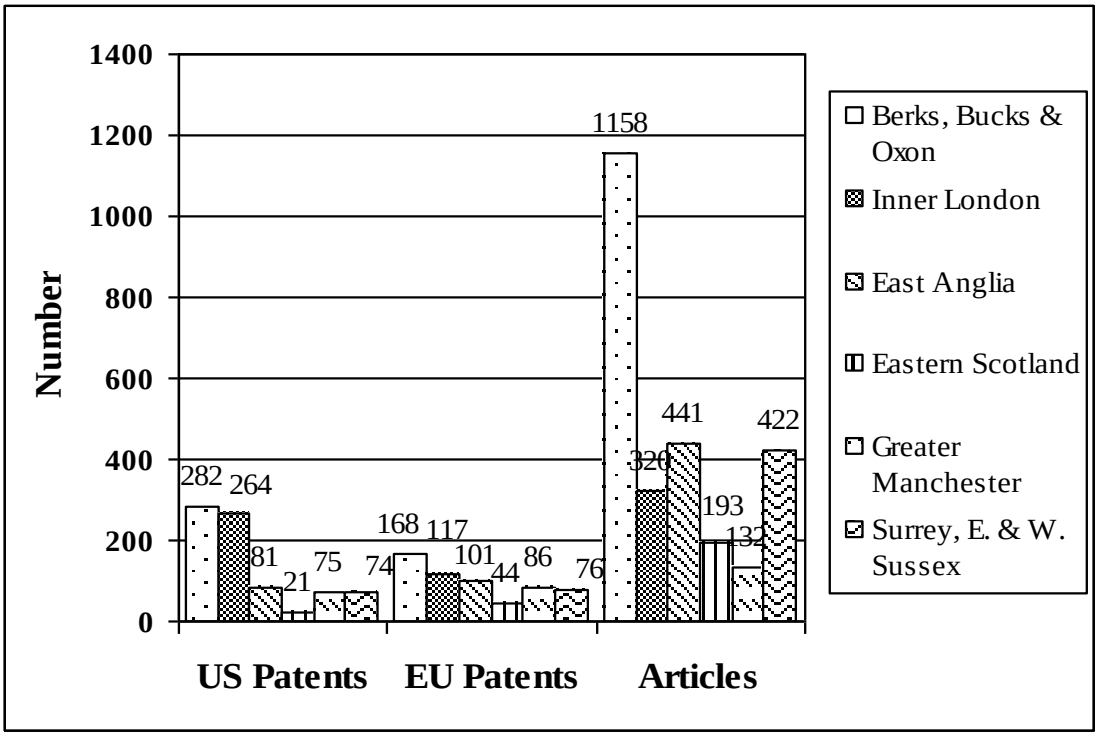
As with public investment in knowledge, the private investment of biotech firms is crucial to production and exploitation of new biotech knowledge. Such investment can also represent the organisational capabilities of biotech firms in terms of their stock of knowledge, its scalar dimension (e.g. national or international) and the extent to which it is freely appropriable (e.g. articles) or not (e.g. patents). The different stocks and capabilities highlighted below include the number of USPTO patents and EPO patents (2003 and before) held by firms, where the former represents international codified knowledge and the latter more 'local' codification. Next is the number of articles (2003 and before) held by firms, which represents the freely appropriable knowledge stock of firms. Finally, the number of UK and international alliances (1997-2004) that firms have represents the organisational inter-linkages and ties to local and international nodes of biotech knowledge, rather than firm-level stocks of knowledge or capabilities.

In total there were 944 USPTO patents, 804 EPO patents and 4209 articles across all UK biotech firms up until 2003. The respective regional average (mean) were 25.5, 21.7 and 113.8. All three types of knowledge were, once again, regionally concentrated with USPTO patents concentrated in two main regions (representing over half of all USPTO patents), with three secondary regions, whilst EPO patents

were more evenly spread across UK regions, although still concentrated in five regions. Finally, articles were concentrated in two main regions, but like USPTO patents there were three secondary regions (see **Figure 5.5**).

What this data show is that such knowledge stocks and capabilities are largely concentrated in the same regions as biotech firms, for obvious reasons. However, there is an interesting anomaly in that Eastern Scotland has lower levels than at least two other regions with significantly lower numbers of biotech firms; Greater Manchester and Surrey, East and West Sussex. It is possible that these two regions have one or more large firm that produced this higher number. It is also worth noting that East Anglia, with more articles than Inner London, has more freely appropriable knowledge stocks, whilst Inner London has more USPTO and EPO patents.

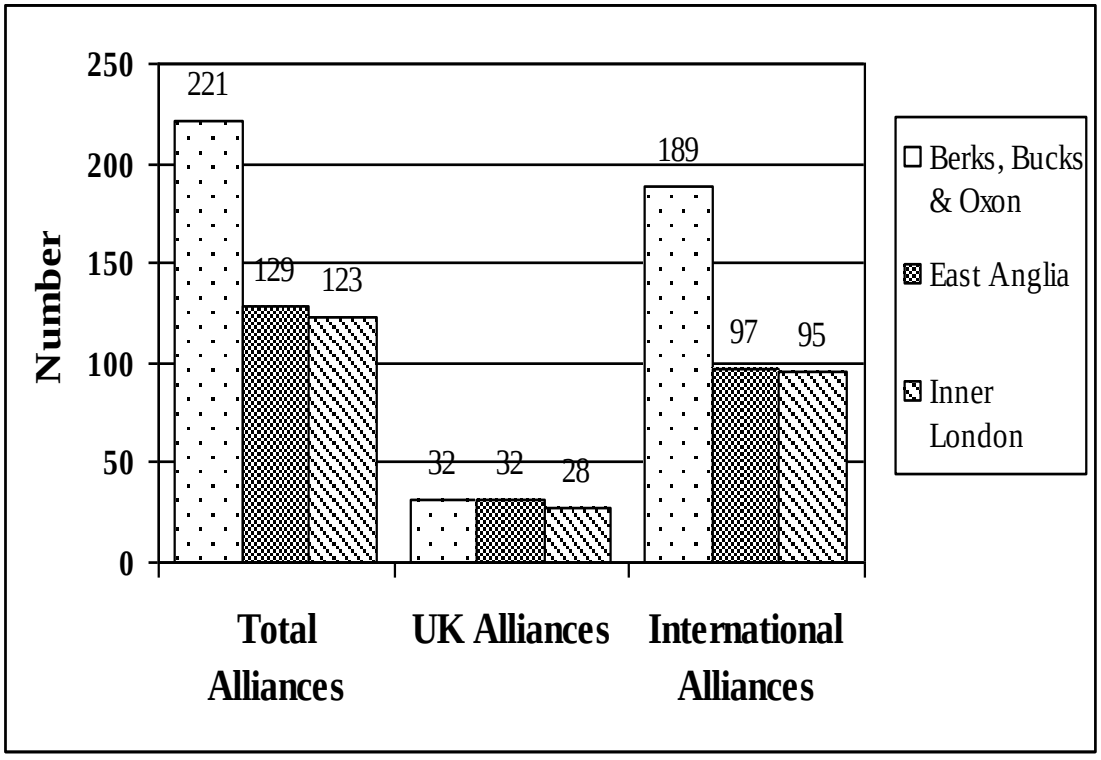
Figure 5.5: Regional Concentrations of Patents and Articles



Source: USPTO; EPO; Web of Knowledge.

There were a total of 671 alliances between 1997 and 2004 with a regional average (mean) of 18, although the median average was only 2. Alliances were even more heavily concentrated than other organisational and knowledge indicators. Between them three regions – Berkshire, Buckinghamshire and Oxfordshire, East Anglia and Inner London – had 70% of all these alliances (see **Figure 5.6**). Alliances can be split between 'local' (i.e. UK) and 'international' (i.e. non-UK) ties to differentiate between the location of this external knowledge. There were 152 local alliances compared with 519 international ones meaning that local alliances only represent around a third of international alliances.

Figure 5.6: Regional Concentrations of Company Alliances



Source: Bioworld.

There was an average (mean) of 4.11 local ties per region, although the median was only 1, whereas for international ties the average (mean) was 14.03, although, again, the median was only 1. The three main regional concentrations had more international alliances (73%) than local alliances (60%) suggesting that these regions were more tied into international nodes of biotech knowledge than other regions.

Although there were three regional concentrations of alliances, these concentrations may have been disproportionately influenced by the location of the larger publicly-listed biotech firms like Celltech Group plc (bought by UCB Pharma in 2004) in Berkshire et al and Cambridge Antibody Technology plc (bought by AstraZeneca plc in 2006) in East Anglia. A map of the alliance structure of these large firms (see **Figure 5.7 and Figure 5.8**) shows that such large firms have an enormous number of alliances that can influence the regional averages.

These alliance networks also show the extent to which the number of international ties depends on the number of large firms in a region. This point will be explored in a little more depth below when mapping economies and externalities of scale. Furthermore, it reveals an interesting feature of the different biotech concentrations, namely the important role that individual firms (e.g. Celltech or Cambridge Antibody Technology) can play in linking regions into wider global markets and sources of knowledge.

Figure 5.7: Celltech Group plc Alliance Network (2000-2004)

Source: Bioworld.

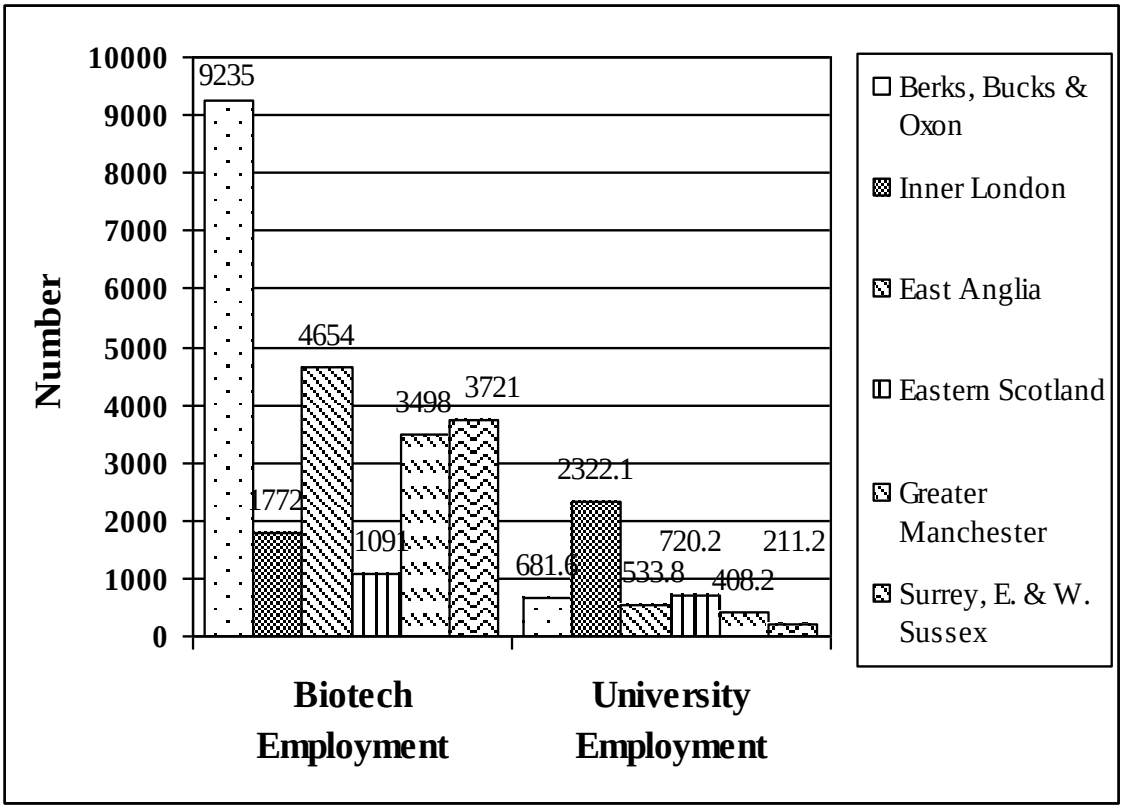
Figure 5.8: Cambridge Antibody Technology plc Alliance Network (1997-2004)

Source: Bioworld.

5.2.2.3Employment levels

Although the knowledge stocks and ties that biotech firms have are important, they can only tell one part of the story. Just as important is the expertise embodied in company employees and university staff that represent a clearer example of regional tacit knowledge stocks (Prevezer 1997, 2003). There were 43,180 biotech firm employees and 9310.3 university staff across the UK. However, there was only data on two-thirds of the biotech firms (296). The regional average (mean) for biotech employees was 1167, whilst for university staff it was 251.6.

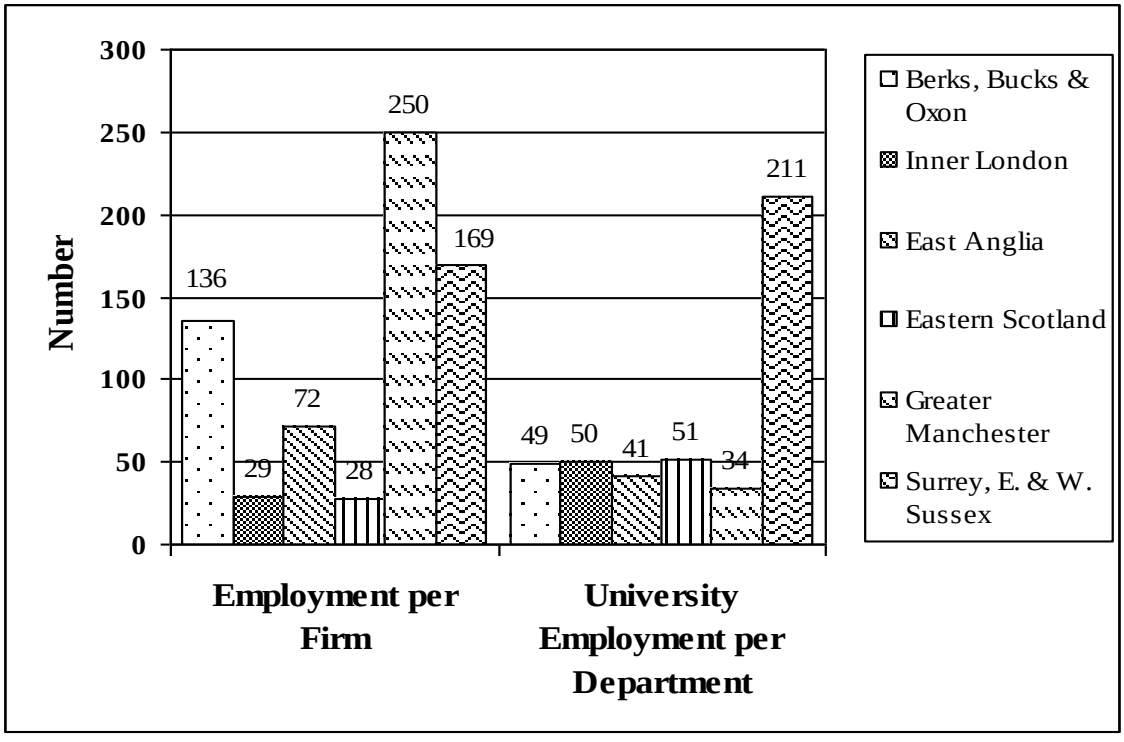
Figure 5.9: Regional Concentrations of Biotech Employment and University Employment



Source: Various (see pp. 97, 99).

There were six main concentrations of the former, representing 61% of the British total, and four of the latter representing half of all university staff (see **Figure 5.9**). One region alone – Berkshire et al – represented over 20% of all biotech employees due to the location of several large firms in that region. In relative terms (see **Figure 5.10**), there were higher concentrations of biotech employees in both Greater Manchester and Surrey et al, regions with only 14 and 22 biotech firms respectively. This suggests that regions have distinct firm compositions, which, in this case, shows that Inner London, East Anglia and Eastern Scotland have fewer large firms than Berkshire et al, Greater Manchester and Surrey et al. In contrast, the relative number of university staff is similar across all these regions apart from Surrey et al where it is significantly higher than the other regions.

Figure 5.10: Relative Regional Concentrations of Biotech Employment and University Employment



Source: Various (see pp. 97, 99).

Overall there is a significant difference in the concentration of private and public employees across the UK. This supports the argument that public science capacity is not a sufficient condition for innovation, although it is still a necessary one (Feldman 2002). Furthermore, it shows that knowledge derived from universities is not necessarily a central feature of biotech innovation processes (see Lawton-Smith et al 2000; Lawton-Smith 2002; Leibovitz 2004; although contrast Cooke 2002c; McKelvey 2004). However, it appears as though a specific relative level of university employment is important in different ways to different regions.

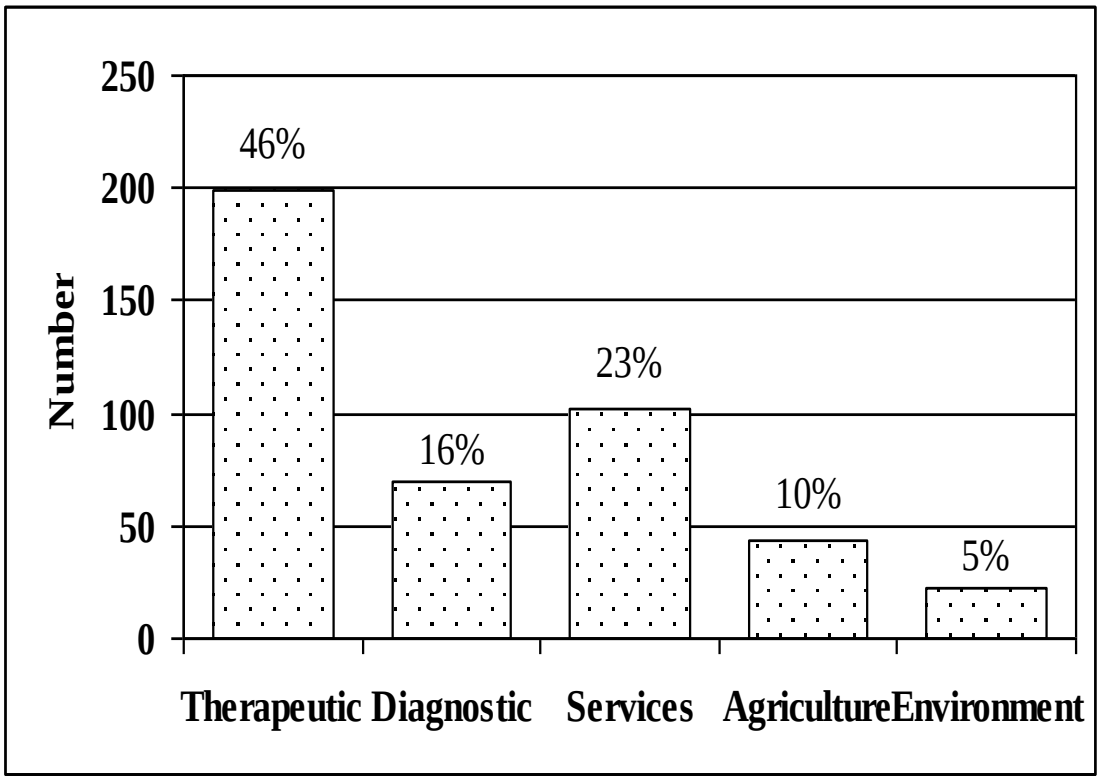
5.2.2.4Firm types

Whilst employment and other knowledge inputs (e.g. patents, alliances) are all important, the identification of the particular characteristics of each biotech concentration involves exploring the specific types of firms in these regions. This relates to the number of firm-level features such as the main sector of activity (e.g. therapeutic, diagnostic, agricultural), firm sizes (e.g. small, large) and firm origins (e.g. spin-outs, subsidiaries). Such characteristics can have an important impact on knowledge economies in a number of ways. First, sectoral similarities across a region can provide firms with both competition and complementary competencies that then stimulates innovation (Prevezer 1997; cf Cooke 2002b). Second, size can provide an indication of economies and externalities of scale. On the one hand the former represents a stock of knowledge in one large organisation that dominates a region (e.g. Walcott 2001). On the other hand, the latter represents the diversity of multiple stocks of knowledge held in a number of distinct small organisations that through

interaction encourage the iterative production of knowledge (von Hippel 1994). Finally, a firm's origin can provide an indication of the importance of local (i.e. spin-out) or international (i.e. subsidiary) knowledge resources to innovation.

At a sectoral level, UK biotech firms were categorised according to a fivefold typology consisting of Therapeutic, Diagnostic, Services, Agriculture and Environment (see **Figure 5.11**). This showed that 46% of the biotech firms were involved in the Therapeutic sector, developing and marketing biomedical products like biopharmaceuticals. This places the UK somewhere between the USA and Europe in terms of industry composition; in the US Human Healthcare represents 53% whereas in Europe it is 37% (Critical I 2006).

Figure 5.11: Sectoral Distribution of the UK Biotech Industry



Source: Various (see p.97).

The relationship between these sectors is not always clear, in terms of complementary competencies, but a correlation analysis showed that, at the NUTS2 scale, the therapeutic sector had a reasonably strong association with both the Service and Diagnostic sectors (see **Table 5.7**). In contrast there was no significant relationship between the Therapeutic sector and either the Agriculture or Environment sectors, suggesting that the Therapeutic sector shares competencies with (or relies upon) Diagnostics and Services. There were weaker associations between the Environment sector and both Diagnostic and Agriculture sectors, which suggested that certain firms benefit from locating near other firms from their own sectors and complementary ones (Woiceshyn 1995; Gray and Parker 1998; Cooke 2004a).

Table 5.7: Correlation Analysis of Regional Biotech Sectors

	Therapeutic	Diagnostic	Services	Agriculture	Environment
Therapeutic	-	-	-	-	-
Diagnostic	.577**	-	-	-	-
Services	.696**	.486**	-	-	-
Agriculture	.319	.171	.127	-	-
Environment	.188	.362*	.106	.434**	-

** Correlation significant at the 0.01 level

* Correlation significant at the 0.05 level

Source: Various (see p.97).

The size of a biotech firm can reveal the extent to which a region benefits from economies of scale and scope (Parr 2002). The former can be represented by the

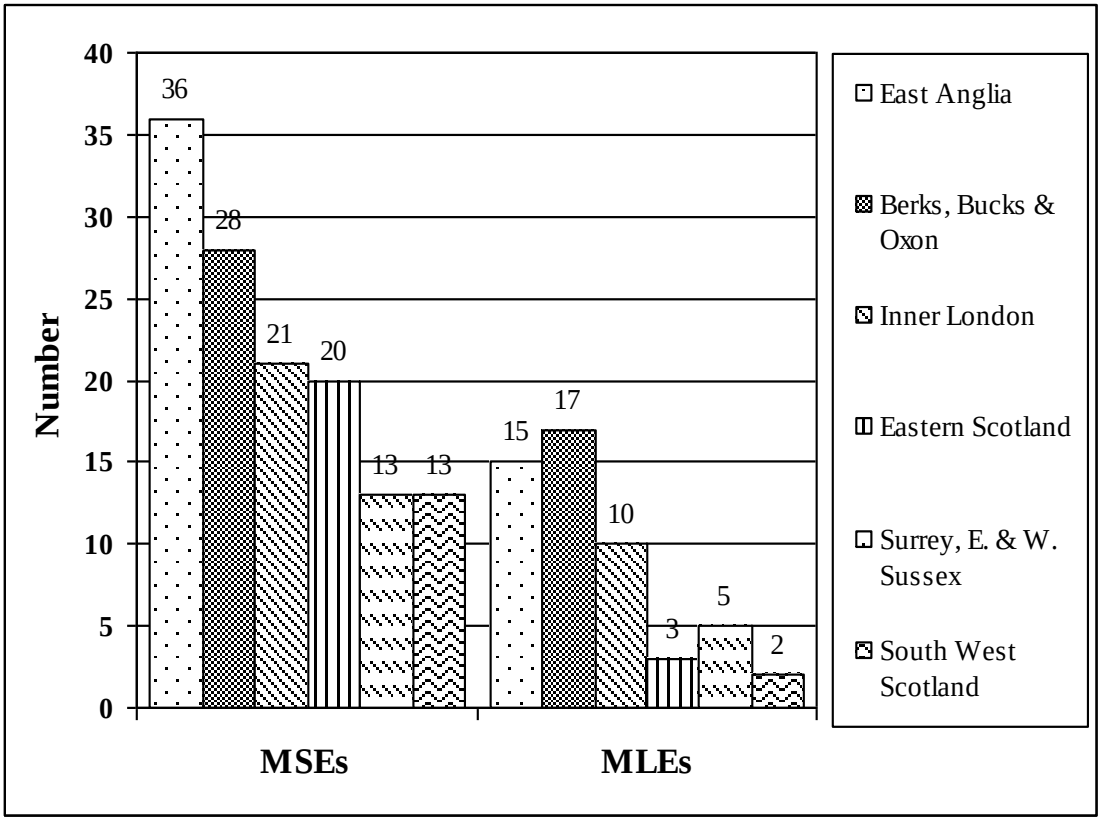
existence of medium and large-sized enterprises (MLEs) because they engage in large-scale internal knowledge production and therefore do not need to acquire knowledge externally (or can do so to a lesser extent). In contrast the latter is represented by micro and small-sized enterprises (MSEs) that engage in small-scale internal knowledge production and therefore need to acquire knowledge externally. This encourages and stimulates greater interaction between organisations. From the secondary data on employment covering 296 firms, it was possible to map the concentration of both MLEs and MSEs to show where regional knowledge production was internalised and externalised (Ernst and Kim 2002; Cooke 2004c).

In total there were 199 MSEs and 97 MLEs with respective regional averages (mean) of 5.4 and 2.62. There was an obvious concentration of MLEs in a few regions with only three having 10 or more and therefore representing 40% of the total. These included Berkshire, Buckinghamshire and Oxfordshire (17), East Anglia (15) and Inner London (10). MSEs were also concentrated in these three regions as well as three other regions (see **Figure 5.12** below). Notably, Eastern Scotland had a relatively low number of MLEs despite being characterised as a concentration by other organisational and knowledge indicators.

The different concentrations of MLEs and MSEs therefore helps to distinguish between different types of region by providing some indication of dynamic change as successful MSEs develop into MLEs, as well as illustrating the extent to which certain regions are characterised by certain types of knowledge production. In this case, the three MLE concentrations also had significant concentrations of many other organisational and knowledge indicators, which suggested that MLEs played both an

important role in promoting knowledge production and were important sites of knowledge production. However, these regions also had high concentrations of MSEs meaning that externalised knowledge production and interaction were just as important as economies of scale.

Figure 5.12: Regional Concentrations of MSEs and MLEs



Source: Various (see p.97).

The final firm-level characteristic – firm origin – is also regionally concentrated. Since previous research has argued that both local and international linkages are important (Leibovitz 2004; Ryan and Phillips 2004), the source of a firm's knowledge capabilities is a useful indicator for considering the scalar relationships of biotech firms. To examine this, secondary data on the origins of firms as either a spin-out or

subsidiary was collected. From the available data, this showed that there were 145 spin-outs and 73 subsidiaries in the UK with respective averages (mean) of 4.26 and 2.09 per region. Over 68% of all spin-outs were concentrated in just four regions and 44% of subsidiaries were concentrated in the same locations (see **Table 5.8**).

Table 5.8: Regional Concentrations of Spin-outs and Foreign Subsidiaries

REGIONS	SPIN-OUTS	SUBSIDIARIES
Inner London	38	5
Berks, Bucks & Oxon	29	9
East Anglia	21	12
Eastern Scotland	10	6

Source: Various (see p.97).

In the first instance the concentration of spin-outs indicated the importance of public science investment as a stimulus of innovation in those particular regions, whilst subsidiaries indicated the importance of international knowledge sources. Secondly, the concentration of spin-outs indicated the age of a particular biotech concentration since on average spin-outs were founded later than other firms.

5.3 THE FOUR CENTRES OF UK BIOTECHNOLOGY

The purpose behind considering the different types of biotech organisation and knowledge indicators was twofold. First, the secondary data can be used to reveal whether there were any regional concentrations of biotechnology in Britain, which it

did and second it helped to outline the particular characteristics of these regional concentrations. We cannot assume that each concentration developed along a similar trajectory or that such trajectories were consistently path dependent once a region 'locked-in' to biotech. In contrast, it was more useful to consider Ray Hudson's (2005) concept of 'path contingency', which seeks to address how both development and decline are processes that regional economies go through as they adapt to changing circumstances.

Using the data outlined above it was evident that the UK biotech industry was heavily concentrated in the East and South-east of England, in what gets characterised as the 'golden triangle' in relation to university research. There was one outlier, Eastern Scotland, although this region covered a relatively large land area stretching from Perth, Dundee and Stirling down through Edinburgh to the Scottish Borders. From these locations it was possible to identify four regions based on NUTS2 categories that represent four centres of UK biotechnology. Each region has different characteristics in relation to both the organisational composition and content, knowledge stocks and production, as well inter-regional and international interaction. In previous research (e.g. Acharya 1999; Cooke 2003b; McKelvey et al 2004; Ryan and Phillips 2004) the characteristic of biotech concentrations and 'clusters' has been represented in stylised terms. As such they include dedicated biotechnology firms (DBFs) – that comprise small and medium-sized enterprises (SMEs) – alongside 'upstream' (e.g. universities) and 'downstream' (e.g. large pharmaceutical companies) organisations which provide complementary competencies. All these organisations are then linked with a number of specialised local service providers including

business, financial and legal services, as well as public sector bodies like local government development agencies.

Instead of using this stylised typology, the four regional concentrations highlighted here were split between knowledge bases and drivers representing the two linked features of the knowledge economy presented by Cooke (2002c). The knowledge base therefore represented new knowledge stocks that can be used to produce new knowledge, which then drives the commercial exploitation of new knowledge. As such the former consisted of endogenous knowledge capabilities in a region (i.e. knowledge production), whilst the latter consisted of both the endogenous and exogenous drivers of knowledge exploitation in a region (i.e. market demand). Neither of these elements means that there is an optimal or necessarily advantageous spatial characteristic (see Boschma 2004), but rather than each region pursues its own contingent path (Hudson 2005). This classification of the four regions according to their knowledge base and driver is outlined in **Table 5.9** and **Table 5.10** below.

In terms of regional knowledge base, it was evident that there were numerous differences between UK regions, which were not the result of the different ages of each concentration. It is useful, rather, to consider that different knowledge bases will lead to path contingent processes of adjustment and change as regions adapt to their specific assets in relation to the biotech industry. Thus both East Anglia and Berkshire et al had a more recent applied public science base (e.g. PROs), although an older basic public science (e.g. universities). This suggested that both regions contained specific features of the biotech industry that were constituted by this knowledge base, such as a focus on biomedical, as opposed to agricultural, innovation.

Table 5.9: Knowledge Base of Regional Biotech Centres

	EAST ANGLIA	INNER LONDON	BERKS, BUCKS & OXON	EASTERN SCOTLAND
Applied public science	New	Old	New	Old
Basic public science	Old	Old, new	Old	Old
Star science	High	High	Low	Low
Public science spend (absolute/relative)	High, high	High, low	Mid, mid	Mid, mid
Public science training (absolute/relative)	High, high	High, low	Mid, mid	Mid, mid
Codified knowledge (local/international)	Mid, high	High, mid	High, high	Low, low
Appropriable knowledge	High	Mid	Very high	Mid
Basic science skills	High	Very high	High	High

However, East Anglia had a significantly stronger public science than Berkshire et al, which also implied that firms in the former region depended more on this source of knowledge than those in the latter region. Despite the stronger public science base in East Anglia, it was actually Berkshire et al that had the highest incidences of both non-appropriable (e.g. patents) and appropriable (e.g. articles, skills) knowledge

stocks. Evidently these were derived from biotech firms rather than the science base in Berkshire et al.

Table 5.10: Knowledge Drivers of Regional Biotech Centres

	EAST ANGLIA	INNER LONDON	BERKS, BUCKS & OXON	EASTERN SCOTLAND
Science commercialisation (firms)	Old, new	New	New	New
Economies of scale and scope	Small, med	Micro, med	Micro, med, large	Micro
Local origins	Mid	High	High	Low
Foreign origins	High	Low	Mid	Low
External relationships	Total, local	Total, local	Total, local, international	Low
Complementary service competencies	New	Old, new	New	Low
Commercial science skills	High	Mid	Very high	Low

Whereas East Anglia dominated the knowledge base, it is less obvious whether any region had a stronger position in relation to knowledge drivers. There were clear differences between regions though, with East Anglia containing older SMEs originating, more often, as foreign subsidiaries. In contrast, Berkshire et al had significantly more large companies and locally derived spin-outs as well as stronger

international ties. Overall then it was possible to differentiate from the features identified in **Tables 5.9** and **5.10** between the four centres of biotechnology based on their knowledge stocks and drivers:

- East Anglia: Older, SME and university based; SME driven.
- Inner London: Newer, university based and driven.
- Berkshire, Buckinghamshire and Oxfordshire: Global, large firm based; firm and university driven.
- Eastern Scotland: Older, university based and driven.

Thus the biotech industry in East Anglia was older and driven more by the concerns of SME commercialisation, whilst in Berkshire et al it was globally-oriented and driven by both basic science and large firms. The Inner London concentration was relatively new and largely based on and driven by university activity, as was the Eastern Scotland concentration, although the latter was considerably more reliant on its older roots in the public science base than Inner London. The next thing to do was therefore to seek to understand why there were such concentrations and whether there was a factor that applies to all such concentrations.

5.4 EXPLAINING BIOTECH CONCENTRATIONS I: PROXIMITY

Because each region had a different set of characteristics yet still represented a concentration of the biotech industry it was plausible that there were endogenous regional characteristics that stimulate knowledge production and commercialisation. Both these aspects of the ‘knowledge economy’ had a different source and effect in

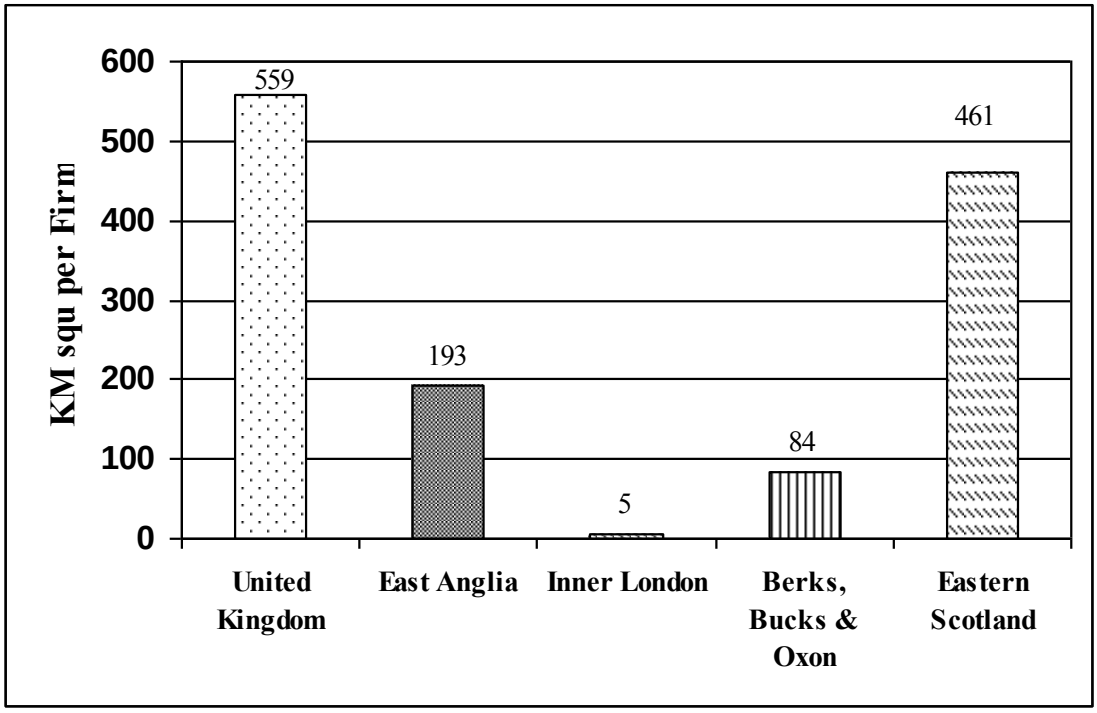
each region, but were still present across all four regions – as well as all other regions. Previous academic work has stressed the importance of proximity with organisations benefiting from both formal interaction and the capture of informal knowledge interaction such as the knowledge spillovers between organisations (for two recent reviews see Moulaert and Sekia 2003; Lagendijk 2006). Proximity goes beyond simple access to knowledge though, since it provides the means for firms or organisational actors to draw upon the resources of each other through competition, interaction and imitation (see Dobbin 2004). Thus firms benefit from proximity to public sector organisations (and vice versa), although the relationship between such organisations is not unambiguous (Audretsch and Stephan 1999; Lawton-Smith 2002; Zucker et al 2002).

Although proximity is important, there are many ways to characterise it (see Zeller 2004; Boschma 2005). First, secondary data on *firm density* (km² per firm) was used to illustrate the importance of spatial proximity to innovation processes. Second, secondary data on *firm propensity* (population per firm) was used to show the importance of social proximity or the extent to which innovation processes depend upon a shared cultural and social structure. Finally, secondary data on *firm intensity* (i.e. population density per firm) was used to show how important organisational proximity was to innovation processes. For each type of proximity a score was calculated for the UK and for each of the four concentrations (at the NUTS2 scale) to see if there were any similarities or differences between the concentrations.

The first graph (see **Figure 5.13**) shows firm density at the national scale and for each biotech concentration. This was used as a proxy because it helps to show how close

firms are to one another in physical terms (i.e. distance). As can be seen from the data there is very little similarity between the four concentrations, although all four have a lower score than the national average. This suggests that physical proximity is important to a certain extent. However, the lowest score was for Inner London (5), which shows that extremes of physical proximity do not necessary explain why biotech concentrates since both East Anglia (193) and Berkshire et al (84) have significantly stronger knowledge bases and drivers than Inner London. Eastern Scotland represents somewhat of an anomaly because of its high score, but this is perhaps explained by the geographic scope of the region

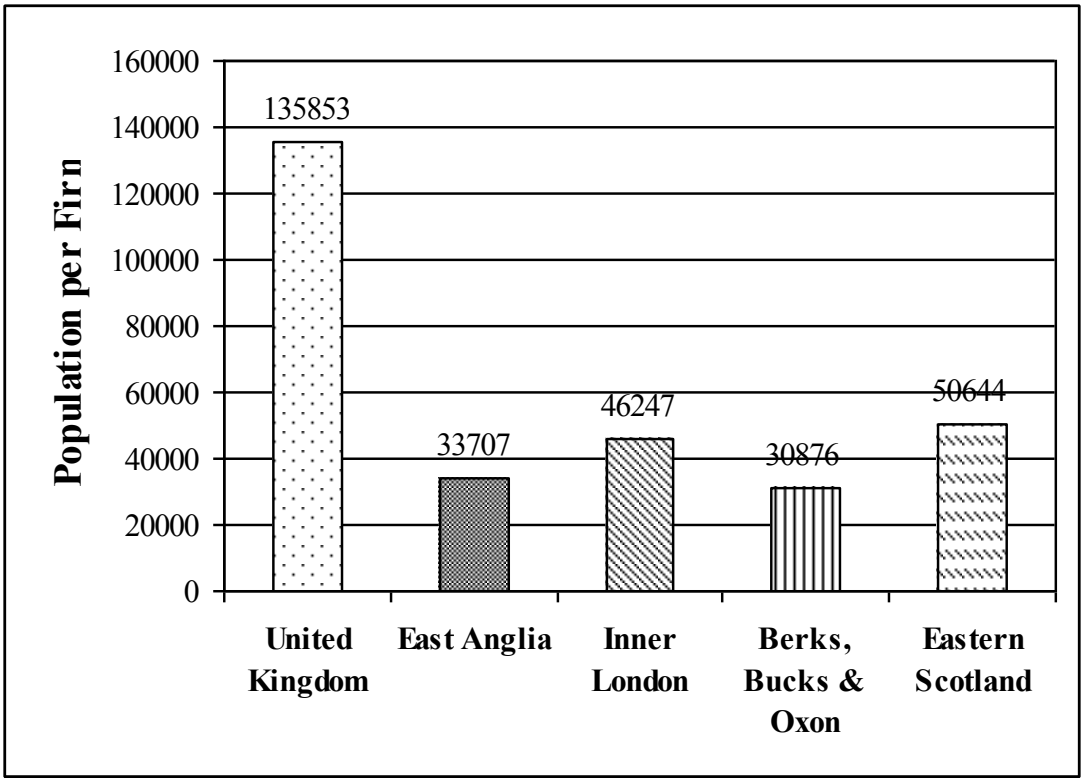
Figure 5.13: Spatial Proximity



Source: Various (see p.97); Eurostat (area).

Firm propensity (i.e. firms per population) was used as a proxy for social proximity because it shows how likely it is that a person shares common social and cultural values and norms (i.e. they work in a similar environment) with other people in a particular place (see **Figure 14**). The data shows that there is a greater degree of similarity between the four biotech concentrations than with physical proximity, especially when compared with the national score. In some ways this supports the argument that social proximity plays an important role in explaining the concentration of innovation (e.g. Powell et al 2002; Cooke 2003a; Fuchs and Krauss 2003). However, there are still differences between locations with lower scores in the two 'strongest' biotech concentrations.

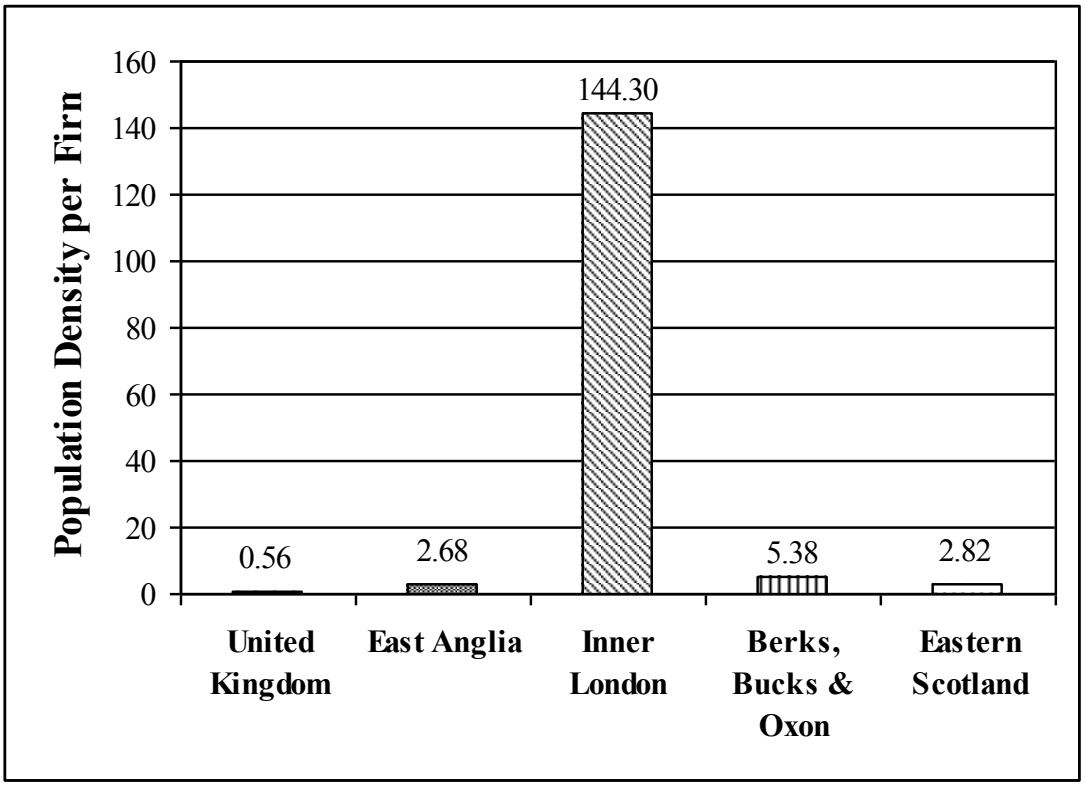
Figure 5.14: Social Proximity



Source: Various (see p.97); Eurostat (population).

The final graph concerns organisational proximity (see **Figure 5.15**) characterised by firm intensity (i.e. population density per firm). As a proxy, this is meant to show the likelihood or chance of interaction and therefore the associative strength of different places. Here the data again shows some similarities between the four concentrations, although there is a major distinction between Inner London and the other locations. Consequently it would be difficult to argue that organisational proximity is the most significant explanatory factor.

Figure 5.15: Organisational Proximity



Source: Various (see p.97); Eurostat (population, area).

The overall conclusion from this analysis of proximity was that whereas spatial and organisational proximity appear to represent an unlikely explanation for concentrations, social proximity was more significant. However, again it is important to reiterate the point that each concencentration is geographical specific since they all have different knowledge bases and drivers, as well as differing proximity explanations. The reason for greater similarity in social proximity than others could be that such proximity provides a 'community of practice' from which all organisations in a location can draw including biotech firms, public science institutes and even service providers (see Audretsch 2003). This meant that the social and cultural values underpinning behaviour is beneficial to economic performance of individual organisations (see Saxenian 1994a). Thus temporal, spatial and social processes are all important in the mediation of innovation processes, which entails a dynamic and systemic approach for explaining the reasons for concentrations (see McKelvey et al 2004).

5.5 EXPLAINING BIOTECH CONCENTRATIONS II: DYNAMIC SYSTEMS

A dynamic and systemic approach to understanding biotech concentrations draws upon work in evolutionary economics (Nelson and Winter 1982) and innovation studies (Freeman 1982), and has recently been applied to understanding 'regional competitiveness' (Boschma and Lambooy 1999; Boschma 2004; Cooke 2004d). The dynamic aspect relates to the cumulative process that leads to an embedded advantage for organisations that operate in a particular location as knowledge accumulates through usage, whether or not there has been 'successful' innovation (Boschma

2004). The systemic aspect concerns the importance of diffusion of knowledge across multiple organisations through specific co-ordination mechanisms that then reinforce particular innovation processes (see Lundvall 1992; Cooke 1998, 2004d). To show that biotech concentrations were dynamic necessitates an historical analysis of the relationships between complementary organisations. To illustrate that they were systemic requires both an historical and proximity analysis of the relationship between different organisations.

First, the biotech territorial innovation system was represented by the relationship between different organisations at NUTS2 scale in the early 2000s (see **Table 5.11**). This showed that there were very strong associations between (a) biotech firms and PROs, (b) service providers and top-rated university departments (i.e. RAE 5*), as well as strong associations between (c) firms and other university departments. There were weaker, although still strong, relationships between PROs and university departments that grew stronger with the department RAE rating.

Table 5.11: Biotech Innovation System (NUTS2)

NUTS2	FIRMS	HEIs	HEIs 5*	PROs	SPs
FIRMS	1.0000				
HEIs	0.6762	1.0000			
HEIs 5*	0.7562	0.9035	1.0000		
PROs	0.9049	0.6297	0.6970	1.0000	
SPs	0.7902	0.8887	0.9007	0.6881	1.0000

Source: Various (see pp.97-100).

This suggested that top-rated university research was undertaken in regions where there are PROs, or that PROs were established in regions where top-rated research was undertaken, supporting the view that 'star scientists' are important to biotech firms (Zucker et al 1998; Zucker et al 2002). The latter interpretation supports the argument that academic links are weaker than sometimes thought, and that applied research provides greater input into innovation in the firm (Lawton-Smith 2002; Leibovtiz 2004), although the role of the scientists is of crucial importance in explaining concentrations (Bagchi-Sen et al 2001).

One important point to consider was whether the scale of the territorial innovation system affected the strength of the association between different organisations. However, using a smaller scale (i.e. NUTS3) to analyses the same data revealed similar strength relationships, although most are slightly weaker (see **Table 5.12**). Certain relationships remained the same or grew stronger, such as between biotech firms and service providers.

Table 5.12: Biotech Innovation System (NUTS3)

NUTS3	FIRMS	HEIs	HEIs 5*	PROs	SPs
FIRMS	1.0000				
HEIs	0.6523	1.0000			
HEIs 5*	0.7145	0.8307	1.0000		
PROs	0.8788	0.6248	0.6976	1.0000	
SPs	0.7912	0.8025	0.7718	0.6877	1.0000

Source: Various (see pp.97-100).

One interpretation of this finding was that it indicated how important intermediate services were in the biotech innovation system, providing firms with access to external knowledge that they have not internalised (e.g. legal, marketing, management services) or providing crucial financial resources through local VC or business angels (Cooke 2001c; Bagchi-Sen et al 2004; Zook 2004). However, it needs to be stressed that the smaller-scale innovation system did not differ markedly from a broader scale system. The importance of scale was also unsupported by an analysis of a large-scale innovation system (i.e. NUTS1). This shows, once again, an almost identically strong set of associations with the smaller NUTS2 and NUTS3 scales (see **Table 5.13**).

Table 5.13: Biotech Innovation System (NUTS1)

NUTS1	FIRMS	HEIs	HEIs 5*	PROs	SPs
FIRMS	1.0000				
HEIs	0.5572	1.0000			
HEIs 5*	0.5570	0.8145	1.0000		
PROs	0.8962	0.5314	0.4395	1.0000	
SPs	0.7785	0.8438	0.9121	0.6165	1.0000

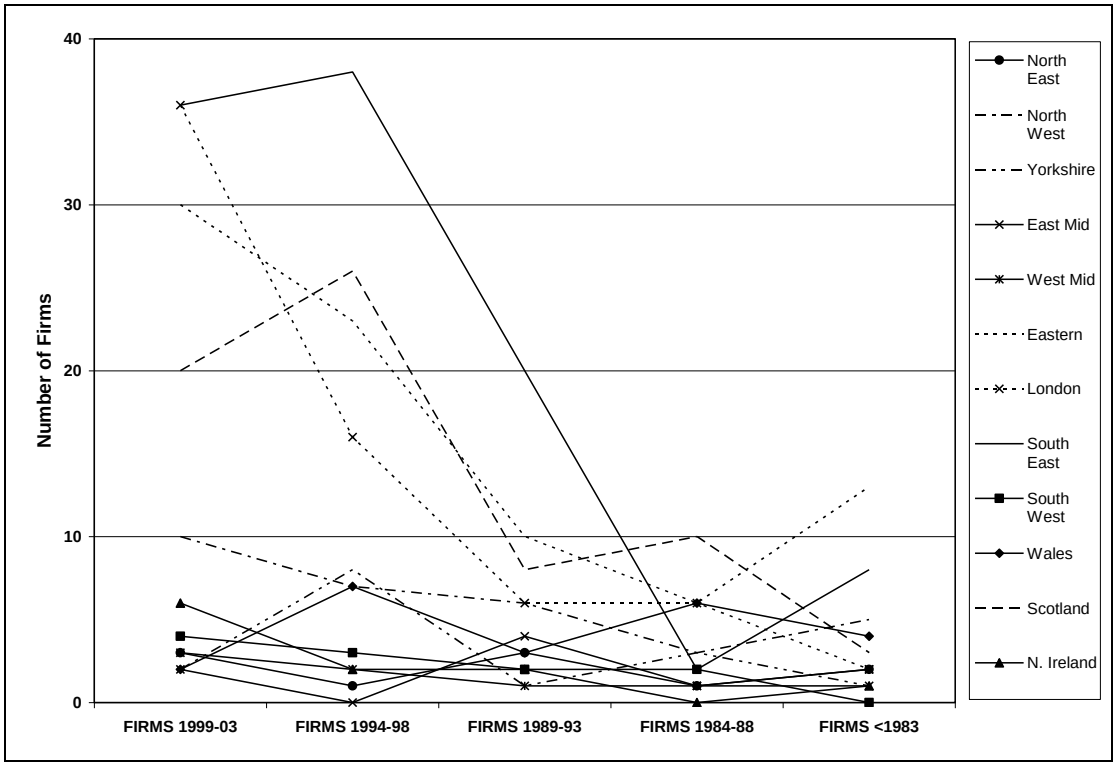
Source: Various (see pp.97-100).

All this suggests that the effect of spatial scales on territorial innovation systems was, at best, ambiguous, but, at worst, did not play a significant role in explaining the concentration of organisations in particular locations. However, the scalar

relationships did show that these connections between biotech organisations were part of a systemic process that involves a number of different organisations, especially applied research and intermediate services.

Second, the dynamic aspect of biotech innovation was represented by the spatial relationship between organisations over time. The data covered the relationship between organisations founded at the NUTS2 scale during 5-year periods of time, where this was possible to ascertain. The time periods were 1999-2003, 1994-1998, 1989-1993, 1984-1988, and pre-1984. There were some limitations with this approach, particularly the lack of data on organisations that have ceased operating, but it provided one means to assess the cumulative process of knowledge production and transfer emphasised in some theories, particularly ones derived from evolutionary concepts (see Cooke 2002c; Boschma 2004). The data showed a clear cumulative accumulation of biotech organisation across British regions (see **Figure 5.16**).

Figure 5.16: Regional Cumulative Accumulation of Biotech Firms



Source: Various (see p.97).

There were associations over time with firms, PROs and service providers, whilst the data on university departments was more limited because it only covered 1996 and 2001 (i.e. RAE years). The latter association was very strong for all departments anyway (R^2 value of 0.931) and indicated that there was a fairly strong trajectory to university research. The association between 'star' university departments (i.e. 5* RAE) was much weaker with an R^2 value of 0.588, which suggested that world-class research was less path dependent, possible because there is more reliance on 'star scientists' (Zucker et al 2002). This finding did support the contention that biotech firms do not necessarily rely upon local experts for their scientific advice; e.g. the number of local scientists on their scientific advisory boards (SABs) are low (see Casper and Karamanos 2003; Casper and Murray 2004).

However, for PROs and service providers there was a strengthening of the association with biotech firms over time, although there was less of an association difference over time when comparing the organisations to themselves. For biotech firms there was a definite cumulative process of association shown in the relationship between adjacent time periods as they became stronger (highlighted in **Table 5.14**). Early foundation (i.e. 1983 and before) also has a strong association across all other time periods suggesting that these firms play a partial role in encouraging later firms to found in similar locations (see Prevezer 1997, 2003).

Table 5.14: Dynamic Biotech Innovation (1983-2003)

NUTS2	FIRM 2003	FIRM 1998	FIRM 1993	FIRM 1988	FIRM 1983
FIRM 2003	1.000				
FIRM 1998	0.835	1.000			
FIRM 1993	0.785	0.788	1.000		
FIRM 1988	0.581	0.478	0.388	1.000	
FIRM 1983	0.615	0.676	0.712	0.352	1.000

Source: Various (see p.97).

With service providers there was no cumulative process since there was a similar level of association between each time period indicating that there was little relative cumulative increase over time; i.e. the R^2 value remained around 0.8 and 0.9 across all

periods. This finding supported the contention that intermediate services were important for concentrations, but because of the diverse knowledge they provide rather than their specific applicability to the biotech industry (cf Kenney 1998; Cooke et al 2003). In contrast to service providers, PROs followed a cumulative process similar to firms although early foundations did not seem to be as important for PROs. This suggested that applied research was also subject to a cumulative process of knowledge production and transfer, like firms but unlike service providers, and that as a consequence public investment in applied research played a crucial role in embedding knowledge capacity in regions and thereby encouraging concentrations.

5.6 ANALYSING THE SCALAR RELATIONS OF BIOTECH CONCENTRATIONS

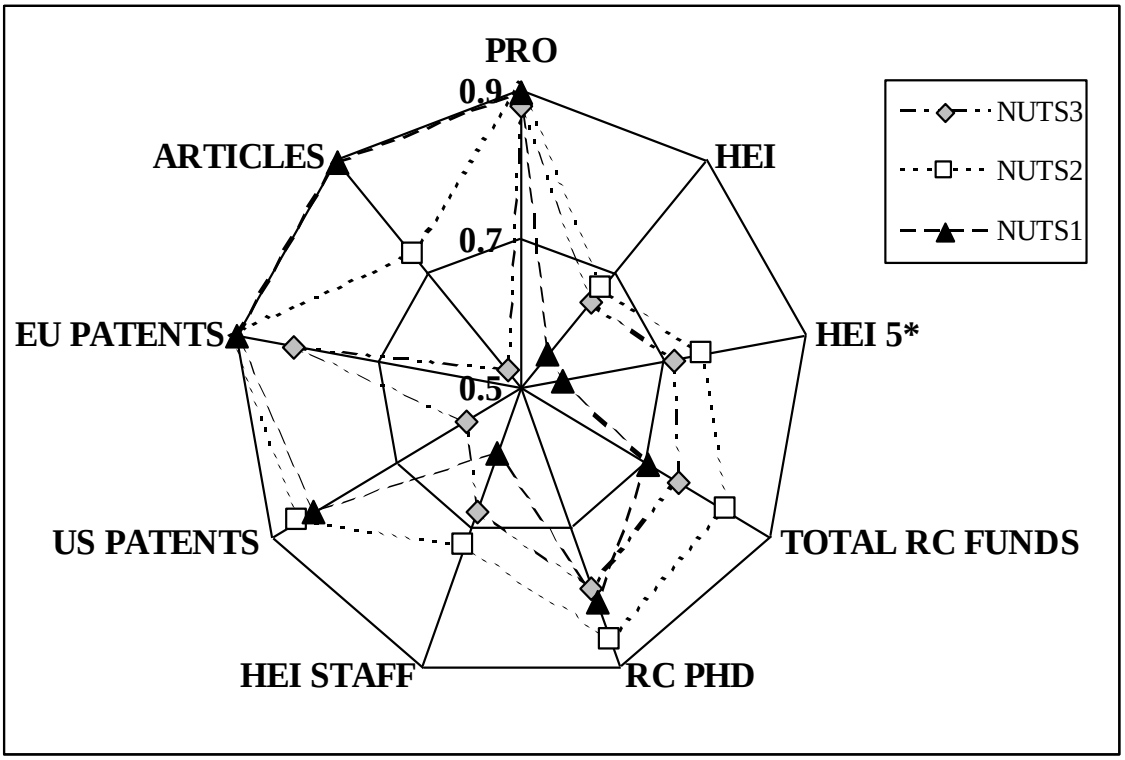
Although the data on organisations shows that there were both systemic and dynamic relationships between them, it provided only a limited explanation of the scalar relationship between organisations because it excluded knowledge and the impact this has on concentrations (Frenken and van Oort 2003, 2004). For example, intermediate services may be more important to firms at a small, localised scale because this spatial proximity provides these services providers with greater local knowledge of the needs of different organisations. Alternatively, intangible knowledge inputs, like patents (Deeds and Hill 1996), may be more important at a wider scale because organisational proximity is more important than spatial proximity (Rallet and Torre 1999; Boschma 2005). To analyse such scale relationships it was necessary to consider the relationship between regional knowledge bases and drivers and the concentration of

biotech firms. All such aspects of the innovation system were analysed using NUTS1, NUTS2, and NUTS3 scales in order to provide comparability with each other.

The main focus of the analysis was whether there was any difference across the three NUTS scales between the knowledge base, knowledge driver and the concentration of biotech firms. This could then provide an explanation as to what scale the knowledge bases and drivers have an impact on the concentration of firms, rather than simply assuming that mere concentration in one location was advantageous. The relationships covering knowledge bases is shown in **Figure 5.17** and for knowledge drivers in **Figure 5.18** below.

For the former (knowledge stocks), scale appeared relatively unimportant in relation to applied public science (i.e. number of PROs), funded PhD studentships, and EPO patents. The smallest scale appeared the most important in no circumstance, whereas the largest scale (NUTS1) was most important only in relation to tacit knowledge stocks (i.e. articles). This means that the mid-scale (NUTS2) was crucial for most of the knowledge base, although it often shared this position with one of the other scales usually the wider, NUTS1 scale. The local knowledge base therefore appeared to be of little importance in explaining the concentration of biotech firms, although basic research was more important at the two smallest scales. In contrast, the widest scale (NUTS1) showed a significant relationship between firms and tacit knowledge (i.e. articles), which implied that localised tacit knowledge was not as important for explaining concentrations of the biotech industry as might be thought (see Gertler 2003; Asheim and Gertler 2005).

Figure 5.17: Scalar Relationships between Knowledge Bases and Biotech Firms

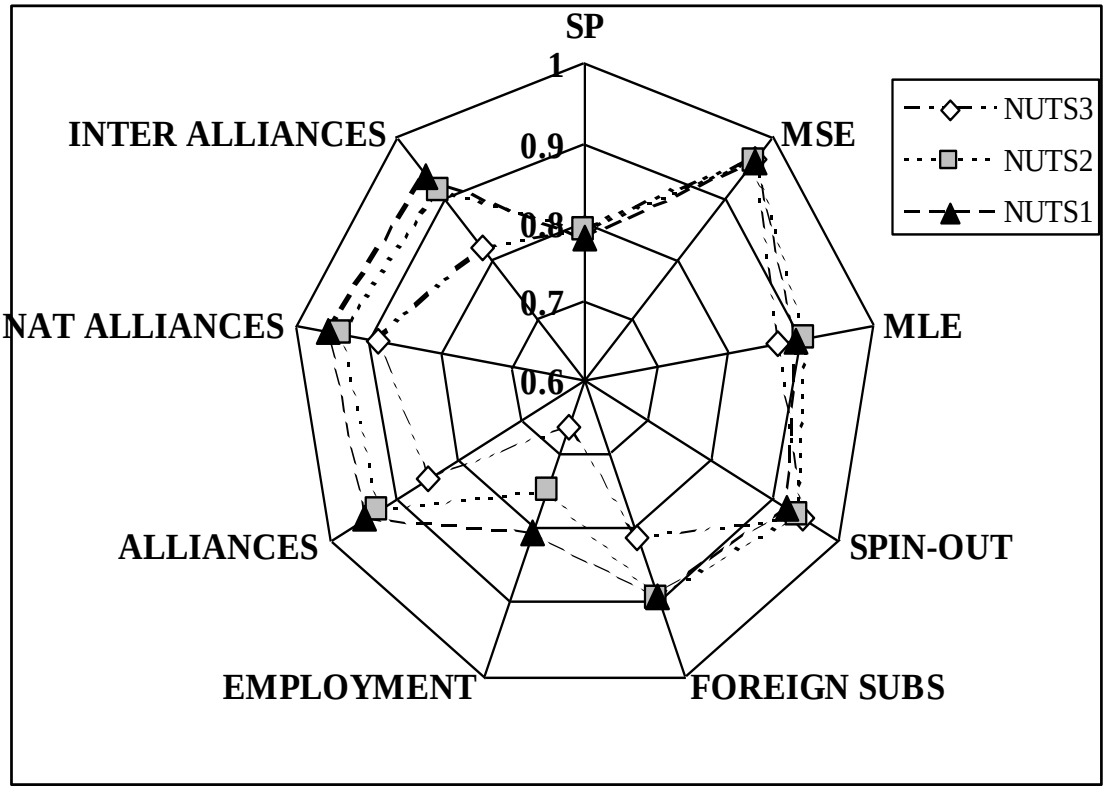


Source: Various (see pp.97-100).

However, this does support research on the biotech industry that argues that local knowledge is less important than might initially be thought (see Breschi et al 2001; Leibovitz 2004). With regards to knowledge drivers, there were even fewer differences between the scales, suggesting that knowledge drivers operate across all three scales. However, there were weaker associations at the smallest scale (NUTS3) with foreign origins, biotech employment and company alliances. This suggested that external interaction, in the form of foreign subsidiaries and inter-organisational linkages, could not be explained by small scale concentration. Instead they were reliant upon wider scales that enabled both wider external search patterns for organisations at that scale and greater visibility of organisations at that scale for international actors seeking partners or investment opportunities in the UK. It was

particularly interesting that biotech employment has a progressively stronger relationship with biotech firms as scale increases.

Figure 5.18: Scalar Relationships between Knowledge Drivers and Biotech Firms



Source: Various (see pp.97-100).

This analysis implied that concentrations were not constituted through local labour markets, which, again, suggests that a localised conception of tacit knowledge – this time embodied in skills – needs to be reconsidered. Again, previous research on the biotech industry has already made similar points, although not explicitly about tacit knowledge. For example, Casper and Karamanos (2003) and Casper and Murray (2004) have both argued that the science advisory boards of UK biotech firms do not rely on local scientists. This finding might be specific to the UK considering the size of the country and relative ease with which scientists can move between biotech

concentrations in the South-east and East of England, if not the rest of the country as well. Overall then, this analysis supported the notion that the knowledge dynamic, whether as stocks or drivers, was constituted by scale (Coenen et al 2004).

5.7 CONCLUSION

In summary, the secondary data analysed above illustrates a number of important points that need exploring further. Before addressing these it is important to note that the extent of the biotech industry in the UK was limited, especially in relation to the claims made by the government (e.g. DTI 1999a; BIGT 2003). The findings here are supported by other research showing that the number of biotech firms in the UK is between 430 and 450 and has not been rising for a number of years (see Critical I 2005, 2006). This aside, the first analytical point to note is that although there are concentrations of biotech organisations and knowledge capabilities across the UK this does not mean that the innovation process is constituted by homogenous factors. In fact the four main regional concentrations exhibited a number of major differences between each other. Although it could be suggested that these differences represent the effect of the age of the respective concentrations, there are differences that cannot be explained simply by age. Thus whilst East Anglia was characterised by an older, SME knowledge base and drive, it had far fewer biotech employees than Berkshire et al because the latter region was dominated by larger firms that were more globally focused. In contrast to both these regions, Inner London was dominated by new firms, universities and service providers suggesting that it was better to consider London as a centre for intermediate services and investment and thereby contradicting the

concept of local services in the biotech industry as some proximity theories have contended (e.g. Stuart and Sorenson 2003).

After the identification of biotech concentrations, the next consideration in this chapter was what form of proximity (see Boschma 2005) could usefully explain these concentrations. Of the three types considered here – social, spatial and organisational – social proximity seemed to be the most consistent factor across all four concentrations. Social proximity can be conceived as the similarity between values and norms shared by organisations, strategies and employees, all of which engender an easy transition for knowledge and labour between such organisations. This meant that the innovation process in these concentrations could be considered as both systemic and dynamic, in that it entails a number of inter-organisational relationships, interactions and movements that occur over a number of years.

The final part of this chapter explores the importance of different spatial scales on the relationship between knowledge and concentrations, to consider not only where these inter-organisational interactions occur, but also what impact different scales have on these relationships and their input into the innovation process. This data revealed that there was largely a limited impact of the different scales on knowledge drivers (i.e. biotech commercialisation), implying that localised explanations are insufficient for understanding the impact of knowledge on successful biotech innovation. It also implied that broader issues around market demand are crucial for understanding the biotech industry and mean that any explanation cannot be confined to the local scale. With regards to the knowledge base, there were a number of clearer relationships. There was little evidence to support the argument that local knowledge specifically is

crucial to the innovation process (e.g. McKelvey 2004) or even the argument that local knowledge connected with global biotech nodes is important (e.g. Coenen et al 2004). Instead there was support for the argument that local knowledge is not as important as may be first thought (Breschi et al 2001; Leibovitz 2004).

However, despite these findings there are a number of issues that could not be explained or even explored using the secondary data available here. These concern the importance of different types of knowledge used by innovators, such as explicit and tacit knowledge, and where such knowledge originates. However, there was limited secondary data available on such knowledge, making it problematic to claim specific arguments. There is also a need to explore the different knowledge uses of actors in different concentrations because the four main regional concentrations had distinct characteristics; in particular, it is important to understand how the different use of knowledge will will impact on innovation processes in those particular locations. Finally then, there are a number of issues around the relationship between knowledge, the scale at which it operates and how this impacts on the innovation process.

CHAPTER 6

EXPLAINING THE BIOECONOMY II: THE *KNOWLEDGE-SPACE* DYANMIC IN THE UK BIOTECHNOLOGY INDUSTRY

6.1 INTRODUCTION

The analysis of secondary data in Chapter 5 showed that there were concentrations of biotechnology in the UK in terms of both the knowledge base and knowledge driver. Although these concentrations mapped onto regions identified in earlier policy reports (e.g. DTI 1999a) and previous academic research (e.g. Lawton-Smith et al 2000; Cooke 2003b; Leibovitz 2004), the size of the identified biotech concentrations was lower than a number of these earlier studies. There were fewer that 450 biotech firms in the UK and no regional concentration had more than 70 of these firms. Furthermore, there was little sense in which knowledge drivers were dependent upon scale and therefore locality. Thus the concentration of biotech can be seen as an effect of innovation processes embedded in specific locations, which entails a territorial understanding of the *knowledge-space* dynamic in and across different places.

Much of the recent theoretical literature on these issues focuses on distinguishing between different spatial innovation processes, defined as territorial innovation models (TIMs) by Moulaert and Sekia (2003), that cover the material, relational and associational characteristics of space (see also Lagendijk 2006). Across this literature

there is a particular focus on the importance of tacit knowledge because it is seen as 'sticky' (von Hippel 1994; Markusen 1996), dependent on constant interaction and learning (Howells 1996; Gertler and Levitte 2005), and transferred through face-to-face contact (Gertler 2003). However, this focus largely assumes that space is important because tacit knowledge is important and restricted to local interaction, which essentially reverses causality (Malmberg and Maskell 2002; MacKinnon et al 2002). In this chapter, the thesis addresses this concern by focusing on what types and forms of knowledge are embedded in particular spaces and at different scales in response to hypothesis two:

H2: Successful innovation in the knowledge economy depends on place-specific dynamic and systemic processes because different types of knowledge originate in different places and at different scales necessitating interaction both within and beyond concentrations.

In order to consider whether tacit knowledge is actually limited to a local space (and explicit to a wider scale), a number of respondents who had been associated with successful innovation (i.e. a commercialised product) were surveyed about where they acquired knowledge during the innovation process. Knowledge was split between different types (e.g. customer, university sources), forms (e.g. explicit, tacit, commercial) and locations (e.g. local, national, international). In each case respondents were asked to rank them according to a Likert 1 to 5 scale. Aside from the central objective to consider the location of tacit knowledge, the objectives of this chapter are to consider whether different concentrations, as outlined in Chapter 5, have different spatially-bounded innovation processes, drawing on different types and

forms of knowledge from different scales. These can be split further into a concern with whether the knowledge bases and knowledge drivers of innovation are particularly spatially embedded and if so at what scale. Throughout there is an assumption that the innovation process is a dynamic system, operating across different scales, which is supported by the overall findings that the various knowledge types, forms and locations all inter-twine in the innovation process although they do so at a distinctly non-local scale.

6.2 KNOWLEDGE DYNAMICS

There are two major issues that need to be addressed in any research on knowledge in the innovation process. First is whether there is a distinction between explicit and tacit *forms* of knowledge and their respective impact on innovation. Second is the breadth of different *types* of knowledge necessary during the innovation process from basic science through to marketing. Both issues are crucial aspects of the knowledge dynamic in the biotech industry.

First then, the literature on the role of knowledge in the economy distinguishes between the concepts of explicit (i.e. codified) and tacit knowledge originally formulated by Michael Polanyi (1967, 1973). The difference between the two depends on the degree of 'articulation' and 'formalisation' (Howells 2002; Gertler 2003; Asheim and Gertler 2005). In Jeremy Howells (1996, 2000, 2002) work he distinguishes between the two forms of knowledge in terms of codification and embodiment, in that explicit knowledge consists of tangible assets (e.g. products) and 'formal' intangible assets (e.g. patents). In contrast, tacit knowledge consists of

'knowing' that arises from the requirement for "speed and simultaneity", the inability to articulate and, even where it can be articulated, the loss entailed in language (Howells 1996: 94). As such tacit knowledge is constituted by learning and is therefore not directly separate from explicit knowledge since use of the latter necessitates the former (Senker and Faulkner 1996; Howells 2000). In the thesis, explicit knowledge was characterised as written material that respondents have access to, whilst tacit knowledge was characterised by direct, verbal communication with people to reflect the need for learning through imitation in close proximity (Gertler 2003).

Second, the innovation and knowledge economy literature focuses on knowledge predominantly drawn from only one aspect of development, namely research and development. This ignores the importance of different types of knowledge used during the innovation process that contribute both a 'push' and a 'pull' effect on knowledge development and commercialisation (Howells 2000). The former consists of knowledge that contributes to the knowledge base (i.e. creation) such as basic science, applied science and manufacturing processes, whilst the latter consists of knowledge that contributes to the knowledge driver (i.e. exploitation) such as market, financial and regulatory processes (Gibbons et al 1994; Cooke 2002c). All such knowledge types, whether base or driver, consist, in turn, of explicit and tacit forms, although again with a necessary connection between the two forms. During the thesis the types of knowledge were differentiated in terms of the origin of the knowledge defined as the organisation from which respondents derived it.

Further to the distinctions between different forms and types of knowledge above, a distinct category for commercial or financial knowledge was considered separately from both other knowledge types and forms. Therefore during the primary data collection three different forms of knowledge were identified as crucial to innovation, although they were still conceptualised as co-dependent. Knowledge was split between explicit and tacit forms, which were themselves both split between different knowledge types consisting of organisational sources that were split between knowledge base and driver as shown in **Table 6.2** below.

Table 6.1: Knowledge Source: Base or Driver

KNOWLEDGE SOURCE	KNOWLEDGE BASE OR DRIVER
Manufacturer	Base
Supplier	Base
University	Base
PRO	Base
Competitor	Driver
Customer	Driver
Business Consultant	Driver
Regulator	Driver
Trade Association (explicit only)	N/A
Informal Network (tacit only)	N/A

The split of the knowledge sources between base and driver mirrors, to some extent, the importance of supply-side and demand-side dynamics in the innovation process, with the latter of particular importance in terms of knowledge of markets, diffusion

and commercial exploitation (Fagerberg 2005). The first knowledge type considered here is explicit knowledge, followed by tacit and then commercial.

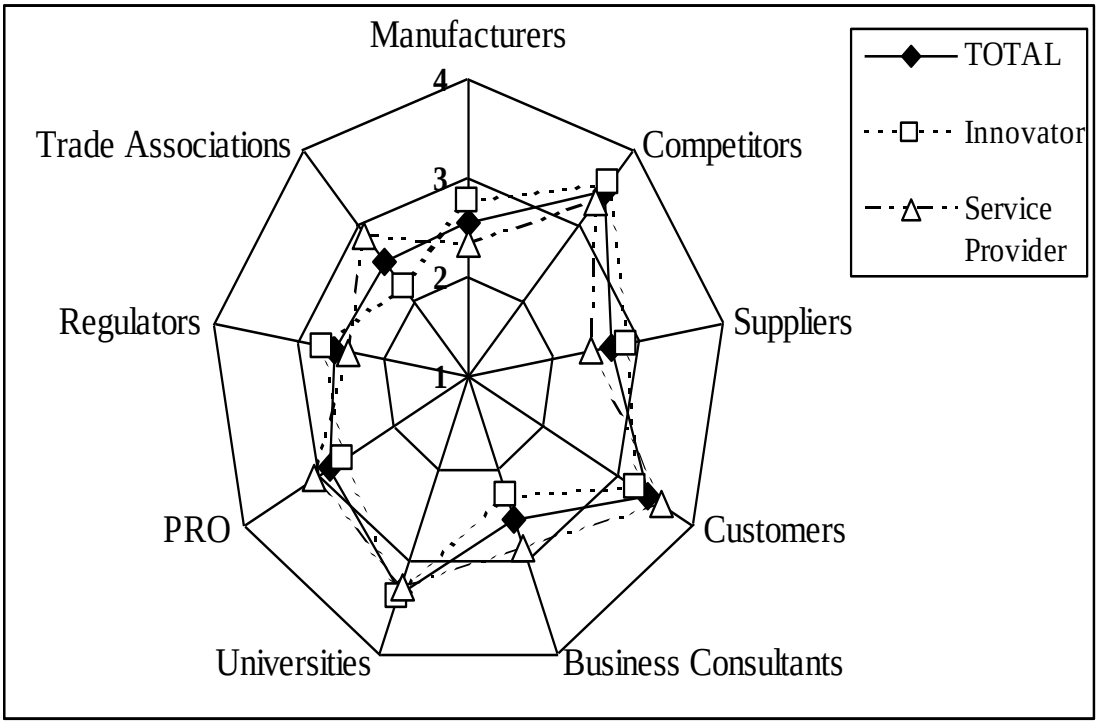
5.2.1 Explicit Knowledge Sources

The primary data on explicit knowledge was split between nine different sources which were all considered to be aspects of the overall biotech innovation process and included manufacturers, competitors, suppliers, customers and so on (see CRIC 2000; also see Chapter 2 and 3). Respondents included both 'innovators' and 'service providers' to cover a range of actors involved in the innovation process, who were all asked to rate how frequently they 'read material' (i.e. explicit knowledge) from nine knowledge sources covering universities through to regulators. All responses were aggregated to provide a total score that represents the overall innovation process, although their separate scores have been disaggregated as well. The different responses are contained in **Figure 6.1** below, which distinguishes between total, innovator and service provider responses.

The numeric value represents the mean score on the 1 to 5 scale referring to the frequency of access that a respondent had to a particular knowledge source. The most frequent sources of explicit knowledge for all respondents were competitors (3.45), customers (3.39), and universities (3.32). There were no major differences between innovators and services respondents, although service providers access customers (3.57) more frequently than do innovators (3.23). One point to make is that whilst competitors and customers have a modal value of 4, universities only have a modal

value of 3 suggesting that respondents had less frequent contact with knowledge bases than knowledge drivers (see **Table 6.2**).

Figure 6.1: Explicit Knowledge Sources



Source: Survey.

Table 6.2: Modal Averages for Consumer, Competitor and University Explicit Sources

	TOTAL	SERVICE PROVIDER	INNOVATOR
Competitors	4	4	4
Customers	4	4	3
Universities	3	4	3

All the other explicit knowledge sources were less frequently accessed by respondents with a mean value around 2.5 for manufacturers (2.56), suppliers (2.68), business consultants (2.55), PROs (2.84), regulators (2.57), and trade associations (2.50). Most had a modal average of 3, except for regulators and trade associations with 2 and 1 respectively. As before, there were few differences between innovators and service providers although innovators 'read' more material from manufacturers, suppliers and regulators, whilst service providers 'read' more from business consultants, PROs and trade associations. This suggested that innovators tended to draw on the knowledge base more, whereas service providers have no obvious preference. However, it was noticeable that in both cases the respondents accessed knowledge drivers more frequently (e.g. customers and competitors) than knowledge bases, aside from university sources. This finding was important because it illustrated the role of demand-side knowledge, something that is often missing in territorial innovation models (TIMs) in regional studies and economic geography because they concentrate on the endogenous aspects of locations (see Moulaert and Sekia 2003 for a discussion).

It is evident that access to explicit forms of knowledge drivers (i.e. demand-led) was an important aspect of the innovation process, even though the knowledge base was still important in relation to universities. There were also very few differences between innovators and service providers, except in relation to trade associations. Such results contrast with the emphasis on the idea that there is a scientific and technical 'logic' that drives biotechnology developments as suggested by McKelvey et al (2004). Furthermore it contradicts the argument by McKelvey (2004) that the

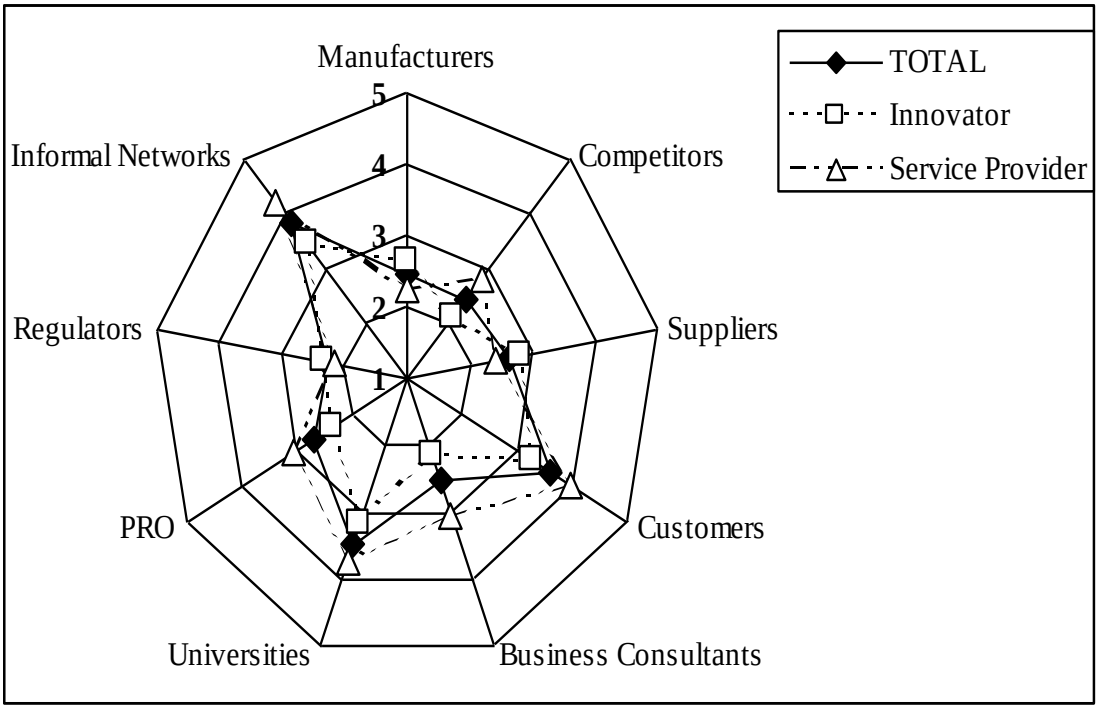
introduction of a product affects the market, rather than that the market encourages the introduction of a particular product type. However, there may be differences in the importance of knowledge base and driver between different global sites of innovation. For example, Ryan and Phillips (2004) have argued that Europe is more supply-side led (i.e. knowledge base) because it has a less mature biotech industry, whilst the US is more demand-side led (i.e. knowledge driver) because the industry is more mature. The results here suggested that, in the UK at least, the market has reached a stage of maturity where demand-side sources were more important than supply-side ones, although only in reference to explicit knowledge sources. Finally, these results confirmed that university research was crucial to the biotech innovation process, whether or not there were established links between industry and academia (cf. Lawton-Smith 2002; Leibovitz 2004). Finally, the relationship between the demand-side (i.e. market) and supply-side (i.e. basic science) could not be clearly delineated, suggesting that the innovation process incorporated both aspects in the development and diffusion of specific products and technologies. There was no correlation relationship at all between the frequency of competitor (0.042) and customer (-0.075) contact and university contact, showing how distinct these two different sources of knowledge were.

5.2.2 Tacit Knowledge Sources

The primary data on tacit knowledge again concerned a similar set of sources, with one difference; trade associations were exchanged for informal networks. Tacit knowledge was represented by direct ‘spoken’, and therefore personal, contact by a respondent with someone from a knowledge source. Again, frequency was measured

on a 1 to 5 scale and the results split between total, innovators and service providers. The most frequent sources of tacit knowledge were customers (3.60), universities (3.45), and informal networks (3.81). There were significant differences between innovators and service providers regarding these sources, with service providers rating the frequency of contact with both customers (3.98 versus 3.27) and universities (3.75 versus 3.19) more highly. Other knowledge base tacit sources were less frequently accessed by respondents, with the average for manufacturers (2.46), suppliers (2.65), and PROs (2.68) disguising low modal values of 1, 2 and 2 respectively. In relation to knowledge driver sources, there were also low mean and modal averages covering competitors (2.49), business consultants (2.55), and regulators (2.27); modal values of 1, 3 and 1 respectively. The final source, informal networks, was the most frequent source with a mean of 3.81 (see **Figure 6.2**).

Figure 6.2: Tacit Knowledge Sources



Source: Survey.

There were few dramatic differences between innovator and service provider respondents, although service providers had frequent contact with more sources of knowledge than did innovators, excluding manufacturers and suppliers (and less significantly, regulators). The two most significant results were the difference in frequency of access to tacit knowledge from competitor sources than with explicit knowledge, as well as the frequency of contact with informal networks. Evidently respondents used knowledge driver sources less frequently when it was tacit implying that the knowledge base – especially if informal networks were considered as a knowledge base – was more frequently tacit. This contrasted with the results above regarding the importance of access to explicit, demand-side knowledge, although service providers more frequently accessed a number of demand-side tacit knowledge sources than innovators, suggesting that the use of different knowledge forms depended on an actor's position in the innovation process.

These results do suggest that there was more of a scientific and technical 'logic' to developments in biotechnology (e.g. McKelvey et al 2004), although there was still a strong demand-side drive (e.g. customers). There was also support for the argument that industry-academic contact was crucial for innovation and therefore supported theories highlighting the role of scientists to biotechnology innovation (e.g. Bagchi-Sen et al 2001; Zucker et al 2002). However, in contrast to the secondary data, basic science was a more frequent source than applied science. Finally, the frequency of access to informal network sources was pronounced. One respondent emphasised this by claiming that:

> "*Local informal/social networks are very important as sources of advice and support. This is why clusters develop*" (SP 33362).

Another respondent claimed that the decision to locate in a specific place was:

> "*Driven by access to clinical expertise*."

Although the same respondent continued by implying that trust was also a particularly important element as well, since:

> "*We happened to be in Oxford; therefore lead partners in that area. [You] Go after opinion leaders irrespective of location. You're after the person and their networks ... Success of any project is dependent on relationships with collaborators - developing trust and peer respect in quality of research and delivering results - after this they'd be more willing to give access to their networks*" (I 208).

In some ways then, this suggested that the development of informal networks and trust occur simultaneously, because access to networks depended on trust (strength of connection) which, in turn, depended on the development of networks (structure of connection). This also depended upon the type of organisations and people involved, with one respondent noting that the academic environment enabled more opportunities to experiment because it was a more 'trusting' environment:

"*The local environment provides access and opportunity to try out ideas and to test ideas with a close and trusting community as we are based on a University Campus. Previously I have worked on Science Parks but have not found the same easy access and interchange with other science park based companies*" (I 133).

These findings confirmed a number of previous theories that emphasise the importance of social and informal relationships to the biotech innovation process (e.g. Lawton-Smith et al l 2000; Breschi et al 2001; Fuchs and Krauss 2003; Cooke 2003a). Although there is a vast literature on the role of trust and 'social capital' in economic (and other) behaviour (e.g. Woolcock 1998), it is often a contentious and opaque debate. Suffice to say here, social capital affects the innovation process by reducing the amount of uncertainty faced by actors within it and therefore encouraging investment in new science and technology (Powell et al 2002; Niosi and Bas 2004). The frequency of contact with these informal network sources also had a reasonably strong correlation relationship with the frequency of university tacit sources of knowledge; the correlation relationship between the two was 0.512**. There were weaker correlations with other tacit sources, such as business consultants and competitors, suggesting that informal networks were more important as avenues of knowledge transfer in the knowledge base, rather than for knowledge drivers. As one respondent put it:

"*I can't speak more highly of the importance of informal / social networks to innovation. The importance of 'social entrepreneurship' where a culture of innovation is created has been seen in Oxford, Cambridge and I'm working on*

it here in [Canadian city]. Create the culture, nationally, locally and socially and the innovation will follow" (SP 33348).

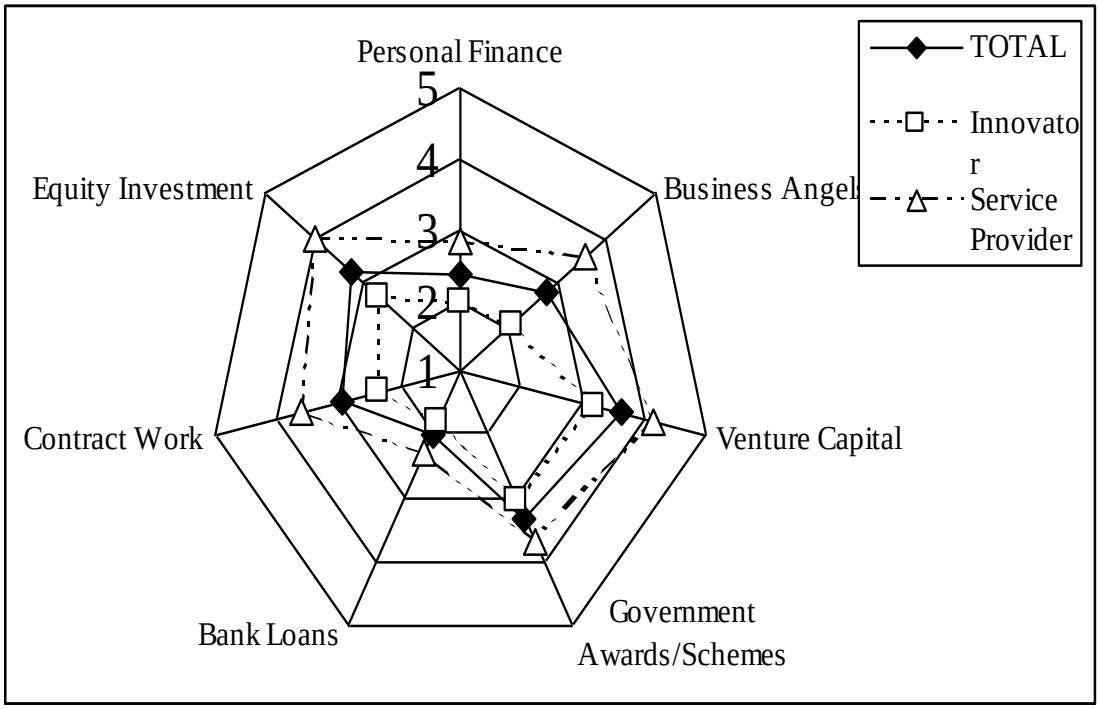
5.2.3 Commercial Knowledge Sources

In academic research on the biotech industry finance and investment are highlighted as central stimulating drivers of innovation, not only in terms of the investment of funds, but also in terms of the provision of managerial resources and advice (e.g. Gompers and Lerner 1998, 2001; Kenney 1998; Cooke 2000; Powell et al 2002). Furthermore, according to some authors, intellectual property (IP) structures have been changed in several countries to suit this specific type of financial investment focused on speculative venture funding (Cooke 2004d; Niosi and Bas 2004; Birch 2007). Instead of asking about the frequency of contact with such commercial knowledge sources, respondents were asked how important different types of finance were to development. Respondents rated importance on a 1 to 5 again, where 1 means unimportant and 5 very important. It is important to note here that despite the stylised characterisation of the biotech industry as dependent upon venture capital (VC), very few firms actually ever receive any VC investment let alone list on a stock exchange (Critical I 2006: 13). Instead, as one respondent joked, firms rely upon the 3F's of funding: "…*family, friends and fools"*.

Despite this comment, the overall mean for personal finance (2.36) was actually relatively low, although still more significant than bank loans (2.02). This did not necessarily reflect the lack of personal financial investment, but rather an assessment of its importance to the innovation process. However, it did cast doubt on the claim

that personal finance is a frequent source of funding for biotech firms in the UK (Salter 2002). This was especially pertinent considering that respondents thought that the most significant commercial knowledge sources were venture capital (VC) (3.63), government awards/schemes (3.35), and public equity investment (i.e. IPO) (3.24). All these represented a number of well known sources of finance that characterise different stages in the innovation process; i.e. government funding until VC which then led to IPO. Interestingly, other early financing such as business angels (2.76) had a modal average of 1, indicating that to many respondents it was a relatively insignificant commercial knowledge source. This was the same modal value as personal finance and bank loans. Finally, contract work had a mean value of 2.90 suggesting that it was seen as partially important (see **Figure 6.3** below).

Figure 6.3: Importance of Commercial Knowledge Sources



Source: Survey.

As the two comments by respondents show, the UK government played an important role in the innovation process, at least in initial stages:

> "*We obtained a SMART award to set up the company, which is a spinout company from the University of [Scottish University]. This award enabled us to set up the company*" (I 134).

> "*The state has an important role at the beginning of a company life eg SMART awards etc and then when a company is big enough to sell products. It does not play much of a role in between*" (I 25).

However, the second respondent also pointed out that the role of government finance after initial stages was limited until firms had a product to sell.

Perhaps unsurprisingly, service providers' valued all forms of commercial knowledge more highly than did innovators. In some cases there were significant differences between their assessments, such as with business angels (3.56 versus 2.05), contract work (3.59 versus 2.35), and public equity investment (3.95 versus 2.66). This illustrated a difference between the knowledge base (innovators) and knowledge driver (service providers) focus of the two respondent groups. For service providers the aim of innovation was the commercial exploitation of knowledge through a successful IPO (i.e. exit – see Loeppky 2005). However, for innovators the aim was the creation of new scientific knowledge through the development of successful technological products. Either way, the lack of early private investment (i.e. business angels) did not appear to be an impediment to respondents, which may either illustrate

the argument that there was a lack of seed capital in the UK (Martin and Thomas 1998) or that such early and often local investment did not play as important a role as has been suggested (e.g. Cooke et al 2003). However, the probability was that the importance of different commercial knowledge types depended on the location of the respondent, rather than that each type played a similar role in each UK location (see Rickne 2004). This is discussed later in the chapter.

5.2.4 The Tacit-Explicit Knowledge Relationship

In discussions of the difference between tacit and explicit knowledge, these two forms are sometimes conceived as separate and dichotomous variables that impact in different ways upon the innovation process (e.g. Lever 2002: 861). However, other authors have emphasised the importance that Michael Polanyi placed on the relationship between explicit and tacit knowledge (e.g. Senker and Faulkner 1995; Howells 2002; Gertler 2003; Simmie 2003). One cannot exist without the other in terms of knowledge production and transfer. The importance of considering this relationship is illustrated in the correlation relationships between the frequency of contact respondents had with explicit and tacit knowledge sources (see **Table 6.3**). As the highlighted cells in **Table 6.3** show, the strongest relationships between explicit and tacit knowledge sources were with the equivalent source. No other relationship was stronger than the weakest relationship between explicit and tacit competitor sources (0.407**), although some came close. It was also notably that the relationship between competitor knowledge forms was significantly weaker than for other knowledge sources.

Table 6.3: Correlation Relationships between Explicit and Tacit Knowledge Sources

TACIT SOURCES	EXPLICIT SOURCES: Manufacturer	Competitor	Supplier	Customer	Consultant	University	PRO	Regulator
Manufacturer	0.654**	0.186	0.340**	0.013	0.116	-0.043	0.050	0.282**
Competitor	-0.171	0.407**	0.062	0.274**	0.382**	0.209*	0.277**	0.106
Supplier	0.317**	0.192	0.717**	0.259**	0.198*	0.02	-0.005	0.202*
Customer	-0.054	0.191	0.118	0.697**	0.313**	-0.004	-0.054	0.005
Consultant	0.044	0.251*	-0.095	0.212*	0.764**	0.208*	0.153	0.234*
University	-0.025	0.220*	-0.142	0.125	0.286**	0.565**	0.299**	0.108
PRO	-0.136	-0.038	-0.182	-0.026	0.132	0.394**	0.767**	0.040
Regulator	0.133	0.333**	0.043	-0.128	0.195*	0.109	0.152	0.655**
Informal Network	0.028	0.189	-0.065	0.164	0.293**	0.161	0.120	0.146

** Correlation is significant at the 0.01 level (2-tailed)

* Correlation is significant at the 0.05 level (2-tailed)

Source: Survey.

The strongest relationships were with supplier, business consultant and PRO sources (all were above 0.7) followed by manufacturer, customer and regulator sources (all between 0.6 and 0.7). From this data it was reasonable to surmise that both knowledge base and knowledge driver sources rely upon the interaction between explicit and tacit knowledge forms, since there was no clear difference between them. However, the clearly weaker relationship of competitor knowledge sources suggested that such knowledge was less reliant on the relationship between different forms of knowledge, which could mean that some knowledge was more reliant upon this relationship than others.

The slightly weaker relationship between university explicit and tacit knowledge forms could indicate that such explicit knowledge was easier to access and therefore required less tacit learning (Cox et al 2000) or that most breakthroughs were tacit and therefore did not necessitate a close relationship between explicit and tacit academic knowledge (Zucker et al 2002). However, one important reason for the weaker relationship between university and also competitor sources, could be that in both cases these sources were globally oriented, rather than locally or even nationally based. The spatial basis of all these knowledge sources has been remarked upon as a crucial aspect of this whole debate, since proximity, in many forms, can have an important impact upon the production, diffusion and absorption of knowledge (see Howells 2002; Boschma 2005). It is to this issue of space that the chapter turns next.

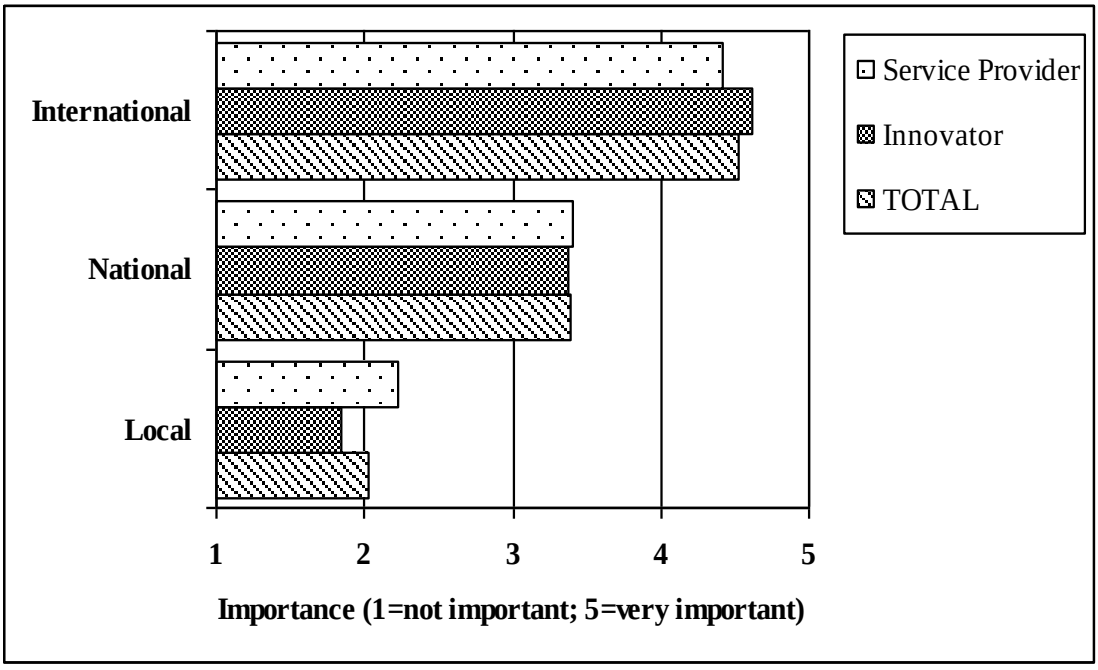
6.3 SPACE DYNAMICS

The literature on territorial innovation models (TIMs) has changed considerably over the past two decades, although theories still largely concentrate on the endogenous features of specific locations. In their critical survey, Moulaert and Sekia (2003) provide a useful outline of a number of these different theories, covering the early work on agglomeration economies through to the latest research in clusters, learning regions and regional innovation systems (e.g. Porter 2000; Morgan 1997; Cooke 2004d). In his own critical survey, Arnoud Lagendijk (2006) splits these theories between 'structuralist-organisational', 'social-institutional' and 'cognitive' conceptualisations. Recent research in economic geography has also explored possible connections between evolutionary economics and geography, creating the idea of evolutionary economic spaces that consist of the accumulation of behaviour and structures at both organisational and environmental levels (Boschma 2004; see also Boschma and Lambooy 1999). However, as mentioned, one issue with this literature is the emphasis placed on the endogenous characteristics of space, particularly the inter-linkages between organisations. Such a focus sidelines the consideration of exogenous influences on economic activity such as national or supranational regulation, global market demands, or simply regional interdependence.

The academic focus on local knowledge embedded in firms and its importance in the innovation process (see Maskell and Malmberg 1999; Malecki 2000) is derived from a concern with the concentration of innovation in particular places and the importance of proximity as a consequence. In contrast, it is important to consider how innovation is also subject to dispersal across different places as a consequence of innovation processes that depend on inter-spatial and inter-scalar learning and knowledge (MacKinnon et al 2002). Thus recent research suggests that there are local sites of

knowledge and innovation that are tied into wider global networks, ensuring that these localised nodes do not get 'locked-in' to a particular trajectory (e.g. Bathelt et al 2004). In relation to the biotech industry this has been variously described through the existence of 'megacentres' or 'nodes of excellence' (see Coenen et al 2004; Cooke 2004a, 2004c). The importance of such global connections was evident in the primary data with respondents' assessment of the location of final demand (see **Figure 6.4**) showing that most respondents rated international markets (4.52) as more important than national ones (3.39), which were rated, in turn, more important that local markets (2.03).

Figure 6.4: Location of Final Demand



Source: Survey.

As one of the respondents argued:

> "*Innovation is helped by having local centres of excellence in a particular field (which usually means more experienced investors) and a highly qualified workforce, but most commercially important projects are aimed at international markets which may be totally different from the UK. Therefore, you cannot really rely on these factors to ensure success, but it all helps!*" (I 141).

This emphasis on international markets resulted from the dominance of the USA in the biotech industry with, for example, 60% of global biopharmaceutical sales (Bibby et al 2003). Respondents' therefore saw this market as the main one for their products, rather than the rest of the world. Either way though, the pronounced emphasis on international markets supports the argument that innovative firms and regions orientate themselves to external markets rather than internal ones (Malmberg 2003; Simmie 2004).

Although some elements of the innovation process, in this case demand, were clearly oriented towards the international scale, it was crucial to understand the particular scalar relations involved in supposedly endogenous spatial features such as knowledge bases and drivers of innovation. As the last chapter showed, such drivers were less dependent upon scale than were bases, although this did not answer the question of exactly at what scale such processes operate. To address such issues, this section considers the primary data collected on the location of explicit, tacit and commercial knowledge sources. Three different scales were used to identify the importance of space – local, national and international – which respondents used to

rate where knowledge sources were most frequently located, again using a scale from 1 (none) to 5 (most).

6.3.1 Location of Explicit Knowledge

Although some research focuses on the importance of spatial proximity to innovation (e.g. Cooke 2002b; Johnson and Mareva 2002), other research on the spatial concentration of biotechnology emphasise the importance of non-local linkages (Leibovitz 2004), although often in relation to concentrated 'nodes of excellence' (e.g. Coenen et al 2004). Such issues were partially addressed in the findings from the primary data on the location of explicit knowledge, although there were significant divergences from this literature in that most of the knowledge accessed was least likely to be from local sources (see **Figure 6.5**). The mean value for local explicit knowledge was only 2.28, compared with 3.60 and 3.76 for national and international sources respectively. This may indicate that global markets were more important than local markets, since the most frequent explicit knowledge accessed by respondents was from customer and competitor sources (see previous section).

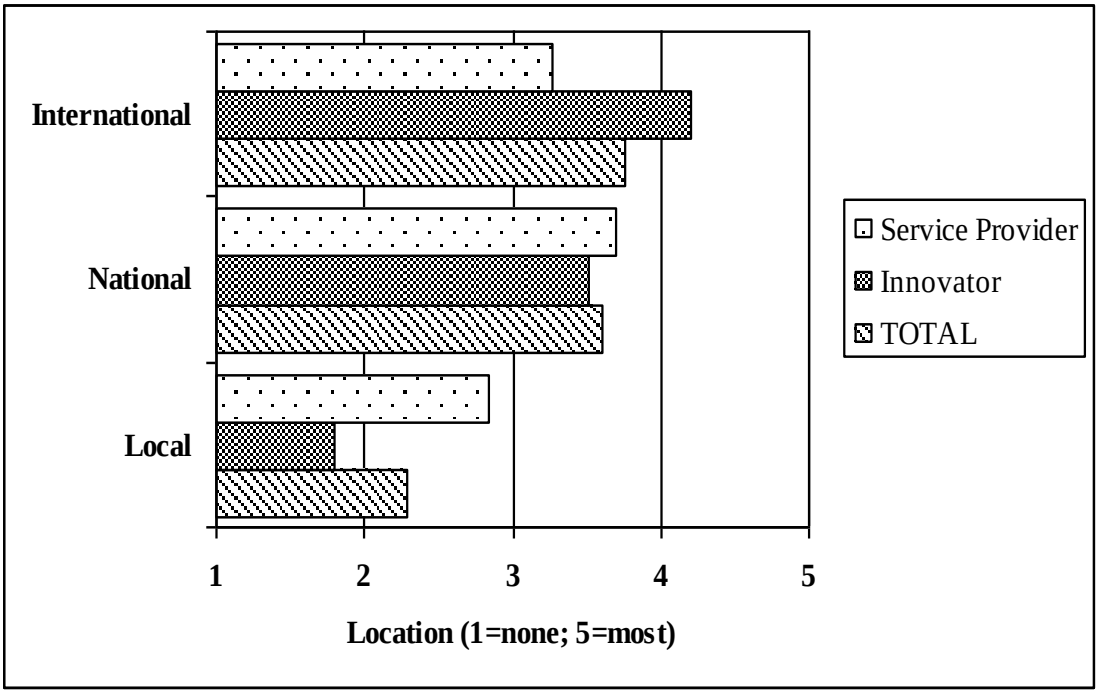
However, it was also possible that local sources of knowledge were simply unimportant, or at least appeared to be unimportant for respondents. As one of the innovator respondents put it:

> "[Location is] *Not at all necessary. Electronic contacts and business travel allow the establishment and maintenance of international contacts…*"

Although they then pointed out that:

> "*…being near to a strong research resource (in my case the University of* [South-east England]) *has always been of fundamental importance. Mostly through intelligence-gathering, hearing about competitors or promising new research*" (I 99).

Figure 6.5: Location of Explicit Knowledge



Source: Survey.

This aside, the different rating of locations of explicit knowledge was even clearer when the data was split between innovator and service provider respondents. The marked difference between the former whose mean rating of local sources was only 1.79 was significantly lower than the rating of the latter (mean of 2.84), illustrating the relative lack of concern with local knowledge within innovating firms and

universities. In contrast the high mean rating of 4.21 innovators gave international sources compared with the much lower 3.27 rating from service providers, showed the importance of globally-based knowledge for some actors. Thinking systemically it would appear as though certain organisations (e.g. lawyers, management consultants, accountants) – probably locally-based themselves – tied other organisations (e.g. biotech firms, universities) into local knowledge. However, such inter-linkages were not necessarily that strong since even for the service providers local knowledge sources were less important than national or even international ones.

Overall, these findings did not support the contention in a number of TIMs that it is the endogenous characteristics of different spaces that constitute successful innovation or even, in more recent argument (e.g. Bathelt et al 2004; Coenen et al 2004), that local-global linkages play a central role. In several ways the findings contradicted both explanations. The dominance of both national and international locations of explicit knowledge implied that localised knowledge was significantly less important, whether in terms of providing endogenous capabilities or tying global knowledge into localised knowledge, than may be thought. However, this finding did support the argument that explicit or codified knowledge has, to some extent at least, become 'ubiquitous' and available to everyone world-wide (Maskell and Malmberg 1999; Malecki 2000).

6.3.2 Location of Tacit Knowledge

The finding that explicit knowledge was not localised did not contradict the argument put forward in most TIMs, especially the most recent theory that local-global linkages

are vital to innovation, as long as tacit knowledge was found to be localised or "sticky" (von Hippel 1994). Academic research treats tacit knowledge as spatially embedded because it is seen as reliant upon face-to-face communication and is therefore more difficult to transfer over spatial distance (Howells 2002; Gertler 2003; Asheim and Gertler 2005). One of the respondents summed this up when they stated that:

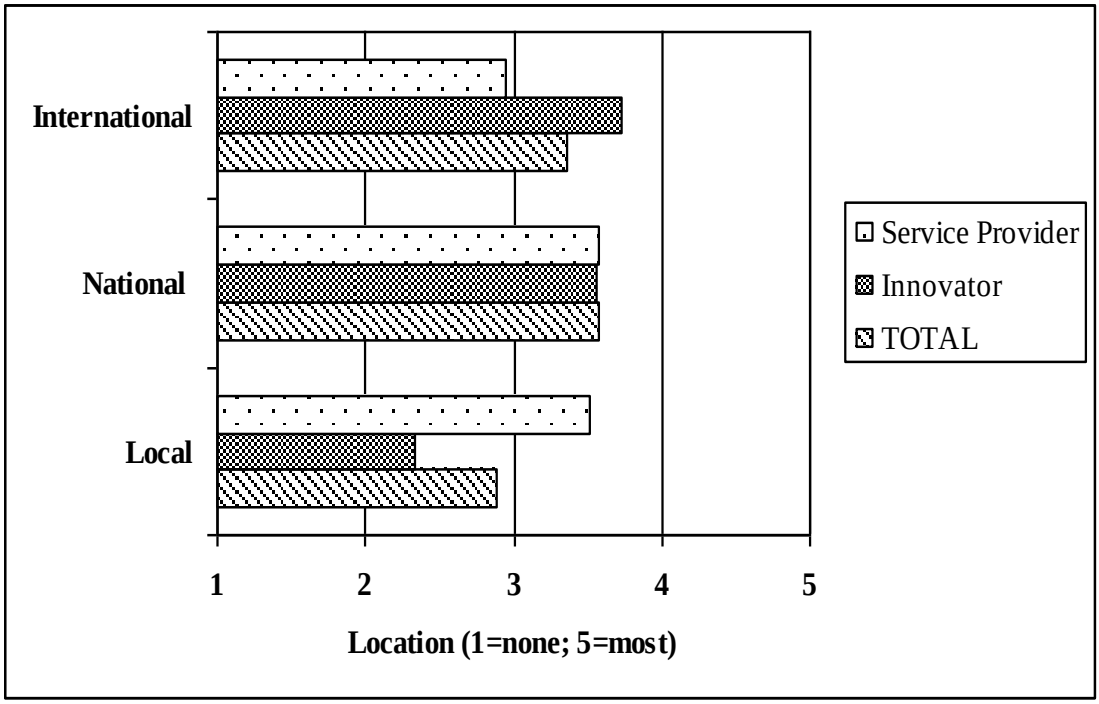
> "*Location can affect the innovation derived from the informal and social network when communication is in person."*

However, they then argued that:

> *"However, this might be not a problem since we have the advanced communication technology for obtaining information internationally*" (I 123).

The importance of such informal networks and the subsequent personal interaction implied that tacit knowledge may be a more localised form of knowledge. However, the findings from the primary data did not necessarily support this conclusion (see **Figure 6.6**). Although the findings were not as clearcut as for explicit knowledge, it was still evident that tacit knowledge was most often drawn from national and international locations since respondents rated these as 3.57 and 3.36 respectively. In contrast, the mean value for local was 2.88, which, although higher than for explicit knowledge, was still lower than the other two locations.

Figure 6.6: Location of Tacit Knowledge



Source: Survey.

Furthermore, these results showed that the difference between innovator and service provider respondents was even more pronounced with tacit knowledge, at least in relation to local sources. Innovators rated local sources much lower than did service providers (2.33 versus 3.51), whilst almost the opposite finding was evident in relation to rating international sources (3.73 versus 2.94). This corroborates the earlier evidence that service providers relied more upon localised knowledge, whilst innovators relied more upon global, and in this case national, knowledge. One of the respondents, whilst extolling several advantages of Oxfordshire as a region, such as:

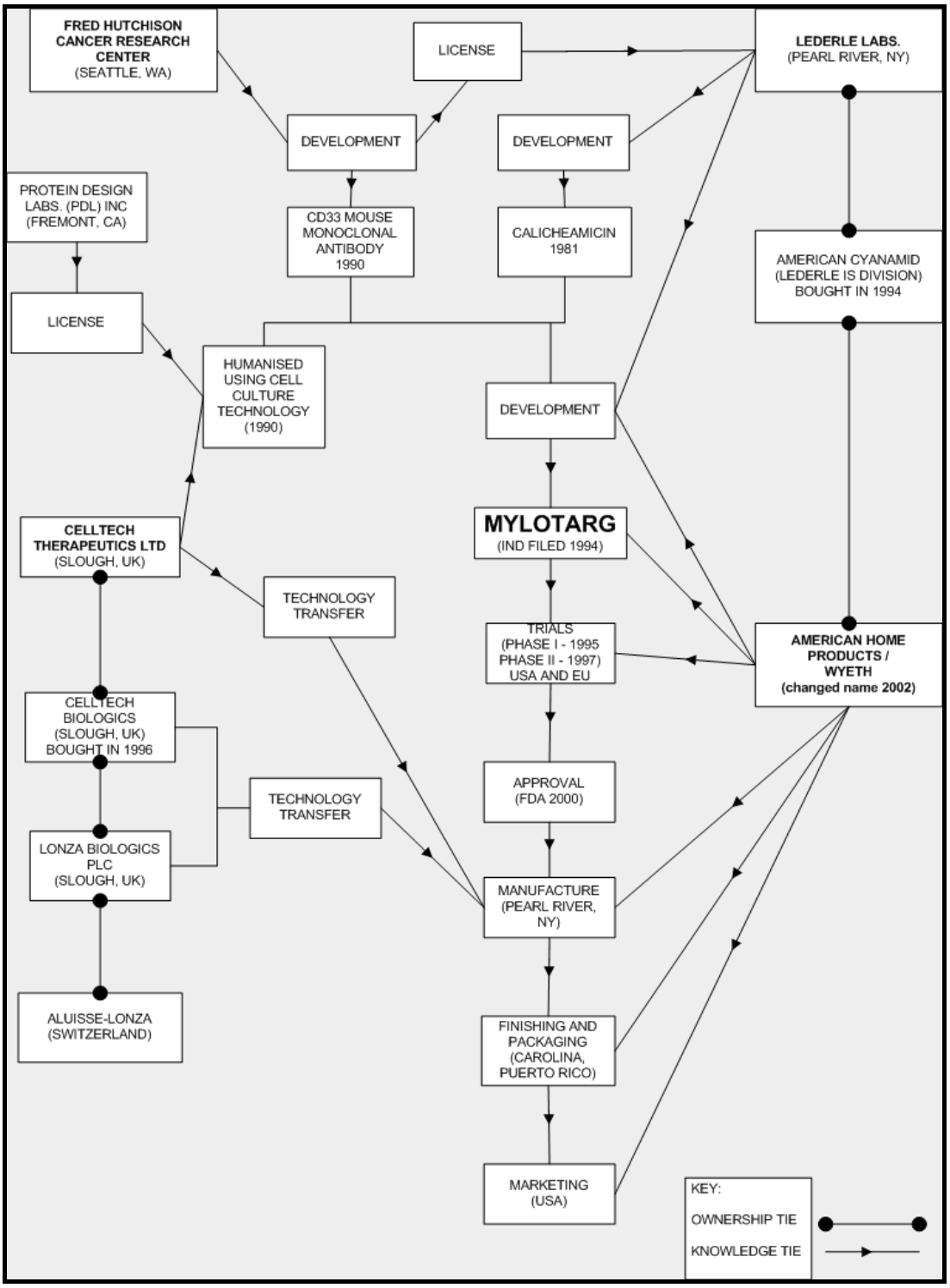
"*Oxford has access to clinical and academic experts…*"

Went on to warn that:

"*...people can be too Oxford-centric though. You need to think globally and not let local boundaries restrict you. Good collaboration will lead to good results ... [although] academic-industry ties are treated apprehensively by academics*" (I 208).

Previous research on tacit knowledge emphasises that tacit knowledge is produced through the interaction between organisations, in that they learn new ways of doing in the process of interaction (Lundvall 1996). As such, learning is an iterative process and tacit knowledge is iteratively produced (Nonaka and Takeuchi 1995) simultaneously during the learning process and as other forms of knowledge (i.e. codified) are produced (Asheim and Gertler 2005). In this sense, one of the central features of the biotech industry then is the systemic nature of the innovation process, in that a variety of organisations are involved, which necessitates the interaction across a number of different locations during product development. An example of this is the product Mylotarg, which was marketed by Wyeth Corporation (previously named American Home Products) and approved by the US FDA in May 2000 (Rader 2003). The development of this product was dependent on a series of global linkages between several organisations, all contributing different knowledge inputs. The UK firm Celltech plc (now owned by the Belgium firm UCB Pharma) played a crucial role in this development process, but so did several other firms. These contributions can be briefly and rather crudely mapped out as shown in **Figure 6.7** below.

Figure 6.7: Product Development History: Mylotarg



Source: Rader (2003); Celltech website; PhRMA website; Wyeth website; survey response.

From the Mylotarg example and the data on tacit knowledge location it was evident that the innovation process was dependent upon a range of different spaces that were constituted through the simultaneous production and transfer of tacit knowledge that occurred across multiple scales. Thus the argument that tacit knowledge is necessarily localised was not supported by the results here; at best such knowledge was constituted at a national scale, although there were still significant international features. This may be a particular feature of the biotech industry or the UK national innovation system, in that the UK is significantly smaller geographically than the USA, although the Mylotarg example also illustrated that even in the USA innovation cuts across different national locations. One of the respondents drew upon this point in their argument that:

> "*However, the UK is a small area (compared to the US) so the cluster argument for areas of the UK is less persuasive. Why is Pfizer located at Sandwich and AstraZeneca in Cheshire, while all other pharma companies cluster round London? It would appear that low cost investment and historical ties were more important in these decisions than anything else*" (SP 333122).

6.3.3 Location of Commercial Knowledge

As another crucial aspect of the innovation system, the location of commercial knowledge was also important to consider. The association of 'enterprise' (as in enterprising) with innovation necessitates the commercial exploitation of knowledge, not just its production, which in turn necessitates the commercial creation and exploitation of markets (DTI 1999c). Regarding biotechnology, some academics

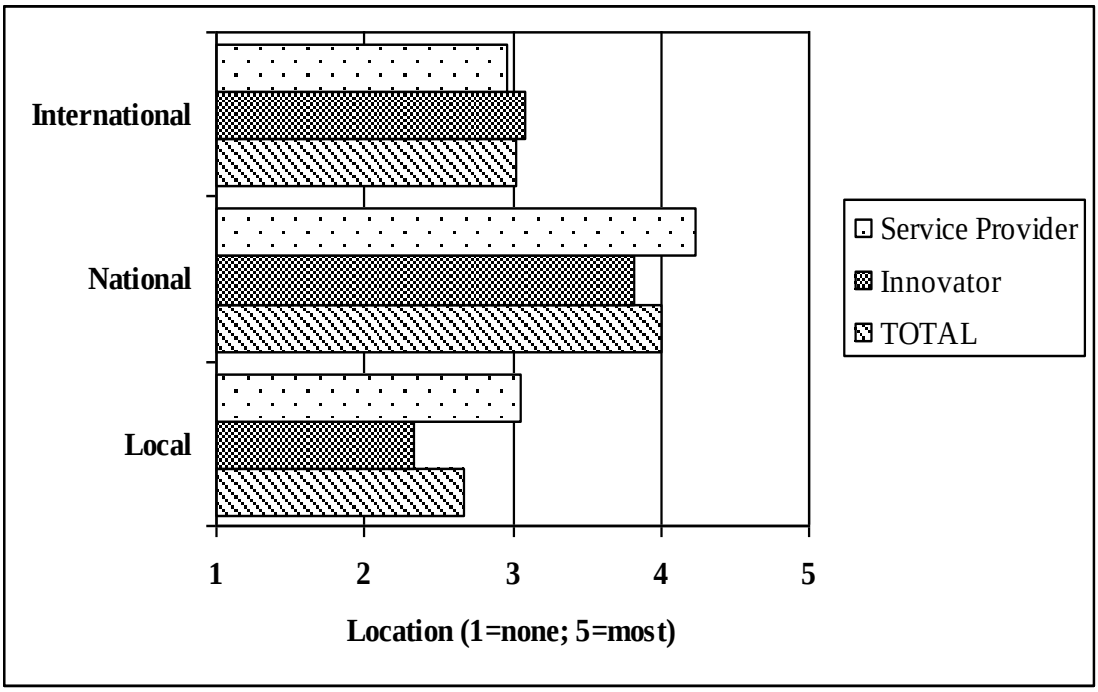
argue that the market itself has been constructed (Green 1991, 2002) or that specific national economies produce specific market orientations (Kettler and Casper 2000; Loeppky 2005). In their work on 'constructed advantage', Cooke and Leydesdorff (2006: 10) also suggest that knowledge-based growth is dependent upon changing structural frameworks covering the economy, governance, knowledge infrastructure, and community and culture. Consequently, the commercial framework of the innovation process has a direct impact upon the type, intensity and global-orientation of innovating firms; for example, elsewhere Cooke (2004d) suggests that localised innovation can be split between 'institutional' (IRIS) and 'entrepreneurial' (ERIS) regional innovation systems. The former is public sector based and driven, whilst the latter is private sector based and driven, and therefore they will produce different knowledge and thus products from each other.

However, the results from the primary data did not conclusively support the idea that there are regional innovation systems with specifically regional financial or investment characteristics in the UK. As one respondent pointed out:

> "*The availability of funding is a national structure, but most providers are south centric, therefore it is easier to raise VC in the South. However, there are recognised centres, which do attract attention. The major restriction is availability of management teams and high networth individuals which are much more prevalent in London and the home counties. In some areas of the UK it is difficult to attract the recognised board members who are required to attract capital investment. 'Money follows people'*" (SP 33332).

This claim was supported by the data on the location of commercial knowledge, which showed that the national scale was the main location for it with a mean rating of 4.01 against 2.67 for local and 3.03 for international locations. The local scale was the least significant since it also had a modal rating of 1 against 2 for the international scale. Again there was a difference between innovator and service provider respondents with the former (2.34) rating the local less highly than the latter (3.06; more significantly the modal rating is 4). However, both rated national and international locations similarly. Thus service providers again emphasised the local scale higher than innovators (see **Figure 6.8**).

Figure 6.8: Location of Commercial Knowledge



Source: Survey.

This difference could have been a consequence of the different positions that each respondent group had within the innovation process. For example, innovators were

more likely to draw upon both basic science funding in the forms of research grants and early stage financing in the form of government awards or schemes. In contrast, service providers because their role came after the initial research and development when firms were seeking to commercialise technologies or knowledge were more likely to emphasise funding particular to commercial exploitation (e.g. VC or IPO sources).

One innovator supported this argument in their statement that:

> "*Financing basic R&D is state driven and an important role to play* [by government in promoting innovation]. *Investment is heavily bolstered by Wellcome, so the government could do better*" (I 18).

However, two service providers commented that:

> "*The government role's in innovation is almost non-existent*" (SP 33362).

> "*The government needs to really support innovation, because for the most part, it pays lip service*" (SP 33320).

The difference between these responses illustrated that service providers and innovators view finance very differently because of their position within the innovation process. Thus innovators saw government funding as crucial, whilst service providers focus more on later investment. However, not all service providers

(or innovators) fell into such simply characterisations. For example, one of the service providers stated that:

> "*The Government has two vital roles in innovation in the bio area: ensuring investment in science at Universities is ongoing and helping the spin out process. The latter is being addressed by Challenge Funds but more is required. The recognition of the importance of business input to the spin out process needs a greater awareness at the top level. More financial input would help as long as it is channelled correctly. The key issue is deciding whether an innovation is sufficient to be a stand-alone business or whether consolidation with other technology is required. If the latter, should it be licensed into an existing business or consolidated with other emerging technologies*" (SP 333122).

Consequently, the location of commercial knowledge, whilst largely nationally based, was not easy to determine overall. The different types of finance needed for a firm meant that at different periods of its life-cycle – or the product life-cycle – they needed different types of finance, a point reiterated by many of the respondents, both innovators and service providers. Thus there was less support for the idea that VC investment was concentrated in the UK (see Powell et al 2002) or that it was a necessary characteristic of the biotech innovation process as has been argued in relation to the USA (e.g. Acharya et al 1998; Cooke 2000). Instead, the UK appeared to be dominated by a financial infrastructure concentrated on London that then fed into concentrations located within easy reach of the capital; i.e. Cambridge and Oxford. One respondent suggested that:

> "*London is a great pull during the early stages of a SME Technology operation, with a wide and capable supply of resources and finance*."

However, the same respondent also suggested that this focus on London was part of a firm's life-cycle, which meant that during early stages it was important to locate close to London, but later on this was less important:

> "*As the organisation grows however, the limitations of the city become a major issue in regard to recruitment and finding suitable premises as scale up and market internationall*y" (I 133).

Overall then, the low importance attributed to local knowledge – whether explicit, tacit or commercial – meant that there had to be other locational characteristics that influenced the concentration of firms, which then prove advantageous to the production, exploitation and diffusion of knowledge, both within a particular space and with other places. These can be considered as the locational assets of such spaces.

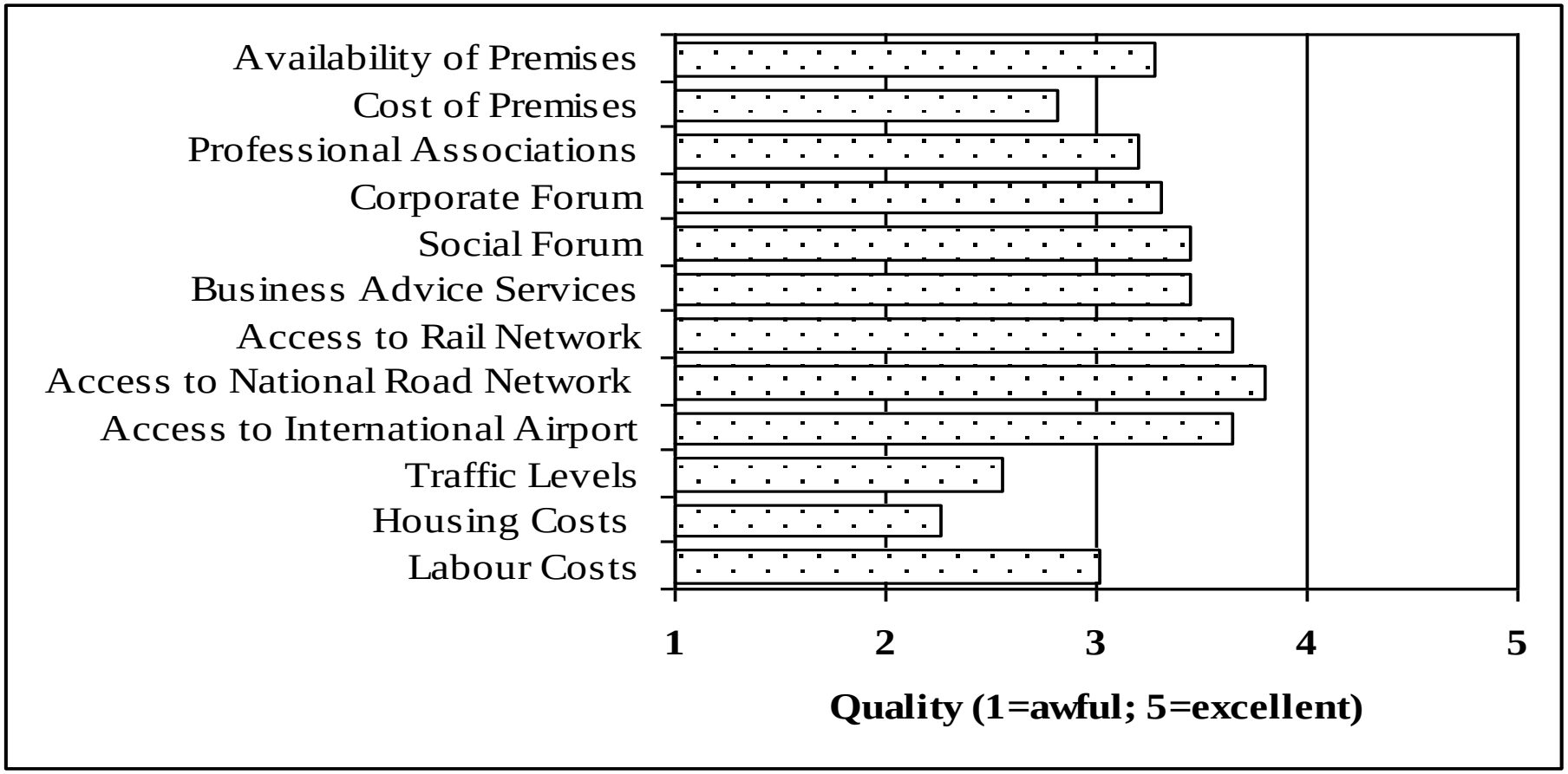
6.3.4 Locational Assets

The wealth of literature on TIMs seeks to explain why innovation occurs in certain places and not others (see Moulaert and Sekia 2003; Lagendijk 2006). The importance of proximate organisations with localised linkages to innovation, as argued in Porter's (1990, 2000) 'cluster' theory, regional innovation systems (RIS) (e.g. Cooke 1998) and learning regions (e.g. Morgan 1997), are not supported by the findings on the

location of knowledge above. Furthermore, there was limited empirical support for the argument that local firms – or more precisely, successful local firms – were predominantly locally oriented; rather, research has shown that non-local linkages are more important (Malmberg 2003; Malmberg and Power 2005). Perhaps more important are the local inter-linkages that encourage trust and co-operation between firms in specific places (Gordon and McCann 2005). This earlier research, however, also highlights the importance of certain features of particular spaces that benefit innovating firms, such as the access to transport links, or the supply of business services; i.e. assets particular to a specific location (Storper 1995; Simmie 2003). These material characteristics may help to explain the concentration of the biotech industry.

To answer these questions, primary data was collected on the 'quality' of locational assets. Quality was derived from respondents' assessment of a series of spatially-embedded characteristics ranging from local labour costs to the availability of premises. Again respondents rated these on a scale between 1 (awful) to 5 (excellent). The range of locational assets was drawn from the literature on biotech TIMs. However, because it only concerned the assessment of respondents, it reflected their judgement of locations rather than any evaluation of the effect of different assets on the innovation process per se (see **Figure 6.9**). Respondents rated housing costs poorly in their regions, suggesting that they were high (mean of 2.26). They also thought that traffic levels were high (2.56). It has been argued that these two factors impact detrimentally on staff recruitment (Walcott 2001; Lawton-Smith 2002), although labour costs were not considered to be as poor (3.02) meaning that housing and traffic may not impact on attracting external labour (see Bagchi-Sen et al 2004).

Figure 6.9: Locational Assets



Source: Survey.

Another anomaly was that the quality of transport infrastructure, congestion aside, was rated highly in the assessment of access to an international airport (3.64), national road network (3.80), and rail network (3.65). Such transport access was important because it provided the means for respondents to contact a variety of different organisational and spatially situated knowledge sources, which can be particularly important for innovating organisations (Simmie 2003). As one respondent said:

> "*Location is important in one respect. One must be located in a good infrastructure, near a good airport, railways, so that international visitors can visit easily. Also, some good hotels and restaurants are important*" (I 25).

The set of locational assets concerned with networking and advisory services were rated very highly by respondents with business advice services (3.45), social forum (3.44), corporate forum (3.31), and professional associations (3.20) all above an average of three. This showed that the regional social network and attendant sources of advice were seen as above average reinforcing the idea that such social ties are important in innovation (Breschi et al 2001; Cooke 2003a; Fuchs and Krauss 2003). However, it was unclear exactly what these contribute to the innovation process, although we could speculate that it provided a means for respondents to reassure themselves about their activities by exploring and then adhering to certain social expectations (see DiMaggio and Powell 2004). The set of locational assets also concerned the cost (2.81) and availability (3.28) of premises, which showed that whilst costs were seen as high the availability of such premises was not seen as a problem. Overall then, the range of these locational assets provided some insight into how different places provided more than just access to different types of knowledge

used in the innovation process. Different spaces also provided a number of other factors that can prove as important, if not as directly influential on the process. Thus expensive housing costs and high congestion can make certain places unattractive for employees and deter them from locating in certain places. Alternatively, lack of access to transport infrastructure may preclude firms from siting in other locations because it could cut them off from access to internationally distributed knowledge. There were a number of different dynamic relationships between both knowledge and space that needed to be addressed to explain the spatial concentration and dispersal of the innovation process.

6.4 *KNOWLEDGE-SPACE* DYNAMICS

Considerations of knowledge and space as distinct aspects of any innovation system produce a distorted picture of their effect upon innovative activity because they reduce both concepts to individual and disconnected factors. Knowledge is reduced to an input that can be derived from internal or external processes, whereas space is conceived in terms of locally-bounded processes involving localised linkages (Phelps 2004), which are expected to feed into the local process. Space is thereby reduced to an external influence on firms through the spatial positioning of productive inputs. Bringing these concepts together produces an explanatory approach, defined as the *knowledge-space* dynamic, that incorporates characteristics of both perspectives representing more than the assumption, in earlier territorial innovation models (TIMs), that a 'successful' region must, of necessity, imply successful knowledge production and diffusion resulting in innovation (see Grabher and Stark 1997). Here knowledge-space is the relationship between knowledge production in space and its

simultaneous diffusion across space, where knowledge cannot be represented by a single factor at a single scale.

This does not imply that all knowledge production and diffusion occurs in the same manner, in fact it implies the opposite; all knowledge is produced and diffused in different ways depending upon the context of its production and context of it diffusion. The interplay between explicit and tacit knowledge forms, of different knowledge types and their sources, operates within and across a number of geographical spaces. Consequently innovation occurs in particular places because of the embedding of different knowledge forms, types and sources produced and diffused across a number of scales. In the knowledge economy, the innovation process is thus constituted by the knowledge relationships within and between locations that necessitate social, cultural *and* organisational proximity as well as functional, relation *and* associational characteristics.

In order to illustrate the significance of this knowledge-space dynamic, primary data was collected on both the source and location of knowledge, as already analysed above. This was then split between respondents based in concentrations of the British biotech industry and non-concentrated respondents, as well as split between the specific concentrations identified in the last chapter; i.e. East Anglia, Berkshire et al, Inner London and Eastern Scotland. Alongside this data, respondents were surveyed on their perceptions of government intervention as well as labour markets to ascertain the importance respondents assign to such macro-scale influences as state action and labour mobility. To start with though we consider the territories from which respondents draw different forms and types of knowledge.

6.4.1 Territories of *Knowledge-Space*

Understanding knowledge-space entails an approach that is both territorial and comparative through the consideration of different sources and origins of knowledge used by actors within different spatial configurations. The territorial framework is represented by the relationship between different sources of explicit and tacit knowledge and its origin in different spaces and at different scales. The comparative framework is provided through a comparison of 'clustered' and 'non-clustered' respondents, as well as comparisons between different types of 'clustered' respondents.

The relationships between the different origins of the two knowledge forms (i.e. explicit, tacit) showed that overall there was a reasonably strong association between similar spatial configurations in that local explicit knowledge was correlated with local tacit (0.557) knowledge. There was a slightly weaker relationship at the national scale (0.522) and a stronger explicit-tacit relationship (0.685) at the international scale. There was a stronger relationship between local knowledge forms amongst non-clustered respondents (0.684) than clustered ones (0.489), and stronger relationships between both national knowledge forms (0.559 versus 0.455) and international knowledge forms (0.722 versus .652) for clustered respondents. These results showed that concentrations of actors did not necessarily lead to the localised production and diffusion of explicit and tacit knowledge within a particular territorial system; rather they somewhat contradicted this perspective in that clustered respondents had stronger relationships between national and international knowledge forms. This confirmed the

work of people like Breschi et al (2001) and Leibovitz (2004) who have argued that local knowledge and linkages are not as crucial to biotechnology than for other industries. However, it also contradicted research that stresses the link between local knowledge and global knowledge in specific 'nodes of excellence' (e.g. Coenen et al 2004) because there were negative associations between both local and international explicit and tacit knowledge forms; the former was –0.506 and latter –0.311.

The relationship between specific sources and their origins concerned explicit, tacit and commercial knowledge. The first of these showed that there were few instances where a particular knowledge source (e.g. manufacturer, competitor, customer) was associated with a particular spatial scale. There were weak or no correlation relationships between local, national and international locations and explicit sources for manufacturers, customers, PROs, and regulators. For the other knowledge sources the strength of the associations was weak or very weak. There were no relationships between local and national location and either competitors or suppliers, but they had a weak association with international location; 0.353 and 0.358 respectively. Explicit knowledge from universities and trade associations had similarly weak relationships with national location, but not with either the local or international scale. This partially corroborated the view of one of the respondents that:

> "*You can't make a company innovative by putting it in a certain location. Innovative people will perform anywhere in whatever field they work in*" (I 160).

For tacit knowledge, there were weak or no relationships between location and manufacturer, supplier, customer, consultant, university, PRO, regulator or informal network sources. The strongest association was between competitor sources and the local scale (0.307). Again for commercial knowledge there were very weak or no relationships between location and venture capital, bank loans, contract work or public equity investment. However, there were weak associations between local origin and personal finance, business angels and government awards/schemes; there was also a weak negative association between international origin and the former two types of finance.

These data results contradicted a number of assumptions about the spatial location of knowledge production and diffusion. In particular the argument that tacit knowledge is, by necessity, contextually specific and therefore difficult to transfer or acquire, whilst explicit knowledge is 'ubiquitous' and therefore easier to transfer or acquire (see Markusen 1996; Malmberg and Maskell 1999; Malecki 20000; Gertler 2003). Although the data did not necessarily support a strong claim otherwise (i.e. that tacit knowledge could originate anywhere), it did provide some support for claims that social and organisational proximity, as opposed to spatial proximity (see Boschma 2005), were more important in biotechnology as Breschi et al (2001) have argued.

After outlining some of the knowledge-space relationships, the next thing to consider is whether there are any differences in these relationships between clustered and non-clustered respondents, which might help explain the argument that localised tacit knowledge is crucial to the innovation process. To illustrate this, the relationships discussed above were split between respondents in the four concentrations outlined in

Chapter 5 and those outside of these four main concentrations; the former were termed ‘clustered’ respondents, whilst the latter ‘non-clustered’. The only major difference for explicit knowledge between these two groups was that non-clustered respondents did not draw upon international origin knowledge from competitors or national origin knowledge from trade associations, although clustered respondents did. There were more differences with tacit knowledge. Non-clustered respondents drew upon more knowledge from the following than clustered respondents:

- Local competitor knowledge
- International supplier knowledge
- Local consultant knowledge
- Local and negative international university knowledge
- Local PRO knowledge
- and local informal networks.

In contrast clustered respondents drew on less local competitor knowledge and more national informal network knowledge than non-clustered respondents did. Finally, for commercial knowledge non-clustered respondents valued national venture capital more highly, whilst clustered respondents did not have a negative association between international location and either personal finance or business angels, as revealed above across all respondents. Clustered respondents also did not stress the local origin of government awards/schemes. Again, these findings did not support the view that clustered actors benefit from localised knowledge upon which they can draw more easily because of spatial proximity (e.g. Porter 2000). Instead they appeared to support the general research finding, summarised by Malmberg (2003), that clusters

or concentrations do not rely upon local linkages and knowledge, but rather upon a range of spatial scales for knowledge inputs into the innovation process. As one of the respondents argued:

> "*The issue of innovation and location are not necessarily linked as implied by your questionnaire. In my mind, innovation is 'people' driven and depends on the interaction of a group who are looking to change/improve something*" (SP 333122).

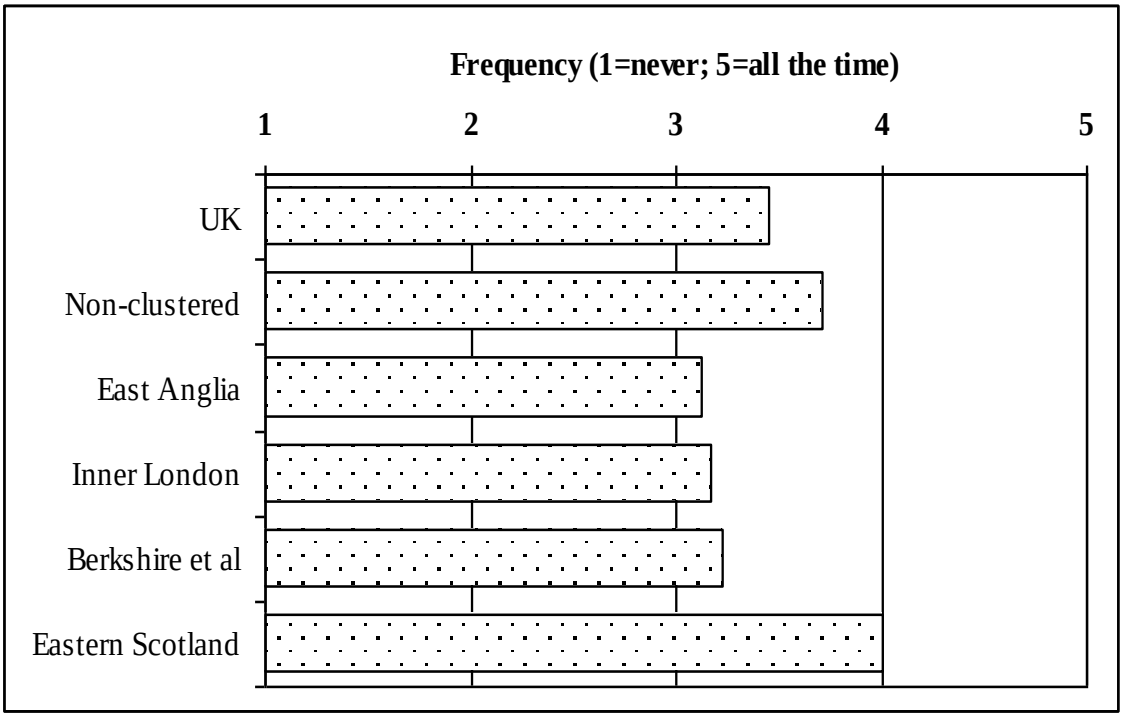
Since these interactions can take place across a number of different scales and contexts, and in a variety of organisational or institutional environments, they precluded a simple territorial explanation of innovation processes and the inherent knowledge characteristics of particular territories or places.

6.4.2 Comparisons of *Knowledge-Space*

As the previous section shows, it is important to consider the knowledge particularities of different spaces. This involved the comparative analysis of the different relationships between knowledge forms, sources and origins against the four main biotech concentrations identified in Chapter 5. These concentrations included East Anglia, Inner London, Berkshire et al, and Eastern Scotland. Respondents were differentiated between these four concentrations and those who came from outside of these locations (i.e. non-clustered). The initial data under consideration was the source of explicit and tacit knowledge. The main difference in mean ratings between the five different spatial sites – four clusters and one non-clustered – were that the non-

clustered respondents access explicit competitor sources more often than respondents in all the concentrations, apart from Eastern Scotland (see **Figure 6.10**). Otherwise, compared with non-clustered respondents, East Anglia and Inner London respondents accessed explicit regulator knowledge less often, whilst Berkshire et al respondents accessed explicit customer knowledge less and Eastern Scotland accessed explicit customer knowledge more often and PRO and trade association sources less often.

Figure 6.10: Comparative Data on Explicit Competitor Sources



Source: Survey.

These results implied that explicit competitor sources were not a vital source for certain concentrations since some concentrations, perhaps because of their location around London and its transport links, did not rely upon such explicit sources because they were closely tied into international markets. As one respondent commented:

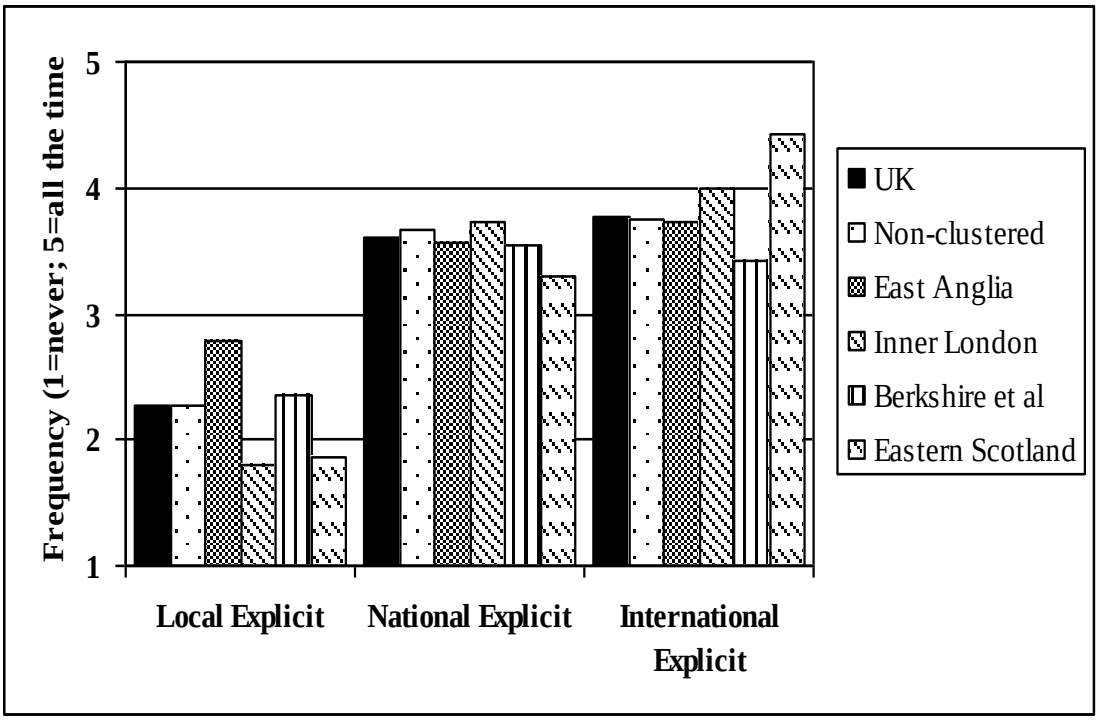
> "*I would never put my business away from the Oxford/Cambridge/London triangle, for example the innovation centre in Sittingbourne (which I have visited) is way too far out of things to be of any use to my two businesses*" (I 153).

More isolated respondents may therefore have had to rely upon explicit knowledge of markets. This possibility was supported by the finding that East Anglia and Berkshire et al respondents did not access explicit customer sources as often as other respondents.

There were more differences with tacit knowledge sources when compaaring respondents. The main ones were the lower frequency of contact between non-clustered respondents and the four clustered groups regarding manufacturer, supplier and customer (excluding Inner London) knowledge sources. Inner London respondents also had more frequent contact with tacit competitor and PRO sources, whilst more interestingly East Anglia respondents had less contact with tacit university sources. Finally, for commercial knowledge sources there were a number of significant differences between non-clustered and clustered respondents. All clustered respondents, no matter which concentration they belonged to, rated venture capital more highly than non-clustered respondents did. They also rated public equity investment more highly, except for Eastern Scotland respondents who rated it significantly lower than all other respondents. Both Inner London and Eastern Scotland rated contract work highly, whilst Berkshire et al rated business angels higher than others.

The origin of the knowledge sources for the non-clustered and four clustered respondents was shown in the difference between the location of explicit, tacit and commercial knowledge (see **Figure 6.11**, **Figure 6.12** and **Figure 6.13** respectively). This was expressed in terms of the mean rating given by respondents to the source of such knowledge between the local, national and international scales.

Figure 6.11: Comparative Spaces of Explicit Knowledge

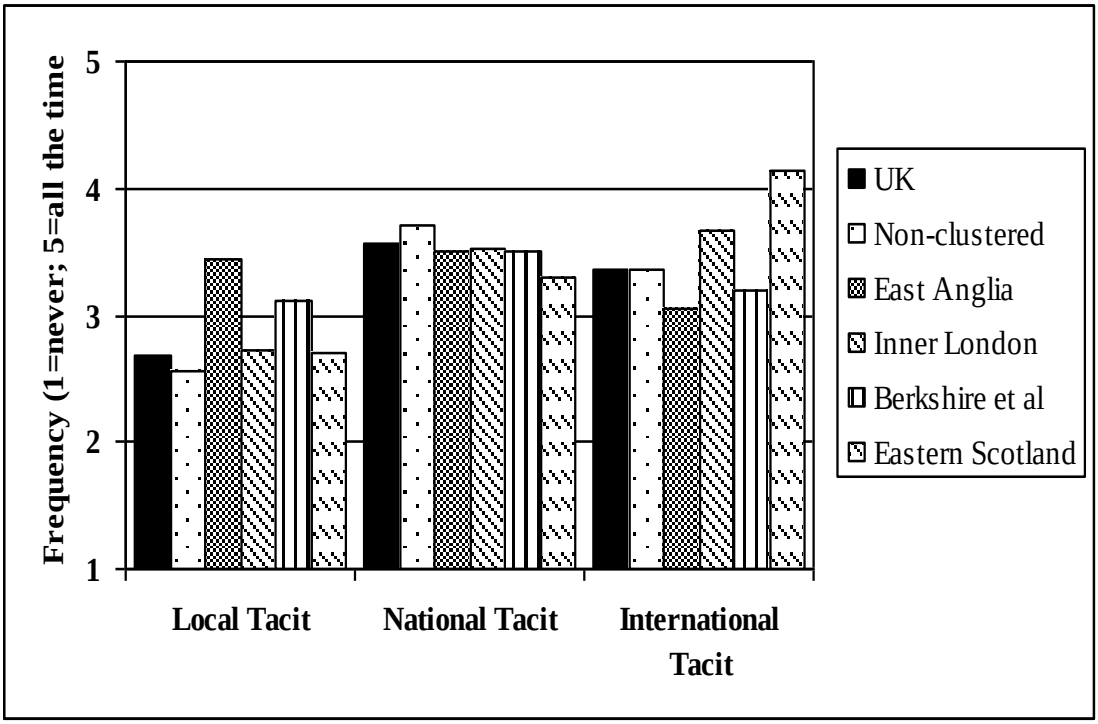


Source: Survey.

East Anglia respondents emphasised local explicit and local tacit sources over non-clustered respondents. More importantly, they also had less frequent contact with international tacit sources. The same trend was evident with Berkshire et al respondents who also had more contact with local tacit sources, as well as local commercial knowledge. In contrast, Inner London and Eastern Scotland respondents were much more internationally focused with higher ratings for contact with

international explicit, tacit and commercial knowledge sources than non-clustered respondents (and the other concentrations).

Figure 6.12: Comparative Spaces of Tacit Knowledge

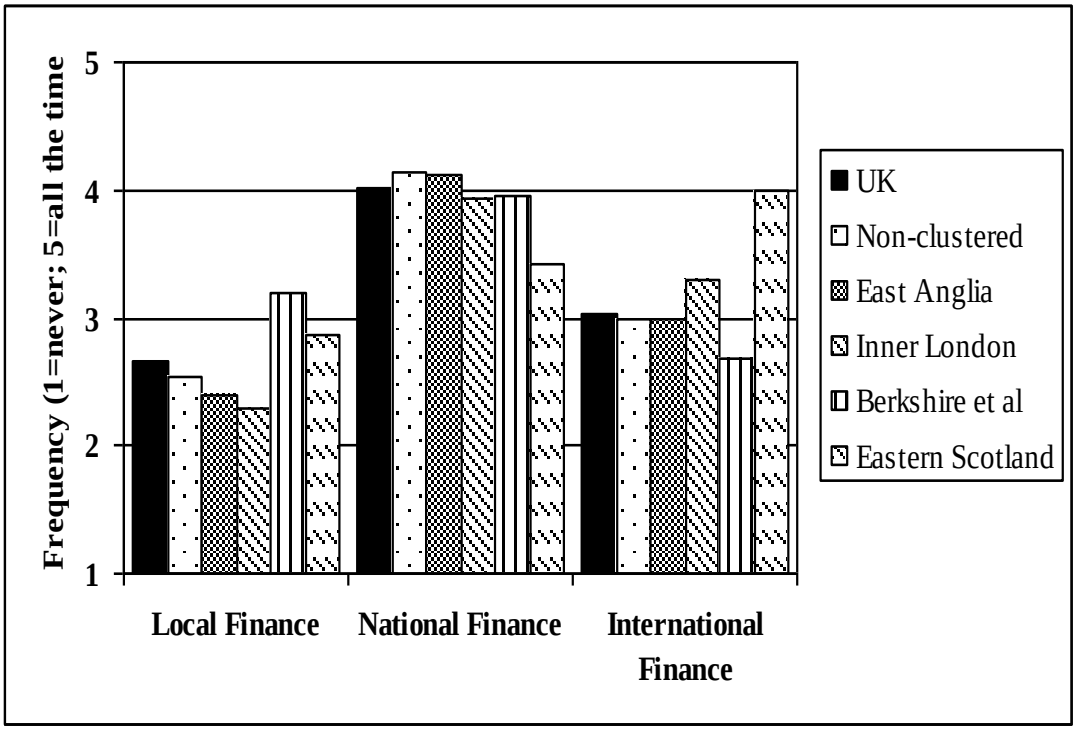


Source: Survey.

It was perhaps unsurprising that each concentration – in some ways at least – was oriented towards different spatial scales since, as one respondent noted:

> "*Location is important from the perspective of bringing together the resources for the innovation process to happen. It is clear that a particular area will favour innovative organisations of the same sort because many of the ingredients are present, especially when new organisations are formed*" (SP 333122).

Figure 6.13: Comparative Spaces of Commercial Knowledge



Source: Survey.

Not all locations contained a diverse mix of organisations for respondents to draw upon and therefore it was necessary for them to search outside of their particular location for the necessary knowledge. One interesting finding was that Berkshire et al respondents stressed local finance implying that there was more early stage financing capability in this region than elsewhere, which contrasted with the global and large firm basis of knowledge in this concentration (see Chapter 5).

Overall then it was possible to use these results to support the earlier finding (see Chapter 5) that there were four distinct concentrations of biotechnology in the UK. There was also some support for the idea that concentrations develop over time (e.g. Cooke 2001), although in this case the importance of local knowledge appeared to strengthen over time rather than weaken as the concentration matured. This

contradicted the argument that mature 'clusters' were more closely tied into global networks rather than local ones (see Wolter 2003), unless the data showed that certain UK concentrations (i.e. East Anglia and Berkshire et al) were overly insular in their focus. Such a finding would suggest that they will in the near future 'lock-in' to a particular innovation process that leads to 'path contingent' development (see Hudson 2005). Another conclusion could be that none of the British concentrations were mature, but instead a number of the more *emergent* concentrations (i.e. Inner London and Eastern Scotland) were reliant upon international connections because they focused more on market drivers, since they were major finance centres, and not the technology base.

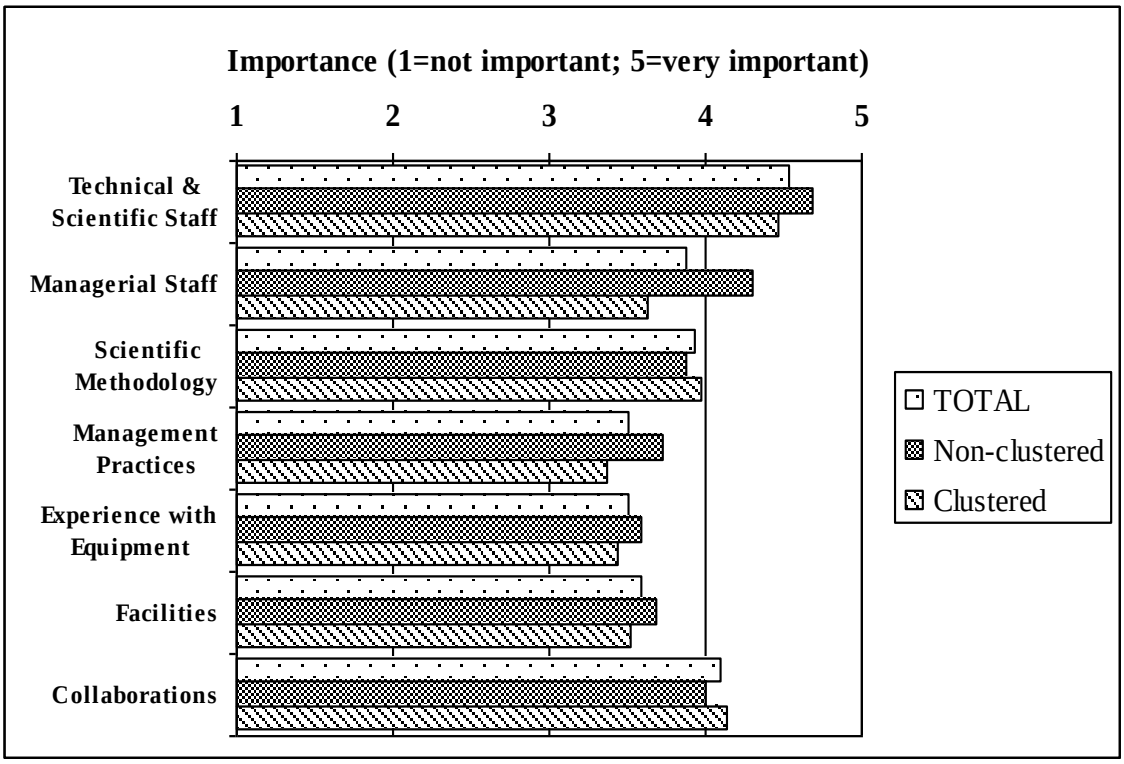
6.4.3 External Influences on *Knowledge-Space*

Although each concentration may have had different characteristics that affected the innovation process in different ways dependent upon the relationship between knowledge and space, there was still a national scale impact from government policy, especially in relation to intellectual (IP) property protection. This was evident in the national institutional framework in which biotech concentrations operated, except it was also important to remember that biotech firms, organisations and even locations can themselves influence the institutional environment.

It was interesting to begin this examination of the role of the state by considering what respondents thought about the importance of internal knowledge to innovation. Across the board, whether respondents were innovators or service providers, cluster or non-clustered, they rated a range of internal knowledge sources highly (see **Figure 6.14**).

For example, the mean rating they gave scientific and technical staff was 4.54 – they also rated the importance of international patents at similar levels (4.46). Of the other internal knowledge none was below a rating of 3.50 suggesting that such internal sources, however represented, were considered as crucial by both clustered and non-clustered respondents. The already mentioned emphasis on the 'logic' of the science and technology of biotechnology (see McKelvey et al 2004) played an important part in the self-understanding of the innovation process, if not also to innovation itself. This perhaps supported the research by Hall and Bagchi-Sen (2001) showing that biotech managers consider success as internally derived and failure as the result of external interference.

Figure 6.14: Importance of Internal Knowledge to Innovation



Source: Survey.

Respondents emphasised this when they claimed that it was:

> "*Senior staff and academics at university [who] were the most important internal knowledge source*" (I 35).

Or that:

> "[The] *Academic stars in groups* [are] *where the knowledge comes from*" (I 36).

However, it was interesting to note that clustered respondents rated the importance of managerial internal knowledge, whether managerial staff or management practices, less highly than non-clustered respondents did. This was evident across all the four UK concentrations, particularly in Inner London, suggesting that certain types of knowledge were less relevant for these respondents, perhaps because they benefitted from external sources of management knowledge derived from the concentration of intermediate services (Powell et al 2002; Cooke 2004c). This contrasted with one respondent's claim that:

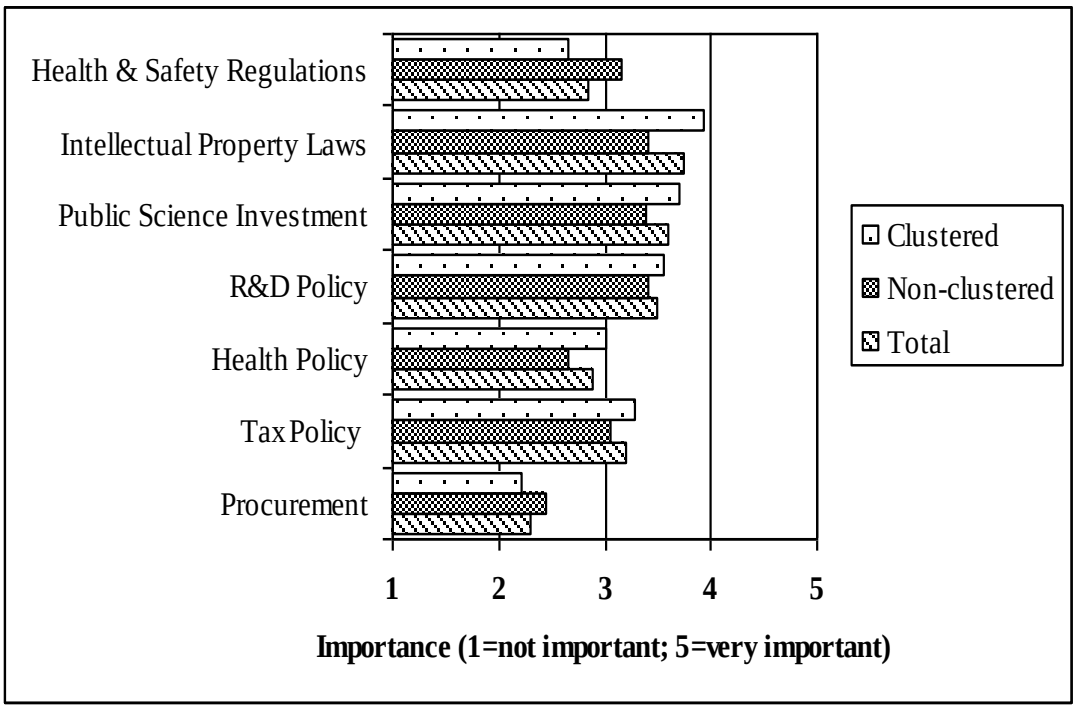
> "*I believe that leadership is an important part of the innovation process and if it is present throughout an organisation and gives a clear message to the innovators about their role and direction, then that organisation will produce high quality innovations*" (SP 333122).

It was therefore possible that clustered respondents were more technology based, whilst non-clustered respondents were more market driven and therefore the latter viewed managerial knowledge as more important. Clustered respondents, in turn, were situated in places of highly concentrated scientific and technical knowledge (e.g. university towns like Cambridge and Oxford), which meant that they were more likely to be embedded in this culture rather than a market-driven one.

6.4.3.1 Government Intervention

Whilst there was a strong emphasis on the impact of internal knowledge on the innovation process, there was less recognition that some external influences like the government played an important role; however, IP protection was highlighted. Such former external influence covered the importance of government intervention on innovation (see **Figure 6.15**). The highest rating that respondents gave was to intervention concerning IP, which was seen by both clustered and non-clustered respondents as important (mean of 3.74). The other highly rated interventions included basic science investment (3.59) and R&D policy (3.50), although clustered respondents' placed more emphasis on the importance of these two interventions. This supported the claim that public investment is crucial to the development of biotechnology and biotech concentrations, both in terms of external contracting (see Feldman and Francis 2002) as well as the large infrastructure investment needed in science and research (Cooke 2003a, 2004a, 2004b). The influence of historical decisions and the public sector therefore had an important impact on the development of the concentrations (see Feldman and Francis 2002; Leibovitz 2004).

Figure 6.15: Government Intervention



Source: Survey.

However, the role of government intervention in other areas of innovation was sometimes deemed irrelevant at best and negative at worst by the respondents. For example, one claimed that:

> "[Government plays] *A very minor role, early stage grants are useful and tax incentives for business angels and VC helps with later stage financing*" (I 141).

Whilst another claimed that government policy was:

> "*Not always handled in most efficient way, such as Finance Act 2003 and tax issue. Massively negative affect*" (I 36).

These issues, alongside the low rating of government procurement (mean of 2.30) and the importance of international markets, perhaps explained why respondents often stress the need for government to be more involved in promoting innovation through funding and regulatory changes. One respondent bemoaned the role of government as:

> "*Currently, sadly, an ever diminishing one. The demise of Smart Awards is a big mistake by the governments and even the old Smart scheme could have been more business friendly*" (I 153).

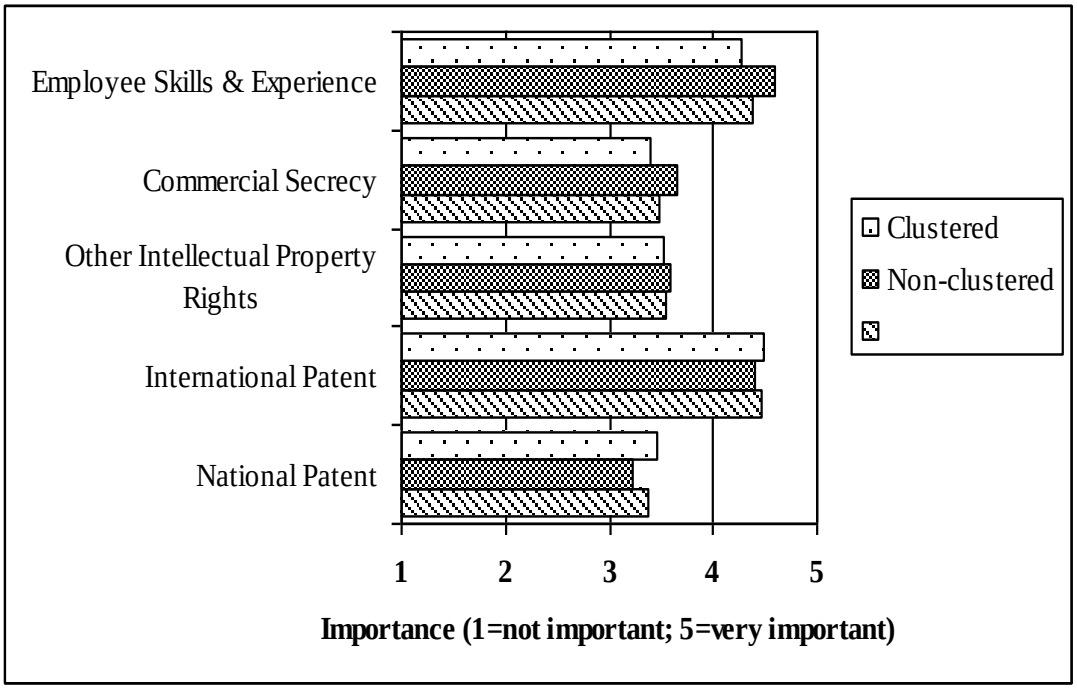
Another emphasised the fairly limited role played by government when they claimed that:

> "*The State can only play a part in making available grants, loans, tax credits and releasing companies from red tape. The red tape applies to all aspects of running a small business. It can't make people innovative however it can help create a culture where people are encouraged to set up a business in the UK. At the present time there are not many positive points to being a UK company. Anybody who is serious about biotech would set up in the USA*" (I 160).

All these views of government intervention illustrated that respondents did not view the government as a particularly important influence when it came to being a customer or regulator, although they did emphasise the important influence government had in relation to public investment in science and promotion of R&D policy. This finding supported earlier research that stressed the impact of such

investment in basic and applied research (e.g. Cooke 2002b, 2003a, 2004b) as well as the importance of national economic structures and systems especially in terms of IP protection (see Tait et al 2006). However, a number of other findings somewhat contradicted this view of the minimal importance of national state involvement such as the emphasis on international markets, which suggested that, for the UK at least, other governments had more of an influence than the UK government. This was also the case with IP protection since international patents were viewed as more important than national ones (see **Figure 6.16**). Consequently, global institutional structures, especially relating to IP, may appear more influential to respondents than their national government.

Figure 6.16: Importance of Intellectual Property Protection



Source: Survey.

Interestingly, clustered respondents' rated almost all government intervention as more important than non-clustered respondents, but most especially health policy, public science investment and IPR regulation. Thus non-clustered respondents rated government procurement and health and safety regulations more highly, suggesting that such government actions had more impact on those in a dispersed innovation system. The higher rating given by non-clustered respondents to national markets supported this finding; however, the higher rating they also gave to international markets did not support this conclusion. In relation to the importance of IP, there were a number of differences between clustered and non-clustered respondents. Non-clustered respondents rated both commercial secrecy and employee skills and experience as more important than IP protection, in contrast to clustered respondents. However, there were distinctions between the four different concentrations on other types of IP protection. For example, East Anglia and Inner London respondents both rated national and international patents more highly than either non-clustered or Berkshire et al and Eastern Scotland respondents. These results suggested that for certain respondents innovation consisted of the pursuit of IP protected knowledge (i.e. clustered respondents), whilst for others such IP was less important (i.e. non-clustered). The latter may be a consequence of the concentration and dispersal of the innovation process in that the latter were subject to less scrutiny by their peers and therefore less in need of protecting their knowledge.

6.4.3.2 *Labour Markets*

The final national institutional framework was the labour market. This represented one of the main features of the innovation process because both the knowledge base and driver can be appropriated from multiple scales as required. This was particularly relevant in relation to the discussion of explicit and tacit knowledge forms, since the latter was largely a product of interaction as it was 'experiential' rather than codified and therefore more difficult to transfer between organisations (see Gertler 2003). This is the main reason that spatial proximity has been highlighted as a crucial factor in the innovation system (e.g. Fagerberg 2005). One means through which knowledge does transfer, however, is through the movement of labour. As one of the respondents put it:

> "*Constantly changing groups of people available within the Biotech Cluster mean we always see new people and new ideas. It's easy to see something in action, we can just drive over to see it without wasting a day*" (I 84).

As mentioned earlier, respondents also stressed the importance of certain internal knowledge sources, particularly those of the technical and scientific staff (mean 4.54), and employee skills and experience as a form of IP protection (mean 4.39). Thus the location of labour markets was a particularly pertinent indicator for knowledge-space in that a large element in the production and diffusion of knowledge across space was dependent upon the movement of people.

For purposes here, labour markets were split between "technical and scientific staff" and "managerial staff" to respectively represent the knowledge base and knowledge driver in the innovation process; the former provided access to science knowledge

whilst the latter provided access to market knowledge. These two labour sources were themselves split between local, national and international scale labour markets. Out of the six different labour markets, the most important one according to respondents was the national-managerial (mean of 3.84) followed by national-technical (3.70). These were closely followed by local-technical (3.51) and then local-managerial (3.08), whilst the international labour markets for both technical and managerial labour were rated lower at 2.69 and 2.80 respectively. However, the local labour markets were considered to be less important by innovators than service providers, in both cases, although for local-technical they were still important. It is possible to argue that this was because the local labour market provided an important means to access both knowledgeable workers and diffuse knowledge across local organisations and institutions. As one of the respondents said:

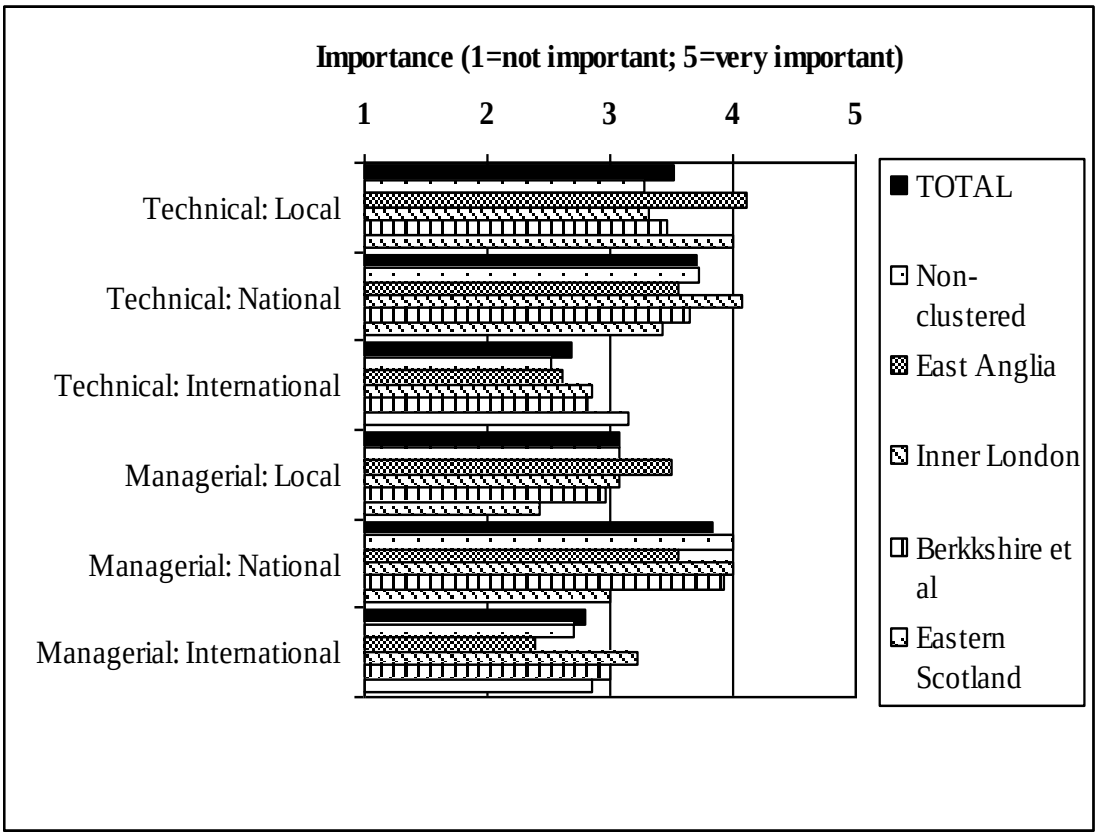
> "[A] *Biotech and High Tech centre of excellence with a mobile pool of workers attracts innovators; we know we can attract, pay and retain good staff because they know there are plenty of jobs for partners also in the tech industry*" (I 84).

The differences between clustered and non-clustered respondents showed that non-clustered respondents saw local-technical and international-technical as less important than the national average of respondents from the four concentrations. East Anglian respondents rated local-technical and international-technical far more highly than other respondents and national-managerial and international-managerial lower than most respondents, except for Eastern Scotland respondents who rated the latter two the lowest (see **Figure 6.17** below). All the concentrations were distinct from each

other, which again emphasised the importance of considering each in terms that did not preclude a specific analysis.

Overall, this data partially confirmed previous research on the crucial role played by local staff turnover (e.g. Henry and Pinch 2000) and the importance of local staff generally because of their immobility (Zucker et al 2002; Fuchs and Krauss 2003; Wolter 2003). This was especially relevant to clustered respondents in comparison with non-clustered ones.

Figure 6.17: Labour Markets



Source: Survey.

One respondent pointed out that:

"*There is a critical mass of biotech in the area that enables companies to keep going and recruit good people. People know that here is more security because as one firm dies another rises up so there are jobs and people don't have to move when they change jobs*" (I 84).

These findings also partially contradicted the claims by Casper and Karamanos (2003) that there was a high inward migration of scientists into concentrations of biotechnology. Instead it would be more accurate to suggest that the inward migration of nationally-based scientists was important, although the internationally migration was actually emphasised more by most clustered respondents (except East Anglians) than for the overall sample and non-clustered respondents. Local-technical labour markets remained important for these clustered respondents as well, implying that there was a mingling of international and local technical labour supporting the theory that the local-global connection is crucial to innovation (e.g. Bathelt et al 2004).

6.5 CONCLUSION

It was notably in each case that respondents acquired and accessed knowledge from a range of sources located in different places. Certain knowledge forms and types may be accessed more than others, but the lowest average rating given to any knowledge form and type was 2.50 for explicit knowledge (trade associations), 2.27 for tacit knowledge (regulators), and 2.02 for commercial knowledge (bank loans). In turn the lowest rating for the spatial origin of these knowledge forms and types was 2.28 for explicit forms (local), 2.88 for tacit forms (local) and 2.67 for commercial forms

(local). In each case the lowest rating was given to locally-based knowledge, no matter what form of knowledge, which suggested that the spatial basis of knowledge had little to do with its form at least in relation to the current conceptualisation of the local-boundedness of tacit knowledge.

A number of other interesting findings were evident in these results. First, the most highly explicit knowledge types (i.e. competitors, customers, universities) were predominantly market-making types of knowledge (i.e. drivers rather than bases). This suggested that knowledge commercialisation was concerned with markets over technology – perhaps obvious – but there was an indication here that this was largely nationally and, more importantly, internationally focused. In relation to biotechnology this is hardly surprising considering the dominance of the North American market. Second, the most highly rated tacit knowledge (i.e. consumers, universities, informal networks) was both technology-making and market-making, although we have to assume that informal nertworks concerned both the demand and supply sides of innovation. Third, the association between the explicit and tacit forms of knowledge was clear, although it was not always of the same strength. Therefore, both forms were vital to understanding the innovation process and both forms tended to originate at the national and international scales, rather than local. In fact, the local scale did not feature as a prime location for any of the three forms of knowledge (explicit, tacit, commercial). Fourth, the rating given to commercial knowledge emphasised the importance of commercial exit (i.e. VC, IPO), although respondents stressed the need for different funding at different stages of development.

Overall though, respondents derived knowledge from all the different knowledge forms, sources and locations; there were no cases in which any instance of the knowledge-space dynamic was missing from the innovation process. In each case there may be a different emphasis on knowledge-space, but across the sample it was not missing. However, there were differences between the respondents based on their positioning within 'clusters' or not. Thus non-clustered respondents rated local explicit and tacit knowledge more highly, whilst clustered respondents rated international explicit and tacit knowledge higher, along with national for both. Non-clustered respondents were more localised than their clustered counterparts, although with certain UK concentrations (i.e. East Anglia and Berkshire et al) this was not the case. There was a striking negative relationship between local and international knowledge across both explicit and tacit forms, which suggested that the linking of global knowledge into local knowledge was not as relevant to the biotech industry (e.g. Bathelt et al 2004). Instead such linkages occured and played out across a number of different scales, all of which proved important to the innovation process in one way or another.

PART II

SUMMARY

In this section the thesis has addressed the three hypotheses outlined earlier in Chapter 1, 2 and 3. The historical background and context of the British biotech industry outlined in Chapter 4 showed how national and global institutional changes have had significant impacts on the commercialisation of biotechnology. As such it illustrated the importance of these different scales. Chapter 5 built on this general overview by exploring the specific concentration of biotechnology across the UK, which showed that there were four main concentrations, although none of these had more than 70 biotech firms. In seeking to explain the reason for such concentrations, the chapter showed how social proximity was important, especially in terms of different dynamic systems of innovation embedded in different places. This then led to the analysis of the primary data in Chapter 6, which focused on the knowledge and innovation processes in different locations. This analysis draw upon the theoretical and methodological framework developed in Part I called the *knowledge-space* dynamic and illustrated how innovation was dependent upon interaction both within and across different concentrations. Consequently it was possible to argue that the positioning and embedding of different knowledge processes in different locations entails an external (i.e. extra-local) outlook on the part of firms and actors involved in successful innovation.

PART III

Conclusions and Policy Implications

This section provides the overall conclusions for the thesis in Chapter 7 that are derived from the data analysis in the last section before exploring a number of policy implications from these findings in Chapter 8. As such this section summarises the overall conclusions from this examination of the relationship between knowledge, space and technology by running through the three hypotheses outlined in Chapter 1 before taking a critical look at the biotech industry. The latter task is important because of the claim that biotechnology represents a revolutionary technological paradigm that totally alters our understanding of individual health and also national economic development (BIGT 2003; see also Rifkin 1999; Oliver 2000). The discussion of policy implications therefore considers how this emphasis on the potential of biotechnology and the wider knowledge economy leads to a focus on certain concerns that encourages specific policy agendas. The pursuit of such agendas precludes the adoption of alternatives that can lock-in innovation, economic performance and technological development to one paradigm, a paradigm that may not actually achieve its claimed potential.

CHAPTER 7

MAIN CONCLUSIONS:

KNOWLEDGE, SPACE AND TECHNOLOGY?

7.1 INTRODUCTION

This thesis has explored the relationship between knowledge, space and technology by focusing on a particular 'knowledge-based' industry in the broader knowledge economy, where this has been defined as the production and commercial exploitation of new knowledge through new knowledge (see Cooke 2002c). As such the definition of biotechnology has also been broadly applied consisting of the application of biological processes in production and / or the production of biological commodities (see DTI 1999a, 1999b); i.e. an enabling technology as much as new series of products (House of Lords 1993). The central contention of the thesis has been that biotechnology, as a case study of the 'knowledge economy', has concentrated in particular places because place-specific processes lead to successful innovation. Thus the central hypothesis is:

> Despite being an internationally distributed sector, biotechnology innovation is concentrated in regional nodes because these locations provide advantage through a *knowledge-space* dynamic that encompasses functional, relational and associational processes.

This hypothesis was developed after reviewing the existing literature on the knowledge economy and the relationship between knowledge and space in the innovation process, which led to the concept of the *knowledge-space* dynamic (Chapter 2). As part of this dynamic, three further hypotheses were developed that considered the relationship between knowledge, space and technology in more depth. These were:

H1: There are 'knowledge economy' concentrations because successful innovation depends on dynamic (i.e. across time) and systemic (i.e. across organisations) processes embedded in and across specific places.

H2: Successful innovation in the knowledge economy depends on place-specific dynamic and systemic processes because different types of knowledge (including supply and demand) originate in different places and at different scales necessitating interaction both within and beyond concentrations.

H3: The knowledge economy depends on different locations and scales of knowledge because different places have different locational assets that contribute to successful innovation in different ways and therefore necessitate linkages within and between locations.

This conceptual perspective was then used to develop a methodological framework in which innovation could be conceived in both dynamic and systemic terms as well as address a number of concerns with existing research approaches (Chapter 3). Following on from this, there were three chapters that covered the background and

context (Chapter 4) of the UK biotech industry, the analysis of secondary data on the biotech industry (Chapter 5), and the analysis of the primary data derived from a mixed methods survey (Chapter 6). These chapters explored the three hypotheses outlined above. The first was addressed in Chapter 5 in an examination of the secondary data on the UK biotech industry, whilst the second was addressed in Chapter 6 using primary data. The third hypothesis was investigated in all three chapters.

The reason that the thesis focused on the knowledge economy and, in particular, the biotech industry is because of the strong policy interest and action in developing a 'knowledge-based' economy and society in the UK and Europe (e.g. DTI 1998; Lisbon Agenda 2000), as well as the pursuit of biotechnology as a central feature in this vision. For example, the European Commission (EC) and Organisation for Economic Co-operation and Development (OECD) have recently defined the biotechnology industry as a 'knowledge-based bio-economy' (EC 2004, 2005) or more simply 'the bioeconomy' (OECD 2005; also see OECD 1999). They characterise the biosciences as a "new wave of innovations" (ibid.: 1) and "significant drivers of productivity and competitiveness" (EC 2004: 1) that offer vital opportunities for the promotion of social, economic and environmental goals, building upon the drive towards a 'knowledge economy' in developed economies. Consequently the biotech industry is meant to provide the possibility for developed economies to over-come some of the problems with changing industrial structure (i.e. de-industrialisation) and the attendant economic, social and political ramifications of these changes. In particular there is a concern with national competitiveness, investments in learning and knowledge as well as skills upgrading, uneven regional

development and changing healthcare. The thesis conclusions and findings (7.2) outlined here will relate to a number of these issues by detailing how the *knowledge-space* dynamic can be usefully applied to the knowledge economy and what the findings mean for different policy-makers, which will be explore in more depth in Chapter 8.

7.2 MAIN CONCLUSIONS

7.2.1 *Knowledge-Space* Dynamics in the Knowledge Economy

To briefly summarise the concept of the *knowledge-space* dynamic it is important to remember that it is derived from a number of different theories crossing several subjects (e.g. economics, economic geography, economic sociology etc.). However, the central proposition is that regional development in the knowledge economy is based on innovation and that each location has a different and place-specific set of characteristics that factor into the innovation process. Furthermore, each location is tied into a wider series of scales (e.g. national, global) that contribute to regional development as much as the local, place-specific characteristics do. The *knowledge-space* concept is therefore concerned with incorporating both supply and demand features in the innovation process although not by considering these as spatially dependent, but rather as existing across all spatial scales. Thus supply and demand features of innovation can both be local or international, or both; all of which depends upon the specificities of place.

The *knowledge-space* dynamic seeks to avoid a number of theoretical and empirical problems with existing research, in particular issues around the conceptualisation of space / scale and causation (see Chapters 2 and 3). These include the focus on 'successful' regions (e.g. Silicon Valley), the assigning of agency to a region and the reversal of causality (Maskell and Malmberg 2002). Instead the aim was to consider what knowledge contributed to innovation processes occurred – at what scale and in what locations – and then relate these to specific concentrations of the biotech industry in order to enable a comparative perspective as well. A fundamental feature of this approach has been the emphasis on the idea of place-specificity in that all concentrations of the biotech industry in the UK are distinct from one another, even though they may share similar characteristics. Consequently it is important to acknowledge that the knowledge economy – at least in relation to biotechnology – cannot be limited to individual countries or even firms, but is constituted by the relationships between such entities. Therefore the knowledge economy is essentially an expansion of linkages between these entities, rather than an inherent characteristic of each entity per se. Thus the pursuit of regional or national based knowledge economy policies will not produce the desired effects unless they focus on expanding the number of extra-locational connections and inter-linkages.

Regarding the specific hypotheses, they were addressed in different analytical chapters of the thesis. The first hypothesis was examined in Chapter 5, which covered the analysis of secondary data on the biotech industry.

H1: There are ‘knowledge economy’ concentrations because successful innovation depends on dynamic (i.e. across time) and systemic (i.e. across organisations) processes embedded in and across space.

This chapter showed that there were four specific concentrations of biotechnology in the UK designated as East Anglia; Berkshire, Buckinghamshire and Oxfordshire; Inner London; and Eastern Scotland using the NUTS2 scale. They all had a higher than average number of biotech organisations (i.e. firms, university departments, PROs and service providers) and a number of other notable knowledge features. The four locations could be crudely split between the more ‘regional’ concentrations of East Anglia and Berkshire et al and the more ‘urban’ concentrations of Inner London and Eastern Scotland, although each was still distinct from the others. In seeking to explain these concentrations it was evident that social proximity (see Boschma 2005) was the most crucial factor, which then led to an explanation based on the theory of dynamic systems. Perhaps most interesting was the differences between knowledge features at different spatial scales, indicating that these factors were not necessarily positioned or embedded at the most local or smallest scale (NUTS3 in this case). Overall though this data showed that there was little support for the argument that local knowledge specificity is crucial (see McKelvey 2004) or that local knowledge was linked into global biotech nodes (see Coenen et al 2004). Rather it supported the view that local knowledge was relatively unimportant by itself and that innovation processes depended upon inter-spatial linkages (see Breschi et al 2001; Leibovitz 2004).

The second hypothesis was explored in Chapter 6 dealing with the analysis of the primary data collected using a mixed methods survey.

H2: Successful innovation in the knowledge economy depends on place-specific dynamic and systemic processes because different types of knowledge (including supply and demand) originate in different places and at different scales necessitating interaction both within and beyond concentrations.

In particular this chapter concerned the relationship between the dynamics of knowledge and space in the innovation system. Although there were place-specific innovation processes, these were not necessarily limited to the local or regional scale, but cut across these scales to enable innovative actors access to a wide variety and diversity of knowledge. Such knowledge originated in different places and had to be acquired by innovators working in specific places and scales, and this entailed working within and beyond these places and scales. It was especially evident in the primary data that actors acquired their knowledge from non-local sources, whether such knowledge consisted of tacit, explicit or commercial forms. The international scale was actually the most frequently accessed by such actors in relation to explicit knowledge and more frequent than local or tacit knowledge. Furthermore, the relationship between explicit and tacit knowledge at these different scales was negative implying that it did not involve the acquisition of international tacit knowledge and then the diffusion at the local scale (see Bathelt et al 2004). Consequently the argument that regional concentrations are successful because of tacit knowledge (see Gertler 2003; Fagerberg 2005) was not strongly supported in relation to the biotech industry. The knowledge processes outlined here showed that

tacit knowledge was acquired from national and international sources more frequently and that the local and international sources did not mix.

The final hypothesis cuts across all three empirical chapters (Chapters 4, 5 and 6) because it explores the specific locational characteristics that contribute to innovation processes across different scales.

H3: The knowledge economy depends on different locations and scales of knowledge because different places have different locational assets that contribute to successful innovation in different ways and therefore necessitate linkages within and between locations.

Chapter 4 outlined the historical background and global context of the UK biotech industry, illustrating how it had developed and been constituted in relation to the US biotech industry. It also showed how dominant the US biotech industry is and therefore the importance of considering the inter-linkages with US firms that were highlighted in the earlier research on European biotechnology (Senker et al 1996; Sharp 1996; Acharya et al 1998; Saviotti et al 1998). This was reinforced in Chapter 5 with the examples of the alliance networks of both Celltech Group plc and Cambridge Antibody Technology plc. However, Chapter 4 also showed how important institutional changes had been in encouraging the biotech industry in the UK (4.3.3), especially international intellectual property rights (IPR), which was supported by the evidence in Chapter 6 on the importance of specific types of IP and government intervention. The emphasis on intellectual property laws and in particular international patents was pronounced (6.4.3.1). Overall this supported the argument

that the linkages between different places and scales was crucial for successful innovation, not least because of the simple fact that the US market dominates global biotechnology (Bibby et al 2003) and therefore the UK biotech industry had to orient itself in relation to it.

The theoretical research on the biotech industry has moved through a number of different conceptual approaches starting with the focus on strategic management in the performance of alliances and collaborations (e.g. Hamilton et al 1990; Chakarabarti and Weisenfeld 1991; Dodgson 1991; Woiceshyn 1995; Deeds and Hill 1996; Powell et al 1996; Powell et al 2004). Building on this literature to some extent, especially in relation to the links between academia and industry (Owen-Smith et al 2002; Chiesa and Toletti 2004; Owen-Smith and Powell 2003), the literature on biotechnology has revolved around innovation studies on academic-industry relationships and technology transfer as well as the importance of different markets and national innovation systems (e.g. Green 1991, 2002; Walsh et al 1995; Sharp 1996; Senker et al 1996; Bartholomew 1997; Martin and Thomas 1998; Saviotti 1998; Saviotti et al 1998; Senker et al 2000). During this period there was also an interest in the importance of 'star scientists' and knowledge spillovers derived from work in the 'new economic geography' (or 'geographical economics') of Krugman and others (e.g. Audretsch and Feldman 1996; Audretsch and Stephan 1996; Prevezer 1997, 2003; Zucker et al 1998, 2002; Audretsch 2002). However, more recently there has been a growing interest in biotechnology in regional studies and economic geography (as opposed to 'geographical economics') that stresses the importance of local *and* global linkages (e.g. Breschi et al 2001; Coenen et al 2004; Cooke 2004b; Leibovitz 2004; Ryan and Phillips 2004; Zeller 2004). Finally, there are a number of scholars

who utilise political economy perspectives like the 'varieties of capitalism' concept (Hall and Soskice 2001) and covering the national and international differences between innovation processes (e.g. Kettler and Casper 2000; Casper and Kettler 2001; Coriat et al 2003; Quere 2003; Loeppky 2004, 2005; Lofgren and Benner 2005).

The *knowledge-space* dynamic builds upon all this research by positioning the innovation process in specific places at the same time that it is embedded across a number of scales from the local through to the global. Thus some places may be more closely tied into other locations and therefore benefit from certain advantages (e.g. external knowledge), whilst others may be more isolated and therefore benefit from a different set of advantages (e.g. knowledge excludability). However, in each case the innovation process incorporates a range and diversity of knowledge that cannot be acquired from the local or even regional scale. Therefore it was vital for innovators to connect across scales to access different sites of knowledge and institutional strength; e.g. it was important for biotech firms to access knowledge on regulations that exist at the national scale and are instituted at this scale. It was the linkages between sites of biotech innovation – e.g. organisations and their inhabitants – which constituted the dynamic and systemic elements in the innovation process. Such relationships were, in turn, constituted by a number of functional (i.e. material), relational (i.e. social) and associational (i.e. interactional) processes that determine their impact on innovation. It was these linkages and connections, at the local, national and global scale, that represent phenomena to be explained, rather than the characteristics of different locations alone.

7.2.2 The Biotech Industry: Fact and Fantasy?

The empirical data collected in this thesis raises a vital question, one that cannot be ignored without leaving some central theoretical and policy concerns unanswered. That is, why is there so much 'noise' about the biotech sector? Perhaps the most significant finding in this thesis is that the biotech industry, whether construed in terms of biopharmaceuticals or the wider application of the biosciences, is relatively small in the UK and across the world. For example, Ernst and Young (2003a: 5) have pointed out that the biotech industry "as a whole has never been profitable". The EC (2004: 1) does estimate that the 'bioeconomy' is worth €1.5 trillion, although the 2005 global biotech report by Ernst and Young (2005) suggests that this is highly optimistic. Instead Ernst and Young report global revenues of $46.5 billion for public companies, which deflates the EC figure somewhat. More importantly perhaps, a significant proportion of this identified revenue comes from a limited number of biopharmaceutical products, whilst a large proportion of other biotech industry pharmaceutical outputs actually consist of chemical products, rather than biologicals.

Several commentators from academia (Nightingale and Martin 2004; Martin et al 2006), government (BIGT 2003; FDA 2004) and industry (Bibby et al 2003; McKinnon et al 2004) have also noted a 'productivity crisis' in the pharmaceutical industry (see **Figure 7.1**).[xxiii] This can be seen as both a cause and consequence of the 'rise' of the biotech industry (see Martin et al 2006). As R&D expenditure increased to $50 billion in 2003 the number of pharmaceutical products has also fallen after a brief rise in the mid-1990s following regulatory changes in the USA that made approvals (especially for orphan products) easier (Nightingale and Martin 2004). During this period biologicals represented a growing proportion – around a third – of

FDA approvals (FDA 2004; McKinnon et al 2004), although there were still less than 10 'biotech' approvals per year between the first product (recombinant human insulin) in 1982 and 2003 (Ashton 2001; Tufts CSDD 2004). It has been claimed that the increasing cost of pharmaceutical product development was the major reason for this 'crisis' (Tufts CSDD 2002, 2004); the current figure claimed is between $800 million and $1.7 billion per product (FDA 2004). However, these figures have been disputed in the past, primarily because they include 'opportunity costs' (see Public Citizen 2001), so do not necessary explain the dearth of 'innovation' (see also NIHCM 2002).

Figure 7.1: Pharmaceutical 'Productivity Crisis'

Source: BIGT 2003.

Alongside the 'productivity crisis' there are concerns about the efficacy and safety of new biological products (Horrobin 2003; Arundel and Mintzes 2004; Joppi et al 2005). Although several organisations (e.g. BIO) and reports (e.g. BIGT 2003) have

claimed that there are a large number of biotech products on the market (over 250 and over 110 respectively), these claims are subject to some criticism (see Pratley 2003). For example, Arundel and Mintzes (2004) argue that there were actually only about 60 biopharmaceuticals approved between 1986 and 2004 for the US and European markets and of these 56% were orphan products for small disease groups (Ashton 2001). In their analysis Arundel and Mintzes (2004: 9) go on to argue that only around a third of the approvals offered 'some advance', an 'important advance' or 'major advance' over existing products. This was better than the 10% for all other drugs, but still meant that two-thirds of biopharmaceuticals were no better than existing treatments (ibid.: 10). In another evaluation, Joppi et al (2005: 895) argued that only 15 out of 61 biotech "products represented therapeutic innovation" with another 22 offering only limited "non-therapeutic advantages". The rest were "me-too" products. However, one distinguishing feature of all these new biotech products is their increased cost for patients and healthcare systems (Rasnick 2003; Joppi et al 2005).

The focus on the biopharmaceutical sector perhaps disguises the broader impact of the biotech industry. However, the focus on this sector is understandable considering the level of profit that such products accrue. For example, Amgen's Epogen product had sales of $8,880 billion in 2002/03 (Nightingale and Martin 2004). Furthermore, the global revenues of the biotech industry – covering public companies only though – stood at $46.55 billion in 2003 (Ernst and Young 2004a) of which around 43 % was derived from only 10 products (WorldPharma 2005). The continuing dominance of this 'blockbuster' model has been questioned (Thayer 2004; Mittra 2005; Martin et al 2006), although the high costs of R&D and marketing excludes smaller companies

from operating throughout the biotech value chain at present. Thus despite declining product pipelines, large pharmaceutical companies still play a central role in the biotech industry and the promise of new biotechnological processes like genomics or pharmacogenetics has not as yet displaced the blockbuster model and may in some ways preclude quick adoption (see Glassman and Sun 2004).

Of particular interest for regional development is the employment opportunities presented by biotechnology, especially in skilled occupations. Again these appear limited. According to Ernst and Young (2005), in 2003 there were around 195,000 global jobs with fewer than 35,000 in Europe. This contrasts with claims of 19,000 in the UK alone by the DTI (1999a) in the late 1990s and 25,885 in 2003 (BIGT 2003). The secondary data analysis in the thesis showed that there were around 43,000 employees in the UK biotech industry in 2003, although this covered total employment and not skilled employment. A consultancy report by Critical I (2005) for EuropaBio – the European trade body – claimed that R&D employment in UK biotech was around 9,500 in 2003. Thus the extent to which the biotech industry contributes to the expansion of skilled employment appears limited and does not justify the notion that it contributes significantly to the promotion of the 'knowledge economy'.

Although skilled employment appears low, the biotech industry may still contribute to regional development through positive externalities and knowledge spillovers and therefore its promotion may still be justified. However, the number of biotech firms has remained fairly static in the UK throughout the 2000s at between 400 and 450 firms (see DTI 2005, 2006). The UK has a relative strength in biotechnology but its

regional spread is highly uneven. The main UK concentrations (over half of all firms) were in just four regions (NUTS2): Berkshire, Buckinghamshire and Oxfordshire; East Anglia; Inner London; and Eastern Scotland. This means that the benefits of the biotech industry accrue to these four regions over and above any other region, which could compound existing disparities between regions in relation to employment opportunities and investment.

7.2.3 The Biotech Industry: Concentrated and Diffused?

Despite the uneven spread of UK biotech firms, the claim that they are embedded in clusters – in the Porterian sense – also requires scepticism especially by national and regional policy-makers. The secondary data showed that there were only four biotech concentrations in the UK. However, even these four locations exhibited very different trends in terms of organisational composition, knowledge bases and knowledge drivers. As the oldest, East Anglia was both small firm and university based, which was similar to Berkshire et al although the latter was also based on large firm as well. In contrast, Inner London was relatively new with a strong service provider sector and university base. This was similar to Eastern Scotland, although the latter had fewer service providers. All four had different strengths and weaknesses that necessitate a more nuanced approach to regional development than the application of one set of policy prescriptions.

It is also important to note that the scale at which these concentrations function was not clear-cut either. Although there were strong correlations between organisations at the smallest scale (NUTS3), further research (see Birch forthcoming.) has shown that

the strength of association did not decline as the scale was enlarged and in some cases it actually increased. These correlations also existed with reference to a number of the knowledge indicators such as number of patents, alliances and journal articles. This would suggest that a focus on the largest scale (NUTS1, equivalent to a GOR) would be as relevant as one that focuses on smaller scales (i.e. NUTS2 and NUTS3).

The differences between locations were also evident in the primary data where respondents in the four concentrations drew upon knowledge from different locations to different extents (see **Figures 6.11, 6.12** and **6.13**, pp.252-254). Most respondents in concentrations (and non-concentrated respondents) drew upon national sources to a similar extent, except for Eastern Scotland respondents who drew upon international sources more often than all other respondents did. This perhaps suggested that Eastern Scotland respondents were more reliant on international knowledge sources than others either because they were located further away from the centres of UK knowledge or because they were more tied into international knowledge networks or markets. The former seems less likely because Inner London respondents also drew more upon international sources than East Anglia and Berkshire et al respondents. However, East Anglia and Berkshire et al respondents drew upon local explicit and tacit sources more than other respondents, which suggested that they were located in concentrations that more closely fit the classic cluster model presented by Porter (1990, 2000; Porter and Solvell 1998) and others.

The lower rating given to international sources by respondents from East Anglia and Berkshire et al also supported this suggestion. The secondary data provided evidence that both regions had a significant number of formal international alliances – 97 and

189 respectively – suggesting that the local sources were less formal. This supported the argument by Bathelt et al (2004) that certain locations represent centres of 'local buzz' that are tied into 'global pipelines'. However, Inner London also had a large number of formal international alliances (95), perhaps as a result of its position as a global city tied into other global cities (Simmie 2004), although Eastern Scotland (another possible global city) only had 30 formal international alliances.

Overall though the primary data did not show that knowledge was spatially embedded in concentrations of biotechnology firms. Neither explicit nor tacit knowledge was localised (nor was commercial knowledge). Explicit knowledge, particularly for 'innovator' respondents, was internationally focused, whilst tacit knowledge was nationally focused with international sources still more common than local ones. This confirmed neither the literature on the importance of localised linkages in cluster theories (e.g. Porter 2000) nor the importance of the binary embedding of local and global knowledge (e.g. Coenen et al 2004; Cooke 2004a). Furthermore it contradicted the broader literature on the importance of localised tacit and explicit knowledge to innovation (Asheim and Gertler 2005; Fagerberg 2005). The data did show that tacit knowledge was more localised (than international) for 'service provider' respondents, although national sources were still more common, suggesting that some actors relied upon it more than others do. Overall this meant that knowledge used in innovation was embedded across a number of spatial scales, necessitating a number of extra-local connections for successful product development. One example of this is the development of the biotech product Mylotarg over a 20-year period from initial research through to marketing (see **Figure 6.7**, p.233).

Despite the low rating respondents given to localised sources of knowledge, they rated the quality of network forums (i.e. social, business) and organisations (i.e. trade bodies) highly in their regions. There might be a simple reason for this. It may be that such activities did not represent sources of knowledge per se, but rather an environment in which respondents could affirm their activities and reinforce their social position (e.g. as members of a 'biotech industry'). Such activities could therefore represent the sites of institutional isomorphic processes (see DiMaggio and Powell 2004) through which respondents develop a shared sense that they belong to a 'community of practice' (see Henry and Pinch 2000). However, this is mainly speculation based on personal experiences at bioscience networking events. As for other regional assets, transport links were rated highly, which supported the argument that innovators were tied into extra-local networks and therefore need easy access to those other locations (Simmie 2003).

Finally then, a particularly interesting finding was that the relationship between explicit and tacit knowledge location was strongest at the local scale for 'non-clustered' respondents; i.e. those outside of the four main concentrations. In contrast for 'clustered' respondents the strongest explicit-tacit relationship was at the international scale, although it was also strong at the national scale. Because explicit and tacit knowledge are not binary distinctions, but are rather co-constituted (see Senker and Faulkner 1996), this suggested that the argument that locations act as repositories of 'local buzz' (i.e. tacit knowledge) tied into 'global pipelines' (i.e. explicit knowledge) (Bathelt et al 2004) may be too simplistic. Instead the findings here implied that 'clustered' actors drew upon international and national explicit and tacit knowledge more than 'non-clustered' actors did. This finding was reinforced by

the negative relationship between locally-based and internationally-based explicit and tacit knowledge. This may be because 'clustered' actors work in sectors (e.g. therapeutics) that were highly complex and reliant upon specific, analytical knowledge and capabilities that cannot be sourced from only one location. Instead they need to be tied into wider, national and international, knowledge networks and spaces. This means that localised, face-to-face contact may not be as essential to innovation as has been suggested (e.g. Fagerberg 2005), at least for the biotechnology industry.

7.3 CONCLUSION

Numerous perspectives on the biotechnology industry are possible. Two opposing ends of the spectrum can be summarised as follows. On the one hand it has huge potential to both create wealth and ameliorate a number of problems (social, health or otherwise) and therefore we need to adopt an optimistic view, as one survey respondent argued. On the other hand it is an industry surrounded by an inordinate amount of hype and unfulfilled potential that detracts resources and attention away from other possible solutions to our problems (social, health or otherwise). In some ways the former leads into the latter because the technological potential highlighted by proponents functions to attract resources and investment on the basis of future expectations. In their Triple Helix model, Etzkowitz and Leydesdorff (2000: 117) have argued that:

> "The classic legitimation for scientific research as a contribution to culture still holds and military and health objectives also remain a strong stimulus to

> research funding. Nevertheless, the future legitimation for scientific research, which will keep funding at a high level, is that it is increasingly the source of new lines of economic development."

Furthermore, Michael and Brown (2003) have argued that these expectations play a part in the subsequent 'failure' of biotechnology to fulfil its vaunted potential, although it may still produce a good return on investment despite this failure. However, the hype surrounding biotechnology (see Caulfield 2000; Helen 2004) may also obscure the wider impact it has on fields outside of the high profile sectors like therapeutics such as biopharmaceuticals.

In theoretical terms, biotechnology is an interesting object of research because it is an industrial sector that is not yet established and may yet never reach its lauded potential, depending on your point of view. As an example of the knowledge economy it usefully illustrates a number of difficulties with the concept that have persisted from its emergence in the 1960s through to the current policy agenda pursued in the UK and European Union. Does knowledge or profit drive the pursuit of innovation? If so, does knowledge depend on wealth? If it does depend on wealth, as Sokol (2003, 2004) argues, then this has major implications for economic development both in developed and developing economies. It would suggest that the possibilities of upgrading less-favoured regions, for example, are going to be limited since they already suffer from regional uneven development and wealth disparities. How useful is the concept of knowledge economy then? Perhaps it represents the culmination of the neoliberal project (see Peck 2001) since it originated in the work of scholars dedicated to 'liberal' tenets such as Hayek, von Mises and Machlup as well

as Michael Polanyi and Daniel Bell (Hodgson 1999; Hull 2000). Perhaps it heralds a new era of enlightened capitalism in which a significant proportion, although not all, benefit from being 'knowledge workers' who do "make our money from thin air" (Leadbeater 1999: viii; also Brint 2001). However, either way it would appear that the benefits of the knowledge economy will be limited to a small proportion of the population – a third at most according to Webster (2001) – whilst the majority work within other forms of industrial or service employment (see Thompson et al 2001). Such concerns are central to policy-making.

CHAPTER 8

POLICY IMPLICATIONS:

WHITHER THE KNOWLEDGE ECONOMY?

8.1 INTRODUCTION

If the notion that the world economy has both globalised and regionalised over the past few decades (see Storper and Scott 1995; Scott 2000; Scott and Storper 2003) is to be understood properly, we need to refer to the vertical (i.e. intra-organisational) and horizontal (i.e. inter-organisational) integration of production across distributed locations (Gereffi 1999; Henderson et al 2002). It is therefore important to consider how regional economic development is bound up in a set of processes embedded not only within the local and even national scale, but also the international scale. In particular regional development appears to depend upon extra-local linkages as well as the connections that combine local, national or global production and distribution processes, embedding organisations in local, national and global institutions (see Dicken et al 2001; Coe et al 2004).

The 'local' and the 'global' processes in the knowledge economy and especially the biotechnology industry are perhaps more pronounced than in other sectors. For example, despite arguments that the biotechnology industry is largely concentrated in intra-linked, embedded 'clusters', the empirical evidence for these claims is more limited (Coenen et al 2004; Leibovitz 2004; see also Malmberg 2003; Malmberg and Power 2005). The thesis supports this more limited and hopefully nuanced

perspective. Thus although locational characteristics contribute to the innovation system, the collective and social processes of knowledge production within and across organisations, institutions and actors produces a spatially-constituted 'virtuous' feedback mechanism and infrastructure (see Asheim and Gertler 2005; Fagerberg 2005; cf Malmberg and Power 2005). In interpreting the implications of such spatial relations it is necessary to consider the links between local, national and global actors in meaningful ways that explain regional development as a consequence of locational attributes, relational linkages and interactional processes. This contrasts with a previous emphasis on the endogenous basis of knowledge, learning and innovation derived from the work of Schumpeter, Penrose, evolutionary economists and others (Best 2001; Cooke 2002c; Boschma 2004; Fagerberg 2005; Cooke and Leydesdorff 2006). Instead it is necessary to consider the effect of the interface between local, national and global places, systems and processes that constitute regional development (e.g. Bathelt et al 2004).

Consequently, the theoretical and empirical basis of this thesis raises a number of concerns around the pursuit of 'knowledge economy' policies such as those built into the 2000 Lisbon Agenda or the particular regional and national policies on the biotech industry in the UK. As outlined in the thesis conclusion (Chapter 7), the state of the biotech industry is not robust with some questioning the 'revolutionary' claims around biotechnology (Nightingale and Martin 2004) and its potential contribution to healthcare (Rasnick 2003; Arundel and Mintzes 2004; Joppie et al 2005) and in particular economic development. The latter is of most concern here in this discussion of the policy implications raised by the thesis conclusions and research findings. It is especially notable that the research and human investment in biotechnology has, so

far at least, not produced a viable (i.e. profitable) industrial sector based on biotechnology (see Ernst and Young 2003a; Lawrence 2006). Nor has this produced a noticeable impact on regional development in the most pertinent regions of the UK or Europe; i.e. less-favoured regions or old-industrial regions. Considering the expense and continuing uneven development of such regional economies, it is surprising that biotechnology and the knowledge economy more generally are offered as potential opportunities (Swyngedouw 2000; Sokol 2003). This chapter will therefore outline a number of ways that the thesis can critically contribute to the ongoing debate around regional development and the policies encouraged and engaged in around the knowledge economy and biotechnology.

8.2 POLICY-MAKING IN THE KNOWLEDGE ECONOMY

8.2.1 Cluster Policy Implications

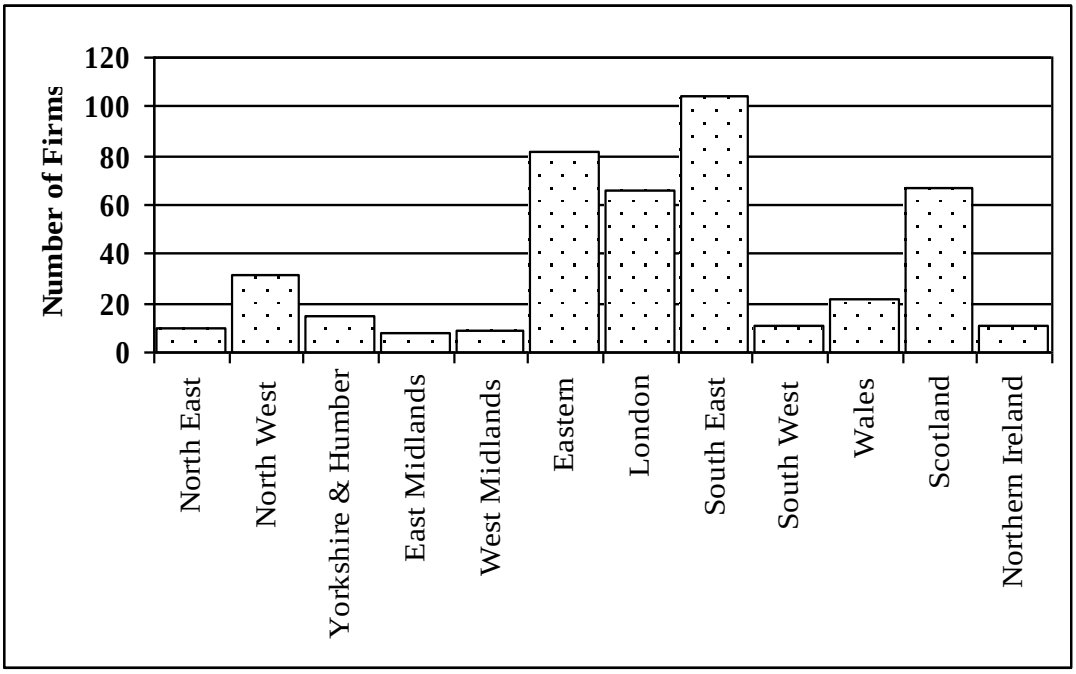
One initial concern is that the current UK government has seized upon the notion that national competitiveness – itself a contentious term (Budd and Hirmis 2004; Turok 2004; Bristow 2005) – and therefore economic growth in Britain are dependent upon the expansion of a 'knowledge economy' (see DTI 1998, 1999c; Brown 2005). In the 1998 Competitiveness White Paper, *Our Competitive Future*, the government outlined how geographical and social organisation – e.g. clusters and networks – promote both regional productivity and regional development (see also HM Treasury 2001). In subsequent policy initiatives the government has therefore sought to encourage such organisational forms and capacity. For example, in 2000 they introduced an Innovative Clusters Fund to finance incubation and cluster infrastructure by regional

development agencies (RDA), which they complemented a year later with a Regional Innovation Fund (DTI 2003: 102-3). Across these cluster policies the position and importance of biotechnology has been pronounced with two Department of Trade and Industry reports concerning biotechnology clusters produced in 1999 called *Biotech Clusters* (DTI 1999a) and *Genome Valley* (DTI 1999b). Alongside the DTI, other government departments have produced policy documents that seek to promote cluster developments in Britain, such as the DETR (now ODPM) *Planning for Clusters* report (DETR 2000), the ODPM *Our Towns and Cities* report (ODPM 2000[2004]), and the Treasury's *Lambert Review* (HM Treasury 2003).

Consequently the promotion of clusters can be seen as a crucial aspect of regional development policies across multiple government departments as well as regional agencies like the RDAs in England and Scottish Enterprise in Scotland; in particular as a means for promoting the knowledge economy (HM Treasury 2001; DTI 2003). Specific cluster-oriented policies include legislation for Business Planning Zones to ensure "flexible planning regimes" for high-technology clusters in disadvantaged areas alongside a regional policy framework that encourage flexibility at the local policy level (HM Treasury et al 2003: 34). Part of this flexibility comes from the establishment of the English RDAs in 1999, which had a budget of £1.7 billion in 2003/04, and the subsequent reforms to their financial structures (HM Treasury 2001: 46-7). Most RDAs have identified biotechnology, in one form or another (e.g. biosciences, life sciences, healthcare), as a key sector in their regional economic strategies, no matter what the size of the sector in their region. For example, the South West Regional Development Agency (SWRDA) has identified biotechnology as an 'emerging' sector even though the secondary data in the thesis showed that there were

only 11 biotechnology firms in that region. Another instance is the North West Development Agency (NWDA) which identified healthcare (and biotechnology) as a key sector even though the data shows only 31 biotechnology firms. More than in the South West, but significantly lower than would be expected for such a regional policy emphasis (see **Figure 8.1**).

Figure 8.1: 'Regional' Distribution of Biotechnology Firms



Source: Various (see p.97).

RDA policy in relation to the biotechnology industry appears over-enthusiastic with the focus on localised industrial clusters not only problematic because of the small number of biotechnology firms, but also in light of further findings from the secondary and primary data considered here. First, and in contrast to the cluster perspective, it is possible to illustrate the importance of national and global inter-linkages over local ones in the development of biotechnology products, especially

biopharmaceuticals. Although the number developed by British firms is limited, one case study suffices to illustrate this point, that of Mylotarg® co-developed by Celltech Group plc (now part of UCB Pharma). Mapping the relationships involved in its development reveal that it arose from a diverse and diffused number of organisations and actors (see **Figure 6.7**, p.233).

Secondly, the primary data shows that there were stronger localised associations between explicit and tacit knowledge for 'non-clustered' respondents and stronger national and especially international associations for 'clustered' respondents. This implied that clustered respondents drew upon national and international based knowledge more often, although there were differences between different concentrations. In some ways this contradicts the argument that clusters facilitate inter-linkages between local and global knowledge (e.g. Bathelt et al 2004) because there were also strong negative associations between locally and internationally based explicit and tacit knowledge. Overall, it was possible to argue that non-clustered respondents were the ones tied into localised knowledge and that such close spatial proximity was relatively unimportant for most actors. Consequently the focus on cluster policies may prove problematic for many regions because it could lock them into a particular set of relationships and expectations that prove hard to break.

8.2. Regional Policy Implications

Regional policy in the UK has its origins in the late 1920s with the establishment of the Industrial Transference Board designed to encourage the movement of workers between regions. Subsequent overcapacity and unemployment problems led to the

Special Areas Acts of 1934 and 1937 and the 1945 Distribution of Industry Act, which sought to aid industry and emphasise the positioning of industry in areas where workers already lived (Tondl 2001; Adams et al 2003; Armstrong and Taylor 2004). Since then the latter policy dimension has been dominant, although the position of regional policy in government agendas has often fluctuated. During the late 1940s and 1950s there was little interest in it, although this changed in the 1960s when regional policy sought to address (a) the perceived decline of UK economic performance, and (b) concerns about the excessive growth of Greater London. During the 1980s this regional policy drive was dismantled as it became embedded in industrial policy focused on competitiveness, rather than social issues, especially in relation to science and technology: e.g. the 1993 *Realising Our Potential* White Paper (Potts 2002; Armstrong and Taylor 2004).

Current regional policy (post-1997) continues to emphasise the importance of science and technology, especially in terms of improving productivity, which is highlighted by the government as the main factor affecting regional GDP difference (HM Treasury 2001; HM Treasury et al 2003). A series of Spending Reviews (1998, 2000, 2002) have been directed at improving the performance of UK regions and reducing regional 'growth rate' disparities, although not absolute disparities (see Adams et al 2003: 5). The government has argued that productivity accounts for around 60% of these regional economic disparities (HM Treasury 2001), which in turn is characterised as the effect of five drivers including skills, investment, innovation, enterprise and competition (HM Treasury et al 2003). However, this emphasis on productivity has been criticised for a number of reasons. First, it relies upon a narrow evidence base derived from mainstream economic sources embodying both an

ahistorical and asocial understanding of regional development and performance (Forthergill 2005). Second, the lack of concern with differences in industrial structure and divisions of labour – both continuing issues in regional development – mean that the policy focus on productivity ignores the "elementary observation that different industries and services have different levels of value added per head" (Fothergill 2005: 663; see also Bristow 2005).

Since regional policy has focused on the endogenous features of different locations, it has promoted economic performance (i.e. competitiveness) above other aspects of regional development (i.e. sustainability, in the strong as opposed to weak sense – see Chatterton 2002). First, as the secondary data presented and discussed in Chapter 5 illustrates, specific concentrations of biotechnology exhibited different characteristics. For example, some regions were university-based, whilst others are firm-based, whilst the relationship between knowledge factors (e.g. patents, alliances) and organisations was relatively similar across three different scales (NUTS1, NUTS2 and NUTS3) (see also Birch forthcoming). Consequently the representation of all regions as atomistic and bounded territories ignores the variety of regional composition and importance of multiple scales (see Phelps 2004). Second, the primary data showed that most knowledge, whether explicit, tacit, or commercial, was not localised. In particular, explicit knowledge was international, whilst tacit and commercial knowledge were national, although still more international than local. It is therefore important to emphasise that innovation processes operate across multiple spaces and scales that necessitate linkages between such dimensions above a focus on endogenous qualities.

8.2.3 National Policy Implications

One possible reason why regional policy is so focused on competitiveness and productivity may be that it has been closely tied to national policy. For example, competitiveness has been the dominant policy concern for over two decades, at least since the founding of the US Council of Competitiveness in the early 1980s by the Reagan administration (see Tyson 1992; also http://www.compete.org/). It has been an increasing concern, despite being a contentious concept (Krugman 1996; Kitson et al 2004; Bristow 2005), across a number of different regional, national and supranational scales and across many different countries. In academic and policy discourse it is defined as the ability to produce goods/services for international markets and the ability to maintain and/or increase living standards (Tyson 1992; Krugman 1996; Rosamond 2002; Budd and Hirmis 2004; Kitson et al 2004; Turok 2004; Bristow 2005; Cantwell 2005). National UK policy seems to have focused on competitiveness because of the assumption that globalisation has endangered the economic performance of countries because they have become more 'open' to external trade, therefore driving the expansion and illustrating the importance of export-based production and services (Porter 2003). Thus the economic development of regions and nations has been constructed and constituted as a consequence of the performance of these locations in a global competitive market, characterised by the expansion of global inter-linkages and inter-dependencies across these regional and national economies (see Brown 2005; also The Sapir Group 2005).

Part of the conceptualisation of economic performance as a consequence of locational (e.g. region, nation, trade bloc) competitiveness, means that these locations are

assumed to be competing for a share of global markets (Gardiner et al 2004). The characterisation of poor competitiveness of the European Union, in comparison to the USA, appears to be a self-confirming explanation for the lower levels of economic growth in the EU because the major global market is the US market. Consequently, any competitiveness policy designed to secure a greater share of global markets would, by definition, be aimed at securing a greater share of the US market and therefore sustaining the dominance of the US economy. In particular this means sustaining the technological solution, product development and organisational change that secure a greater share of this market (see Harvey 2003, 2005). For example, the global pharmaceutical and now biopharmaceutical markets are dominated by the North American market which represents 50 % (Thayer 2004) and 60 % (Bibby et al 2003) of world sales respectively. Consequently countries are forced to adopt the institutional features of US capitalism such as the emphasis on particular types of innovation processes (see Cooke 2004d) or specific intellectual property rights (Drahos and Braithewaite 2002). This process is not simply one-way, however, with the USA increasingly adopting regulatory changes pursued by the EU to ensure competitiveness in pharmaceutical production (see Abraham and Reed 2002, 2003).

A critical look at the concept of competitiveness reveals it to be a contentious concept because it is largely derived from the idea that locations (e.g. regions, nations) compete against one another, as would firms, for global market share. Despite being a problematic notion, the ‘competitiveness agenda’ has come to dominate government policy in developed economies (see Slaughter and Rhoades 1996). In this agenda, the market is presumed to exist as an external environment in which firms, economic actors and even locations operate and compete; according to Schoenberger

"competitiveness simply describes the result of responding correctly to market signals" (quoted in Bristow 2005: 286). Instead, markets can be conceptualised as instituted processes – as Polanyi (1957) and others have suggested – in that the specific decisions and subsequent behaviour of actors constitute markets; i.e. they are internally produced.

Since the biotech industry in the UK was unevenly spread, its systemic and dynamic development compounds the unequal concentration of firms and other organisations around the country (see **Figure 5.16**, p.195). The changing processes of interaction over time mean that the competitiveness of the national biotech industry is constituted by the operation of a small number of organisations in a limited number of places, primarily in the South-east and East of England, and, to a lesser extent Central Scotland. Consequently these regions come to represent the basis for national competition in the global biotechnology market, embedding the uneven spatial relationships further and the uneven access to and distribution of knowledge-based production factors like skilled labour, R&D investment and intermediate services (e.g. knowledge-intensive business services). These 'growth regions' thereby dominate national industrial and competitiveness policy precluding other regions from 'competing' in the same value-added sectors because such sectors necessitate an enormous historical investment in specific infrastructure. For example, these geographically uneven processes benefiting some regions at the expense of others have led, according to Jamie Peck (2001), to interest-rate policies that seek to control inflation in the South-east of England and London, but have led to manufacturing job losses in the North of England (Harvey 1999).

8.2.4 Supranational Policy Implications

Simultaneous with the national agenda, policy at the European supranational level mirrors the changes in emphasis on the importance of competitiveness and the knowledge economy both with the 2000 Lisbon Agenda and the follow-up Sapir Group formed in 2002. In their report the Sapir Group outlined their aims as driving Europe to "become the most competitive and dynamic-knowledge-based economy with sustainable economic growth and greater social cohesion" (The Sapir Group 2005: 962). These are exemplified in the present EU interest in the promotion and expansion of the 'bio-economy' as a crucial part of this development of the knowledge economy. Thus the EU Science and Research Commissioner, Janez Potočnik, claims that the "life sciences and biotechnology are significant drivers of growth and competitiveness" (EC 2005: 1), whilst more broadly the OECD (2005: 1) has started an 18-month project to "design a bioeconomy policy agenda for governments". The push to adopt a specific set of policies oriented towards promoting the knowledge economy, particularly in relation to biotechnology, entails a number of problematic issues concerned with the possibility of regional, national and supranational path dependency and lock-in to this agenda.

First of all, although there has been an ongoing theoretical and research concern with the concepts of path dependency and lock-in in economics (e.g. Dosi 1988; Arthur 1989, 1999) and regional studies (Boschma 2004; Hassink 2005; Hudson 2005), this has tended to focus specifically on innovation, technology and knowledge, rather than the overall economic system. Regional path dependency and lock-in are constituted through the operation of particular industrial sectors and the associated organisational

and institutional actors that embed processes of production, consumption and exchange embodying the features of the particular sector. Since regional performance has previously benefited from these embedded processes there is little motivation to change them; instead they are strengthened and deepened producing lock-in. This sits uneasily with the focus on regional drivers of growth and innovation because such a view privileges the status quo – e.g. current technologies and organisations (see Chapman et al 2004) – meaning that regions lose the capacity to adjust or adapt to changing circumstances (Hassink 2005). When they do change they become subject, once again, to another set of embedded processes of production, consumption and exchange.

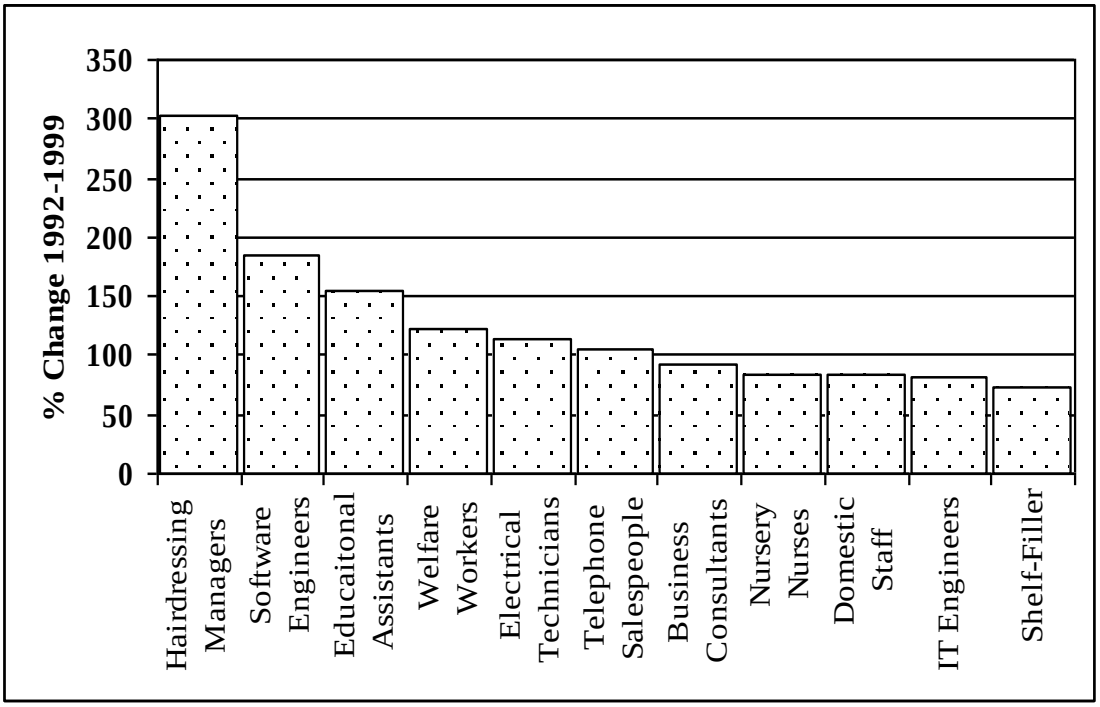
Secondly and alongside the concern with micro-scale path dependency and lock-in, there are broader questions about the problem of a wider, macro-scale lock-in to specific economic strategies, ideologies and processes encompassed by neoliberal discourse and policy (Peck 2004) or the 'American economic model' (Kitson 2005). The work of Jamie Peck and Adam Tickell, jointly and individually, stresses the need to understand neoliberalism not as a "naturalized, external force" producing globalising effects, but instead as a "self-actualizing" discourse through which specific policies and structures are institutionalised as prescriptions for economic development; e.g. deregulation, privatisation, 'free' markets (Peck and Tickell 2002: 382). Such development is unevenly spread as neoliberal processes form their own localised identity through local policies, decisions and discourses (see Harvey 2005). Overall there is a threat that the pursuit of deregulation, privatisation and other neoliberal policies "produces a neoliberal "lock-in" to public-sector austerity and

growth-chasing economic development" (Peck and Tickell 2002: 394), where the consequences for certain regions are placed above those of other regions.

Thus there are a number of criticisms that can be levelled at the 'knowledge economy' focus in supranational policy. The main one is that the extent of knowledge-based employment is significantly lower than such policy prescriptions emphasise. This has been shown in the thesis in relation to the level of skilled employment in the biotech industry, which, at around 10,000 in the UK, may not warrant the public and private investment in the sector. Furthermore 46% of all British jobs are in sectors where under 15% of the workforce are graduates, mainly in the service sector (Hepworth and Spencer 2003: 7), whilst some of the highest growth occupations in the UK during the 1990s – i.e. the height of the 'knowledge economy' – were in hairdressing, educational assistants, welfare workers, telephone sales, nursery nurses, domestic staff and shelf-filling (see **Figure 8.2**).

These changes during the height of the 'dot.com' era illustrate the dominance of employment growth in sectors that cannot be characterised as hi-tech (e.g. hairdressing), high skilled (e.g. shelf-fillers) or dependent upon high levels of R&D investment (e.g. educational assistants), although they are all no less central to economic performance. In contrast it is possible to argue, as Thompson et al (2001) have done, that the high growth sectors of employment in developed economies have been in sectors dependent upon personal and communicative skills rather than knowledge skills.

Figure 8.2: Highest Growing Jobs in the UK 1992-1999



Source: Adapted from Thompson (2004: 30).

A major question is whether the employment potential of the UK biotech industry warrants the material investment, especially in light of the finding that there were only around 43,000 direct jobs and 10,000 'knowledge economy' jobs (i.e. in R&D employment). Employment was also limited to an average of around 1200 total jobs per region with the South-east and East of England containing over half of all biotech employment (23,000).[xxiv] Furthermore a significant proportion of the total university employment in 'biotechnology' departments was also concentrated in the South-east and East of England although this time including London. In these circumstances, any focus on promoting the knowledge economy as the source of future growth and performance at a supranational level reinforces the advantages of such regions, especially when policies are pursued alongside those that promote the clustering and concentration of such 'knowledge' sectors. The focus of policy on these 'growth

regions' leads to the possibility that policies promoted as part of the knowledge economy are directed at a small number of already dominant and high performing regions at the expense of less favoured regions (see Swyngedouw 2000).

From the primary data analysis it would be difficult to contend that there is one overall 'knowledge economy' at the supranational scale that is effective for promoting regional economic performance and development across all regions. For example, survey respondents drew upon explicit sources of knowledge from more demand-side sources (i.e. customers, competitors) implying that they drew upon this 'market-making' knowledge, in innovation terms (see Fagerberg 2005), as opposed to tacit sources. In turn, respondents drew upon tacit knowledge from more supply-side sources (i.e. universities) and informal networks, implying that such knowledge was important for 'technology-making'. In particular, respondents highlighted the more 'trusting' environment provided by the academic environment, which suggested that such tacit sources require an element of trustworthiness to reduce uncertainty (see Gertler 2003). However, the relationship between explicit and tacit sources cut across both demand-side and supply-side sources suggesting that in both cases there was a need for both explicit and tacit knowledge, rather than an approach that adopts a false dichotomy between both forms of knowledge (see Senker and Faulkner 1996).

8.3 CONCLUSION

The policy implications discussed above raise a number of issues for social scientists about their role in society. The relative dearth of technical, as opposed to market, innovations in relation to biopharmaceuticals – the predominant focus of much

biotechnological endeavour – may threaten the future funding of science and technology, not only in the biosciences but also in other new technologies: e.g. nanotechnology. However, it may also distract, more importantly for social scientists, resources and attention from other forms of problem solving such as economic, social and political change (see Duster 2003). What role then do social scientists play in the promotion and maintenance of a particular approach to understanding the social world and offering solutions to social problems? Thus by writing about the biotech industry and focusing on its potential and possible impacts, social scientists can unreflexively extol the benefits of such technologies to the world, society and regional development, despite the contentious nature of such claims. This thesis shows that the biotech industry has not – as yet at least – warranted such investment of time and money. This is not to say that it will not in the future, just that by focusing on it now we may inadvertently produce a self-fulfilling prophecy in which we help to embed a specific technological paradigm or technological trajectory that entails a number of problematic characteristics (see Ferraro et al 2005; Ghoshal 2005; Birch 2007).

The challenge then comes from recognising where biotechnology both as an industry and a technological paradigm may have an important impact on our lives. In part, this may arise accidentally during the everyday processes of the dynamics between knowledge, space and technology. Or, more likely perhaps, it may arise as a consequence of deliberate policy initiatives pursued for particular agendas. In the latter case it is important to consider the specific intention and motivation behind these agendas in order to address the broader concern with economic development that benefits all equally, rather than producing and embedding further inequality and uneven development. In part then, this is a political issue and social scientists need to

acknowledge this in order to avoid adherence to certain policies and politics. The 'knowledge economy' may not exist as it has been constituted and characterised by policy-makers, academics and others, but it can still offer an inspiring vision of society. It is question of how we separate this vision (or visions) from its actuality (or actualities) that we must ultimately address.

PART III

SUMMARY

Part III provides the final touches to the thesis by outlining the major theoretical conclusions and analytical findings from the research process. As a whole the process has been driven by a theoretical and methodological framework that sort to concentrate on the 'basics' of the innovation process, namely the types, forms and sources of knowledge that successful innovators access along a particular biotechnology value chain. As such it has shown that the knowledge economy is built upon a dynamic that combines knowledge and spatial processes, which means that a focus on the internal operations of any innovation system will occlude the important external inputs. However, to conceive of them as 'external' misses the point. They are as much part of the innovation process as the 'internal' features because they directly impact on the success or failure of innovation. Consequently we can conceive of innovation as the effect of a *knowledge-space* dynamic which operates across different scales and is embedded in different places, all of which contribute in some way to the specificities of innovation.

APPENDICES

APPENDIX 3.1 MIXED METHODS SURVEY CODING FRAME

QUESTION	ANSWER	CODE
SECTION A: Relationships		
1. Please rate how often you read information from the following sources.		
Manufacturers	No information	0
READMAN	None	1
	1-2 times a year	2
	Intermittently	3
	Regularly	4
	All the time	5
Competitors	No information	0
READCOM	None	1
	1-2 times a year	2
	Intermittently	3
	Regularly	4
	All the time	5
Suppliers	No information	0
READSUP	None	1
	1-2 times a year	2
	Intermittently	3
	Regularly	4
	All the time	5
Customers	No information	0
READCUST	None	1
	1-2 times a year	2
	Intermittently	3
	Regularly	4
	All the time	5
Business Consultants	No information	0
READCONS	None	1
	1-2 times a year	2
	Intermittently	3
	Regularly	4
	All the time	5
Universities	No information	0
READUNI	None	1
	1-2 times a year	2
	Intermittently	3
	Regularly	4
	All the time	5

Public Research Organisations	No information	0
READPRO	None	1
	1-2 times a year	2
	Intermittently	3
	Regularly	4
	All the time	5
Regulators	No information	0
READREG	None	1
	1-2 times a year	2
	Intermittently	3
	Regularly	4
	All the time	5
Trade Associations	No information	0
READTA	None	1
	1-2 times a year	2
	Intermittently	3
	Regularly	4
	All the time	5

2. Please indicate where these sources of information are produced.

Local	No information	0
LOCLREAD	No sources	1
	A few sources	2
	Some sources	3
	A lot of sources	4
	Most sources	5
National	No information	0
NATREAD	No sources	1
	A few sources	2
	Some sources	3
	A lot of sources	4
	Most sources	5
International	No information	0
INTREAD	No sources	1
	A few sources	2
	Some sources	3
	A lot of sources	4
	Most sources	5

3. Please rate how often you talk to people from the following sources.

Manufacturers	No information	0
PPLMAN	None	1
	1-2 times a year	2
	Intermittently	3
	Regularly	4
	All the time	5
Competitors	No information	0
PPLCOMP	None	1
	1-2 times a year	2
	Intermittently	3
	Regularly	4
	All the time	5
Suppliers	No information	0
PPLSUP	None	1
	1-2 times a year	2
	Intermittently	3
	Regularly	4
	All the time	5
Customers	No information	0
PPLCUST	None	1
	1-2 times a year	2
	Intermittently	3
	Regularly	4
	All the time	5
Business Consultants	No information	0
PPLCONS	None	1
	1-2 times a year	2
	Intermittently	3
	Regularly	4
	All the time	5
Universities	No information	0
PPLUNI	None	1
	1-2 times a year	2
	Intermittently	3
	Regularly	4
	All the time	5
Public Research Organisations	No information	0
PPLPRO	None	1
	1-2 times a year	2
	Intermittently	3
	Regularly	4

	All the time	5
Regulators	No information	0
PPLREG	None	1
	1-2 times a year	2
	Intermittently	3
	Regularly	4
	All the time	5
Informal Networks	No information	0
PPLINFOR	None	1
	1-2 times a year	2
	Intermittently	3
	Regularly	4
	All the time	5

4. Please indicate where these people are located.

Local	No information	0
LOCLPPL	No sources	1
	A few sources	2
	Some sources	3
	A lot of sources	4
	Most sources	5
National	No information	0
NATPPL	No sources	1
	A few sources	2
	Some sources	3
	A lot of sources	4
	Most sources	5
International	No information	0
INTPPL	No sources	1
	A few sources	2
	Some sources	3
	A lot of sources	4
	Most sources	5

5. Please rate the importance of the following sources of finance to innovation.

Personal Finance	No information	0
FINPF	Not important	1
	Not very important	2
	Slightly important	3
	Important	4
	Very important	5

Business Angels	No information	0
FINANGEL	Not important	1
	Not very important	2
	Slightly important	3
	Important	4
	Very important	5
Venture Capital	No information	0
FINVC	Not important	1
	Not very important	2
	Slightly important	3
	Important	4
	Very important	5
Government Awards/Schemes	No information	0
FINGOV	Not important	1
	Not very important	2
	Slightly important	3
	Important	4
	Very important	5
Bank Loans	No information	0
FINBANK	Not important	1
	Not very important	2
	Slightly important	3
	Important	4
	Very important	5
Contract Work	No information	0
FINCONTR	Not important	1
	Not very important	2
	Slightly important	3
	Important	4
	Very important	5
Equity Investments	No information	0
FINEQUIT	Not important	1
	Not very important	2
	Slightly important	3
	Important	4
	Very important	5

6. Please indicate where the finance sources are based.

Local	No information	0
LOCALFIN	No sources	1
	A few sources	2
	Some sources	3
	A lot of sources	4
	Most sources	5

National	No information	0
NATFIN	No sources	1
	A few sources	2
	Some sources	3
	A lot of sources	4
	Most sources	5
International	No information	0
INTFIN	No sources	1
	A few sources	2
	Some sources	3
	A lot of sources	4
	Most sources	5

SECTION B: Location

7. Please rate the quality of the following in your region.

Labour Costs	No information	0
COSTLAB	Awful	1
	Bad	2
	Ok	3
	Good	4
	Excellent	5
Housing Costs	No information	0
HOUSCOS	Awful	1
	Bad	2
	Ok	3
	Good	4
	Excellent	5
Traffic Levels	No information	0
TRAFFIC	Awful	1
	Bad	2
	Ok	3
	Good	4
	Excellent	5
Access to International Airport	No information	0
AIRPORT	Awful	1
	Bad	2
	Ok	3
	Good	4
	Excellent	5

Access to National Road Network	No information	0
ROAD	Awful	1
	Bad	2
	Ok	3
	Good	4
	Excellent	5
Access to Rail Network	No information	0
RAIL	Awful	1
	Bad	2
	Ok	3
	Good	4
	Excellent	5
Business Advice Services	No information	0
BUSADVIC	Awful	1
	Bad	2
	Ok	3
	Good	4
	Excellent	5
Social Forum	No information	0
SOCIALF	Awful	1
	Bad	2
	Ok	3
	Good	4
	Excellent	5
Corporate Forum	No information	0
CORPF	Awful	1
	Bad	2
	Ok	3
	Good	4
	Excellent	5
Professional Associations	No information	0
PROFASS	Awful	1
	Bad	2
	Ok	3
	Good	4
	Excellent	5
Cost of Premises	No information	0
COSTPREM	Awful	1
	Bad	2
	Ok	3
	Good	4
	Excellent	5

Availability of Premises	No information	0
AVAPREM	Awful	1
	Bad	2
	Ok	3
	Good	4
	Excellent	5

8. Please indicate the importance of the following geographic labour markets in the recruitment of innovative staff.

8a. Technical & Scientific Staff

Local	No information	0
LABTECLO	Not important	1
	Not very important	2
	Slightly important	3
	Important	4
	Very important	5
National	No information	0
LABTECUK	Not important	1
	Not very important	2
	Slightly important	3
	Important	4
	Very important	5
International	No information	0
LABTECIN	Not important	1
	Not very important	2
	Slightly important	3
	Important	4
	Very important	5

8b. Managerial Staff

Local	No information	0
LABTECLO	Not important	1
	Not very important	2
	Slightly important	3
	Important	4
	Very important	5
National	No information	0
LABTECUK	Not important	1
	Not very important	2
	Slightly important	3
	Important	4
	Very important	5

International	No information	0
LABTECIN	Not important	1
	Not very important	2
	Slightly important	3
	Important	4
	Very important	5

9. Please rate the importance of the following in attracting technical and managerial staff to your region.

Wages	No information	0
WAGES	Not important	1
	Not very important	2
	Slightly important	3
	Important	4
	Very important	5
Working Conditions	No information	0
WORKCON	Not important	1
	Not very important	2
	Slightly important	3
	Important	4
	Very important	5
Regional Reputation	No information	0
REGREP	Not important	1
	Not very important	2
	Slightly important	3
	Important	4
	Very important	5
Social Network	No information	0
SOCIONET	Not important	1
	Not very important	2
	Slightly important	3
	Important	4
	Very important	5

10. Please rate the importance of the following internal sources of knowledge to innovation.

Technical & Scientific Staff	No information	0
TECSTAFF	Not important	1
	Not very important	2
	Slightly important	3
	Important	4
	Very important	5

Managerial Staff	No information	0
MANSTAFF	Not important	1
	Not very important	2
	Slightly important	3
	Important	4
	Very important	5
Scientific Methodology	No information	0
SCIMETH	Not important	1
	Not very important	2
	Slightly important	3
	Important	4
	Very important	5
Management Practices	No information	0
MANPRAC	Not important	1
	Not very important	2
	Slightly important	3
	Important	4
	Very important	5
Experience with Equipment	No information	0
EQUIP	Not important	1
	Not very important	2
	Slightly important	3
	Important	4
	Very important	5
Facilities	No information	0
FACILITY	Not important	1
	Not very important	2
	Slightly important	3
	Important	4
	Very important	5
Collaborations	No information	0
COLLAB	Not important	1
	Not very important	2
	Slightly important	3
	Important	4
	Very important	5

SECTION C: External Influences

11. Please rate the importance of the following to innovation.

National Patent	No information	0
NATPATEN	Not important	1
	Not very important	2
	Slightly important	3
	Important	4
	Very important	5
International Patent	No information	0
INTPATEN	Not important	1
	Not very important	2
	Slightly important	3
	Important	4
	Very important	5
Other Intellectual Property Rights	No information	0
OTHERIPR	Not important	1
	Not very important	2
	Slightly important	3
	Important	4
	Very important	5
Commercial Secrecy	No information	0
COMSECRE	Not important	1
	Not very important	2
	Slightly important	3
	Important	4
	Very important	5
Employee Skills & Experience	No information	0
SKILL	Not important	1
	Not very important	2
	Slightly important	3
	Important	4
	Very important	5

12. Please rate the importance of the following markets for innovations.

Local	No information	0
DEMLOC	Not important	1
	Not very important	2
	Slightly important	3
	Important	4
	Very important	5

National	No information	0
DEMNAT	Not important	1
	Not very important	2
	Slightly important	3
	Important	4
	Very important	5
International	No information	0
DEMINT	Not important	1
	Not very important	2
	Slightly important	3
	Important	4
	Very important	5

13. Please rate the effect of the following UK government interventions on innovation.

Procurement	No information	0
PROCURE	No effect	1
	Little effect	2
	Some effect	3
	Effect	4
	Vital effect	5
Tax Policy	No information	0
TAXPOL	No effect	1
	Little effect	2
	Some effect	3
	Effect	4
	Vital effect	5
Health Policy	No information	0
HEALTH	No effect	1
	Little effect	2
	Some effect	3
	Effect	4
	Vital effect	5
R&D Policy	No information	0
RDPOL	No effect	1
	Little effect	2
	Some effect	3
	Effect	4
	Vital effect	5
Public Science Investment	No information	0
PUBSCI	No effect	1
	Little effect	2
	Some effect	3
	Effect	4

	Vital effect	5
Intellectual Property Laws	No information	0
IPRREG	No effect	1
	Little effect	2
	Some effect	3
	Effect	4
	Vital effect	5
Health & Safety Regulations	No information	0
HEALTHRE	No effect	1
	Little effect	2
	Some effect	3
	Effect	4
	Vital effect	5

APPENDIX 3.2: BIOTECHNOLOGY PRODUCT SAMPLE

Product Type	Sector	Launch / Approval Date	MAIN Research Location	Second	Third	Fourth
Vaccine	Therapeutic	2001	East Anglia	USA	Austria	x
Test	Diagnostic	2003	East Anglia	x	x	x
Test	Diagnostic	2005	Gloucestershire, Wiltshire & N. Somerset	x	x	x
Food test	Diagnostic	1998>	South Western Scotland	x	x	x
Treatment	Therapeutic	1993>	Cheshire	x	x	x
Animal resistance	Agriculture	1988>	East Anglia	x	x	x
Test	Diagnostic		East Anglia	East Anglia	x	x
Animal resistance	Agriculture	1984>	East Wales	East Wales	East Anglia	x
Animal resistance	Agriculture	1984>	East Wales	East Wales	Kent	x
Animal resistance	Agriculture	1984>	East Wales	East Wales	USA	x
Vaccine	Therapeutic	1994	Surrey, East and West Sussex	x	x	x
Test	Diagnostic	2000	Berkshire, Buckinghamshire and Oxfordshire	Ireland	x	x
Biomaterial	Therapeutic	2001>	Inner London	Inner London	East Anglia	x
Marine test	Agriculture	2001>	Eastern Scotland	x	x	x
Platform technology	Services	1999>	East Anglia	East Anglia		x
Software	Services	1999>	East Anglia	East Anglia		x
Animal test	Agriculture	1995>	Eastern Scotland	x	x	x
Drug delivery	Therapeutic	1999	Surrey, East and West Sussex	Inner London	x	x
Biomaterial	Services	2001	West Midlands	West Midlands	x	x
Platform	Services	2002	Kent	x	x	x

technology						
Platform technology	Services	1997>	Kent	Outer London	x	x
Treatment	Therapeutic	200	Inner London	Eastern Scotland	x	x
Test	Diagnostic	2000	East Anglia	South Africa	x	x
Platform technology	Services	1998	North East Scotland	x	x	x
Platform technology	Services	1990>	East Anglia	x	x	x
Platform technology	Services	1990>	East Anglia	East Anglia	USA	USA
Platform technology	Services	1990>	East Anglia	x	x	x
Drug	Therapeutic	2002	East Anglia	USA	x	x
Test	Diagnostic	1981>	East Anglia	x	x	x
Drug	Therapeutic	2001	Berkshire, Buckinghamshire and Oxfordshire	Merseyside	x	x
Drug	Therapeutic	2000	Berkshire, Buckinghamshire and Oxfordshire	USA	USA	x
Drug	Therapeutic	1999	Berkshire, Buckinghamshire and Oxfordshire	East Anglia	USA	x
Vaccine	Therapeutic	2000	Berkshire, Buckinghamshire and Oxfordshire	Merseyside	x	x
Test	Diagnostic	1992>	East Anglia	x	x	x
Test	Diagnostic	1992>	East Anglia	x	x	x
Drug (delivery)	Therapeutic	2000	East Anglia	South Western Scotland	x	x
Bioremediation	Environment	2003	Surrey, East and West Sussex	x	x	x

Test	Diagnostic	2000>	Northumberland and Tyne & Wear	x	x	x
Software	Services	2001>	Berkshire, Buckinghamshire and Oxfordshire	Berkshire, Buckinghamshire and Oxfordshire		x
Drug (delivery)	Therapeutic	1995	South Western Scotland	x	x	x
Test	Diagnostic	1999	Berkshire, Buckinghamshire and Oxfordshire	x	x	x
Platform technology	Services	2002>	Eastern Scotland	Eastern Scotland	x	x
Delivery system	Therapeutic	1996>	Eastern Scotland	x	x	x
Platform technology	Services	1996>	Eastern Scotland	France	x	x
Software	Services	1996>	Eastern Scotland	Eastern Scotland	x	x
Platform technology	Services	1996>	Eastern Scotland	West Yorkshire	West Yorkshire	x
Platform technology	Services		East Anglia	x	x	x
Platform technology	Services	2005	Inner London	Inner London	x	x
Platform technology	Services	2002	Kent	x	x	x
Animal feed	Agriculture		Gloucestershire, Wiltshire & N. Somerset	Denmark	x	x
Animal feed	Agriculture		Gloucestershire, Wiltshire & N. Somerset	Denmark	x	x
Treatment	Therapeutic		Northern Ireland	x	x	x

Treatment (delivery)	Therapeutic		Northern Ireland	Ireland	x	x
Treatment	Therapeutic	2001	East Anglia	China	x	x
Test	Diagnostic	1999>	Greater Manchester	Greater Manchester	x	x
Drug	Therapeutic	1986	Outer London	Kent	x	x
Drug	Therapeutic	1986	Outer London	Kent	x	x
Test	Diagnostic		Northumberland and Tyne & Wear	x	x	x
Platform technology	Services	1999>	Inner London	East Anglia	Inner London	x
Treatment	Therapeutic	1984	Berkshire, Buckinghamshire and Oxfordshire	East Wales	x	x
Drug	Therapeutic		Berkshire, Buckinghamshire and Oxfordshire	Gloucestershire, Wiltshire & N. Somerset	x	x
Test	Diagnostic	1998	Surrey, East and West Sussex	x	x	x
Intermediate manufacture	Services	1992	Berkshire, Buckinghamshire and Oxfordshire	x	x	x
Drug delivery	Therapeutic	2000	Shropshire & Staffordshire	USA	x	x
Treatment	Therapeutic	2002	Shropshire & Staffordshire	USA	x	x
Treatment	Therapeutic	2000	Shropshire & Staffordshire	South Yorkshire	Inner London	x
Platform technology		2002>	Greater Manchester	Greater Manchester	x	x
Test	Diagnostic	1997>	Berkshire, Buckinghamshire and Oxfordshire	Berkshire, Buckinghamshire and Oxfordshire	x	x
Test	Diagnostic	2000>	Berkshire, Buckinghamshire and Oxfordshire	Berkshire, Buckinghamshire and Oxfordshire	x	x

Software	Services		Berkshire, Buckinghamshire and Oxfordshire	USA	x	x
Drug	Therapeutic	2002	Berkshire, Buckinghamshire and Oxfordshire	Berkshire, Buckinghamshire and Oxfordshire	Switzerland	x
Test	Diagnostic		Berkshire, Buckinghamshire and Oxfordshire	Berkshire, Buckinghamshire and Oxfordshire	x	x
Animal treatment	Agriculture	2000	Kent	x	x	x
Platform technology	Services	1996>	Bedfordshire & Hertfordshire	x	x	x
Platform technology	Services	1996>	Bedfordshire & Hertfordshire	x	x	x
Animal treatment	Agriculture	2004	East Anglia	x	x	x
Vaccine	Therapeutic	1988	Berkshire, Buckinghamshire and Oxfordshire	Merseyside	x	x
Vaccine	Therapeutic	1993>	Berkshire, Buckinghamshire and Oxfordshire	Sweden	x	x
Drug delivery	Therapeutic		Berkshire, Buckinghamshire and Oxfordshire	Berkshire, Buckinghamshire and Oxfordshire	x	x
Drug delivery	Therapeutic	1993>	Berkshire, Buckinghamshire and Oxfordshire	x	x	x
Vaccine	Therapeutic		Berkshire, Buckinghamshire and Oxfordshire	Merseyside	x	x
Platform technology	Services	1999>	East Anglia	Canada	x	x
Platform technology	Services	1999>	East Anglia	East Anglia	x	x

Test	Diagnostic		Inner London	Cheshire	Ireland	USA
Drug	Therapeutic	2000	Inner London	Cheshire	West Wales & the Valleys	USA
Test	Diagnostic	1997	East Wales	x	x	x
Test	Diagnostic	2000	East Wales	Isle of Man	Canada	x
Test	Diagnostic	1999	East Wales	Denmark	x	x
Platform technology	Diagnostic	2003	Northern Ireland	x	x	x
Bioremediation	Environment	1994>	South Yorkshire	x	x	x
Bioremediation	Environment	1994>	South Yorkshire	x	x	x
Test	Diagnostic	2000>	Hampshire and Isle of Wight	x	x	x
Drug	Therapeutic		Eastern Scotland	Northern Ireland	x	x
Treatment	Therapeutic	1999	USA	East Anglia	x	x
Drug	Therapeutic	2001	Hampshire and Isle of Wight	x	x	x
Drug	Therapeutic		Hampshire and Isle of Wight	Canada	Berkshire, Buckinghamshire and Oxfordshire	x
Platform technology	Diagnostic	2000>	East Anglia	East Anglia	x	x
Test	Diagnostic	2005	Berkshire, Buckinghamshire and Oxfordshire	x	x	x
Treatment	Therapeutic	2001	East Riding	USA	x	x
Platform technology	Services	2005	East Anglia	x	x	x
Test	Diagnostic	1992>	East Wales	Greater Manchester	x	x
Treatment	Therapeutic	2001	North Yorkshire	x	x	x
Test	Diagnostic	1998	East Anglia	Kent	x	x
Test	Diagnostic	1995>	Bedfordshire & Hertfordshire	x	x	x

Treatment	Therapeutic	2002>	Eastern Scotland	USA	x	x
Drug delivery	Therapeutic	2002	East Anglia	USA	x	x
Platform technology	Services		East Anglia	South Western Scotland	x	x

APPENDIX 3.3: BIOTECH PRODUCT CHARACTERISTICS

3.3.1 Location

In relation to the products, around 44 percent of them had R&D that occurred in more than one location in the UK. The two main locations for R&D were East Anglia (23.6%) and Berkshire, Buckinghamshire and Oxfordshire (19.8%). Only three other locations had more than minimal levels; these were West Wales and the Valleys (5.7%), Inner London (5.7%), and Eastern Scotland (8.5%). In relation to the secondary R&D site, where relevant, the most significant sites were again East Anglia (21.3%) and Berkshire, Buckinghamshire and Oxfordshire (14.9%). Another four sites were also important: Kent (8.5%), Inner London (8.5%), Greater Manchester (6.4%) and Eastern Scotland (6.4%).

A cross-tabulation of the primary and secondary R&D locations reveals that products from Berkshire, Buckinghamshire and Oxfordshire represent the most products with a secondary location (30.4% of the total). In these cases 85.7% of the time the primary location was also Berkshire, Buckinghamshire and Oxfordshire. As such the knowledge used in their development, whether internal or external, was locally based. This appears to be the same in most other regional cases, although East Anglia represented a popular secondary location across the board in that only 44% of the primary and secondary locations corresponded.

3.3.2 Sector

Most of the 107 products were derived from only three sectors within the industry: (i) therapeutic, (ii) diagnostic and (iii) services (e.g. platform technologies). Just over a third were therapeutic products (35%), whilst another quarter (25%) were diagnostic and 17 percent were services. Apart from these three sectors, the only other sector represented above a minimal level was the agriculture sectors at nearly 6 percent of the total products.

The three major sectors were concentrated in specific regions of the UK. The therapeutic products came from four regions, although the majority were concentrated in Berkshire, Buckinghamshire and Oxfordshire. The regions were Shropshire and Staffordshire (3 of 36), East Anglia (5), Eastern Scotland (3), and Berkshire, Buckinghamshire and Oxfordshire (12). In the services sector the products were concentrated in Kent (3 of 18), East Anglia (8), and Eastern Scotland (3). Finally the diagnostic sector was concentrated in West Wales and the Valleys (3 of 27), East Anglia (8), and Berkshire, Buckinghamshire and Oxfordshire (6). Of the less represented sectors, agriculture was concentrated in West Wales and the Valleys (50%) and bioinformatic was concentrated in Inner London (33%) and Berkshire, Buckinghamshire and Oxfordshire (33%).

3.3.3 Launch Date

The launch date of the products is sometimes difficult to discover; therefore some of the following is based on an assessment of when a firm started operating rather than an official launch date. Even with this caveat, there are only details for 91 products. The data shows that just over half (50%) of the products were launched between 1999

and 2002. Nearly 10 percent were launched in the 1980s, with the earliest being 1981. Between 1991 and 1998 another 32 percent were launched. Most of the products launched between 1999 and 2002 originated in either East Anglia (11) or Berkshire, Buckinghamshire and Oxfordshire (9).

3.3.4 R&D Influence

Around 45 percent of the products' R&D occurred in external institutions as well as – or instead of - the marketer, of which half occurred in either universities (45.8%) or public research organisations (PRO) (4.2%). Around 40 percent occurred in other firms and the final 10% occurred in multiple settings. Some of this externally conducted R&D also occurred in foreign countries. Around 20 percent of all the products had some form of R&D conducted overseas, with the majority of this taking place in the USA (47.6%) or EU (33.3%).

3.3.5 Overall

Most R&D occurred in two locations: East Anglia, and Berkshire, Buckinghamshire and Oxfordshire. Of these East Anglia appears to be the most open location since where Berkshire, Buckinghamshire and Oxfordshire was a secondary location it invariable relates to a product originating in the same location. East Anglia also represents a significant secondary location, ahead of Berkshire, Buckinghamshire and Oxfordshire, for other regions to draw upon. This may be an indication of the type of product in that therapeutic products predominantly came from Berkshire, Buckinghamshire and Oxfordshire, whilst research and diagnostic products came

from East Anglia. It is also significant to note that the products were launched relatively recently, over 50 percent since 1999.

APPENDIX 5.1: REGIONAL ORGANISATIONAL DISTRIBUTION

NUTS2	FIRMS	UNIVERSITY DEPTS	SERVICE PROVIDERS	PROs
Tees Valley & Durham	4	4	0	0
N' land, Tyne & Wear	6	9	6	0
Cumbria	2	0	2	2
Cheshire	10	0	8	0
Greater Manchester	14	12	14	3
Lancashire	1	3	2	0
Merseyside	4	8	4	0
East Riding	1	3	1	0
N. Yorkshire	9	2	3	1
S. Yorkshire	2	5	5	0
W. Yorkshire	3	8	10	0
Derbyshire & Nottinghamshire	7	9	8	1
Leics, Rutland & Northampton	0	12	5	3
Lincolnshire	1	0	0	1
Herefordshire, Worcestershire & Warwickshire	2	0	3	1
Shropshire & Staffordshire	4	3	1	0
West Midlands	3	12	9	0
East Anglia	65	13	49	15
Bedforshire & Hertfordshire	9	3	21	5
Essex	8	1	1	0
Inner London	62	46	149	12
Outer London	4	4	3	1
Berks, Bucks & Oxon	68	14	50	12
Surrey, E. & W. Sussex	22	6	22	5
Hamps & Isle of Wight	9	5	5	2
Kent	5	1	13	1
Gloucs, Wiltshire & N. Somerset	6	12	13	5
Dorset & Somerset	2	0	2	0
Cornwall	1	0	0	0
Devon	2	6	4	3
W. Wales & the Valleys	11	6	6	6
E. Wales	11	8	4	3
N.E. Scotland	7	7	2	2
E. Scotland	39	14	17	13
S.W. Scotland	18	11	23	5
Highlands & Islands	3	1	0	3
N. Ireland	11	7	5	1
Total	436	255	470	106
Mean	11.8	6.9	12.7	2.9

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ENDNOTES

[i] NUTS1 scales are used by the European Union (EU) to designate areas with between 3 million and 7 million people http://ec.europa.eu/comm/eurostat/ramon/nuts/basicnuts_regions_en.html (accessed December 2006).

[ii] It is also important to emphasise that Schumpeter positioned science and invention as exogenous influences on the firm during his earlier work (Rosenberg 1976; Freeman 1982).

[iii] Some authors raise the obvious point that knowledge was crucial to the Industrial Revolution (e.g. Mokyr 2002) and therefore we could argue that knowledge has always been a central feature of economic development. However, the more relevant discussions around the knowledge economy also focus on specific features of economic change, such as the shift to service sector employment or growth in information technology, as specific features of current trends (e.g. Bell 1973; Castells 1996).

[iv] Godin (2006) provides a list of 75 different 'buzzwords' used between 1950 and 1984 to describe changing industrial structures in developed economies, including the 'knowledge economy'.

[v] As a sidenote it is interesting to point out that Machlup was von Mises doctoral student and an active member of the Mont Pelerin Society, founded by Hayek and von Mises in 1947, along with Michael Polanyi who met Daniel Bell in the 1950s (Hull 2000). According to Hull (2000) the discussions around 'knowledge' that the likes of Machlup, Polanyi and Bell engaged in were a direct response to their view of the dangers of totalitarian ideologies. However, the Mont Pelerin Society, Hayek, von Mises and others are also the forebears of what is now termed neoliberalism – i.e. the unfettered influence of markets on society – which has been identified as an ideology in its own right (Armstrong 2001; Blyth 2002; Harvey 2005).

[vi] This definition includes (1) new information technologies, (2) the importance of science, (3) globalisation, and (4) changing consumption patterns (DTI 1999c: 12).

[vii] The relationship between the public science base and industry has also been problematised in research on conflicts of interest and bias in biomedical research (see Agryres and Liebeskind 1998). This has shown that academic-industry ties influence the likelihood to publish, intellectual exchange, and research agendas (Blumenthal et al 1986) and also that it influences the publication of data from clinical trials (Krimsky 2003).

[viii] The various functional, relational and associational features of the innovation process are illustrated in the **Table** below. As can be seen from the table, each aspect has unique properties that both precludes its designation as the 'single' cause of innovation and precludes ignoring those aspects altogether.

Table: The Functional, Relational and Associational Features of the Innovation Process

	FUNCTIONAL	**RELATIONAL**	**ASSOCIATIONAL**
Growth Conditions	Material	Social	Interactional
Market Advantage	Comparative	Competitive	Complementary
Agglomeration Economies	Scale	Scope	Complexity
Institutional Basis	Hierarchy	Market	Network
Knowledge Source	Internal	External	Iteration
Proximity	Spatial	Organisational	Social

[ix] It is important to note that the NIS literature is broadly speaking technologically determinist in that it ascribes to the long-wave model of technological change or the view that "Capitalism is characterized by unpredictable technological development paths" (Lagendijk 2006: 389). Consequently regions adjust to such changes as well as stimulate them.

[x] The origins of 'old' institutional economics are found in the late nineteenth and early twentieth century work of Thorstein Veblen (1857-1929) who critiqued the concept of 'rational economic man' and argued that institutions represented a repressive force on human creativity (Foster 1991; Hodgson 2005). The later work of John Commons (1862-1945) sought to address this initial negative view of institutions by suggesting that they enable humans to act collectively and therefore lead to economic growth and development; this in turn led to an evolutionary perspective that incorporated cooperation into economic action (Foster 1991; Hodgson 2005). Somewhat in contrast to this approach, 'new' institutional economics developed around the work of Ronald Coase (b.1910) and his famous article on the firm (Coase 1937). This work was developed by Oliver Williamson – who coined the 'new' definition – in the 1970s as an attempt to incorporate the rational actor into an institutional approach (Hodgson 2005) and concerns different modes of organising economic activity.

[xi] GREMI stands for Groupement Europeen des Milieux Innovateurs (Simmie 2005).

[xii] The importance of 'culture' has also been highlighted by a number of authors, particularly AnnaLee Saxenian (1994a, 1994b), whose research showed how Silicon Valley and Route 128 (Boston) had different corporate cultures that affected the development of both regions (see also Gertler 1997).

[xiii] Even if wealth drives knowledge, as Sokol (2003, 2004) contends, we can still argue that the success of regional economies is dependent upon innovation, where innovation is conceived as a process of profit production – e.g. the search or construction of new markets through institutional change (see Birch 2007).

[xiv] There has been a strong interest in value chains and similar approaches since the work of Porter, although often originating in very different fields. For example, there is considerable work on the idea of global commodity chains (GCC) which is derived from the World Systems theory (Hopkins and Wallerstein 1994) and propounded by the likes of Gary Gereffi (1994, 1996, 2001a, 2001b; Gereffi et al 2005). Other perspectives, such as global production networks (GPN) have come out of economic geography (Coe et al 2002; Ernst and Kim 2002; Henderson et al 2004).

[xv] https://fame.bvdep.com/cgi/template.dll?product=1 (last accessed December 2006).

[xvi] Through licensing Cohen and Boyer's patented rDNA technique earned over $200 million between 1975 and 1997 for their two universities and themselves (Dutfield 2003: 138).

[xvii] The dates for the foundation of the Biotechnology Directorate at SERC and Biotechnology Unit at the DTI vary across sources.

[xviii] http://www.merlin-biosciences.com/People/VentureTeam.asp (last accessed December 2006).

[xix] Because origin was based on marketing company, the development of the product could have occurred in a different country.

[xx] Ernst and Young (2004: 17) claim that 50 percent of the 2003 sales of the top 13 blockbuster biologics "initially developed by biotech companies" accrued to 'big pharma'.

[xxi] The first blockbuster biopharmaceutical (Bibby et al 2004).

[xxii] Countries like Germany, Sweden and Denmark had such regimes (Senker et al 2000).

[xxiii] It is important to note that whilst the number of pharmaceutical approvals has declined in recent years, the level of profit has not. McKinnon et al (2004: 3) showed that whilst the number of new drugs

has fallen by 33 % between 1998 and 2002, the “sales potential” of these new drugs has increased by 57 % per drug.

[xxiv] Berkshire, Buckinghamshire and Oxfordshire (9235 jobs), East Anglia (4654), Surrey, East and West Sussex (3721), Hampshire and Isle of Wight (2951), and Bedfordshire and Hertfordshire (2535).