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Regional environments and sector developments: the biotech sector in Oxfordshire

Abstract

This paper explores the interdependence between national policy, the local characteristics of the UK's biotechnology sectoral system of innovation and the growth of Oxfordshire's biotech sector. It considers on the one hand the county's research capacity and on the other its innovation performance. The latter is captured by a series of indicators from a recently completed study of the sector, recording the sector's evolution both in the number of firms and their employment size, their status (independent, merged/acquired), product group and contribution to local employment and wealth creation. It considers the implications of the relative weaknesses in the system of innovation in this sector which relate to an underperformance of its firms in relation to the strength of the science base.

Keywords

Biotech sector, sectoral systems of innovation, regional systems of innovation, Oxfordshire, universities

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1. INTRODUCTION

From industrial districts through islands of innovation to the literature on clusters, studies have explored the link between firms' location and innovation capacity. To a greater or less extent work has been focused on the economics, social relationships, institutional and cultural characteristics of successful regions – those that have concentrations of innovative firms (Cooke et al., 1997; Maskell et al., 1998). In this paper we are interested in the organisational and institutional contexts in which innovation takes place. It uses the regional/local environment of the biotech sector in Oxfordshire as an exemplar of how sectors develop over time in particular places.

The paper explores the interdependence between national policy, the geo-historical characteristics of the locality's institutional configuration in relation to biomedical research and commercial activity and its support infrastructure, and the growth of the county's biotech sector. It considers on the one hand the county's research capacity and on the other its innovation performance. The latter is captured by a series of indicators from a recently completed study of the sector, recording the sector's evolution both in the number of firms and their employment size, their status (independent, merged/acquired), product group and contribution to local employment and wealth creation.

The conceptual focus is as much on how sectoral systems of innovation (see for example Carlsson and Stankiewicz 1991, Carlsson et.al. 1999, Malerba 2002, 2005) function in particular places as it is on regional innovation systems RIS (Cooke, 1992, 1998), a concept which had its origins in national systems of innovation (e.g. Lundvall, 1992 Nelson, 1992). This results from the special characteristics of the biotech sector: Breznitz and Anderson (2006) state that the differences between life sciences and other clusters are the specific requirements relating to the capital infrastructure including laboratory facilities, health and safety regulations, people with formal scientific qualifications and that many innovations come directly out of university laboratories. Typically, a biological agent is discovered in a university lab and is patented – and a licensing agreement with a company is reached. Moreover, Autant-Bernard et al. (2006) found that high levels of scientific activity within a region are necessary in order to sustain a continuous flow of new business creation in the biotech sector.

This paper addresses the research questions: what are the key features of this local sector's development; and, what are the local strengths and weaknesses as a sectoral system of innovation? The paper is based on a combination of sources and data from different research projects undertaken by the authors. The major source of data is a database of Oxfordshire's biotech firms compiled for a European Union FP7 project, HeathTIES (2010-13). The HealthTies consortium aimed to benchmark different European based biotech hubs and draw policy conclusions from that activity[1]. The main partners were Oxfordshire (& the Thames Valley) plus three other European biotech centres Medical Delta (Netherlands), Zurich, (Switzerland) and Biocat (Spain). Data collected by members of the Oxfordshire Economic Observatory (OEO) since the 1990s[2] analysing the biotechnology sector in Oxfordshire provides background to the Oxfordshire case study. The paper assesses the performance of the sector in the county and the quality of the local/regional institutional environment in the national sectoral context[3].

2. INNOVATION, REGIONAL ENVIRONMENTS AND SECTOR GROWTH

Innovation in general is not a linear process, but a system of relations among components (agents, organisations), relationships among these, and their characteristics or attributes (Carlsson et al 1999). Possible relationships are shaped by the country and its configuration in the sense in which kinds of organisations does innovation take place, their sectors and their region/locality. The national system of innovation framework aims to explain the innovation pattern within a system, which has the boundary of a nation (Freeman, 1995). Key agents of the system are firms, the knowledge base such as R&D institutions, technologies and inputs and demand.

Malerba (2002) defines a sectoral system as a set of products and agents carrying out non-market and market interactions designed to bring those products to market. Sectoral systems are based on three building blocks: knowledge and technologies, actors and networks, and institutions (Malerba 2005). They also have their own geography: in some cases a sector starts out in a cluster and then disperses or is dispersed and then firms are attracted to particular locations where conditions for innovation have developed or are increasing over

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[1] http://vrr.healthties.eu/ (accessed November 7 2014)

[2] http:/oeo.geog.ox.ac.uk)

[3] This paper draws on material to be published in Romeo, S and Lawton Smith, H (forthcoming) The Biotechnology System in Oxfordshire: A long history," submitted to "Handbook of Research on Global Competitive Advantage through Innovation and Entrepreneurship" in *Handbook of Research on Global Competitive Advantage through Innovation and Entrepreneurship.* IGI Global

time. In each case connections to other parts of the system also undergo transformation. Carlsson and Stankiewicz (1991) argue that innovation takes place in a network of agents which are involved in the creation and diffusion of technology. The boundary of the sectoral or technological system is a specific technology rather than a particular location or country: hence networks are not place-bound.

Technological systems of innovation are therefore multi-dimensional and multilevel within selection environments, in which variations in activities including the innovation process occur. Examples are market transactions and economic impacts, public policy and developments in scientific and technical knowledge – which affect the search space open to firms and individuals (McKelvey 2004). In the biotech sector, what is important is the extent to which key organisations and institutions work with other parts of the value chain to enable their specific locations to function as places of high efficiency in the creation, transfer and application of knowledge (Breznitz and Anderson 2006) through locally available choices. This includes the presence of anchor firms, in this case R&D and production activities of big pharma (see Feldman 2003). Such a diversity of actors gives rise to a possible range of interacting dominant influences.

Why and when the regional/local level is significant also depends on context. Howells (1997) identifies two ways of analysing regional systems of innovation: a top-down perspective and a bottom-up perspective. The top-down perspective aims to transfer the concept of a national system of innovation at regional level. Every region has some elements that differentiate it from the others and from the national context. Regions can have a strong governance structure such as the Lander in Germany or the "Regioni" in Italy. The bottom-up perspective argues that regions have peculiar features that make them indispensable for innovation. It bears similarity to Marshall's industrial districts using the Lundvall's interactive learning idea. For example, regions are the locus for face-to-face contacts and tacit-knowledge exchanges, which foster the interactive learning process among agents, which, in turn, is a main engine for innovative activities (Asheim 1999).

Whatever the perspective, the regional system of innovation framework lacks clarification on what is a region and in what way a specific region can be labelled as an innovation system (Doloreux et al, 2004). Moreover, the term 'region' has been used for different geographic units of analysis: cities, metropolitan regions, local systems referring to clusters and districts within areas, EUROSTAT NUTS II and III regions, and to supra-regional areas such as the Province of Ontario in Canada and the Province of Wallonia in Belgium.

Cooke (1997) recognizes this problem within the regional system of innovation framework and so divides regions into cultural regions and administrative regions. The latter taxonomy in some countries has been institutionalised by the central government in order to create local administrative bodies with direct powers that can influence public and private investment decisions – in this case in its organisations (firms, universities, other kinds of research institutions) etc. Cooke (1997) argues that a region or local area can be labelled as a regional system of innovation if it has its own learning system, financial capacity, and the existence of tangible and intangible infrastructures.

The learning system is particularly important to connect the productive system (goods and services) with the institutional infrastructures of the region. The regional production system or knowledge exploitation system, which consists mainly of firms, and the regional supportive infrastructure or knowledge generation system, which consists of public and private research and knowledge transfer institutions, are systematically engaged in interactive learning (Asheim et al., 2006). The innovative capacity of a region is strongly dependent on the density and quality of networking within the regional productive system, and between this and the regional supportive infrastructure (Oughton, 1997). Fritsch (2002) similarly argues that an embeddedness in a well-functioning innovation system should result in a relatively high propensity to innovate and a high productivity of efforts in research and development (R&D).

However, the importance of networking within clusters/regions is not empirically proven to be universal (see Wolfe et. al. 2005 and Asheim et. al. 2006 for critiques). Here the word 'cluster' is used interchangeably with concentration and not meant to imply interconnections unless explicitly discussed. Systems analysis (Woolthuis et al 2005) analyses missing elements in what is defined as a system, but such thinking has also been criticised as identifying the symptoms of rather than the underlying reasons for market imperfections which provide the rationale for policy intervention. The framework also suffers from severe shortcomings with regard to practical implementation (Schröter 2009). Moreover, Power and Malmberg (2008) critique the notion of a regional innovation system arguing that the co-presence of research, innovation and value creation must necessarily imply the presence of a system.

Against these reservations, indicators used to examine the evidence of the presence of a local sectoral system of innovation in the biotechnology sector in Oxfordshire. It identifies where interactions can be demonstrated, where there is only evidence of co-presence, and where expected elements of a system are missing.

3. METRICS FOR LOCAL SECTORAL SYSTEM OF INNOVATION AND ANALYSIS OF ITS LONGEVITY

Measuring innovation is a complex task because innovative activities are the results of unpredictable interactions among various actors (Archibugi, 1988). Despite this unpredictability, it is important to identify indicators for innovation as tools of analysis for understanding the effects of innovation on the economy and firms' performance and to plan strategies and policies (Grupp et al., 2004; Smith, 2001). It is also important in evaluating a system to examine how (or if) each of the players are connected in an entire system (Carlsson et al. 1999). Measures can also indicate the quality of a system for example a regional innovation system using the knowledge production function method (Fritsch 2002). This was introduced by Griliches (1979) for measuring the contribution of R&D and knowledge spillovers to productivity growth.

The most common approach to measuring systems of innovation, however, and the one used here is based around three groups of metrics: input metrics such as R&D expenditure and human resources; output metrics such as number of patents and bibliometrics (academic papers); and networking metrics that identify ways of assessing the density and effectiveness of the system networks. A fourth set of metrics has been sometimes used with sectoral system of innovation. This set goes under the label of outcome metrics.

Outcome metrics look at the effect that the system has had on the industry and on the economy as all. The indicators used are those for market penetration such as industry turnover and number of market players; economic benefits such as number of employees in the entire sector or in a specific region in which the sector are analysed and, finally, sector-specific indicators are assessed through evaluation programmes. The set of outcome indicators represent an indication of the ways that the innovation system of a local biotech sector can be measured over time. The overall intent of this paper is to look at how the biotech sector has evolved in Oxfordshire and its impact on the Oxfordshire economy through outcome indicators.

4. THE BIOTECH SECTOR IN OXFORDSHIRE: HISTORY AND DYNAMICS

4.1 Context and methodology

Oxfordshire is one of the three key UK academic centres where biotech research centres and departments are located (Sainsbury Report 1999): Oxfordshire, Cambridgeshire and Central Scotland. This showed that those three locations held more than a third of the entire UK biotech industry. London is also a significant player in the sector with some 800 pharma, biotech and services companies[4]. The history of the pharmaceutical and biotechnology industry (during the paper the term biotech will be used) forms the basis of the methodology for interpreting the evolution of the regional environment in the biotech sector in Oxfordshire. Examples of input metrics, output metrics, networking metrics and finally outcome metrics are used to assess the evolution of the biotech systems (its extent and systemness) data collected for HealthTies is used in to show the longevity and the growth of the biotech cluster of firms in Oxfordshire and indicators of (some) system elements.

Also included is data and information collected on the biotech sector since the mid-1980s. In the first study (1984-199) data was collected on individual firms through survey questionnaires of 164 high tech firms in Oxfordshire (Lawton Smith 1990). Information was obtained on origin of firms, their performance and also on engagement with other organisations (firms, universities, national laboratories and so on) and on formal network support. Other studies focused specifically on the sector in Oxfordshire (see for example Lawton Smith et al. 2000; Lawton Smith, Romeo and Bagchi-Sen 2008).

The HealthTIES database of biotech companies used in this analysis was collated by OEO (2010-2013) for the HealthTIES consortium to provide a picture of a geographically focused

[4] http://www.liftstream.com/london-cluster.html#.VM4Ty52sXWQ (accessed February 1 2015)

sectoral system of innovation - the biotech cluster in Oxfordshire & the Thames Valley. This was used to demonstrate how this is related to technological change in the form of the increasing number of firms in the cluster (Edquist, 1997). It identified the number of companies that belong to the system and some indicators of performance (outcome metrics).

Examples of input metrics

During the first part of the 2000s, continuous long term inputs into a system of innovation in Oxfordshire took the form of government investment supported university and biotech research centres. Examples of input metrics show that the University of Oxford has one of the largest biotech environments in Europe with more than 2500 members of staff and 800 postgraduate students in medical sciences, pharmaceutical studies and biotechnology degrees (Lawton Smith, 2014).

The county's strengths lie in the highly skilled labour market, which is associated with high levels of entrepreneurship (Fritsch and Schindele 2011), and which is also related to the presence of Oxford's universities. Over half (55%) of Oxford's working-age residents hold degrees, which ranks fifth of all 380 local authority districts in England (Lawton Smith et. al. 2013). Thus in this cluster of firms, Oxfordshire has the specific requirement of people with scientific qualifications (Breznitz and Andersen 2006).

Oxford University is important in sustaining regional specialisations (and in diversification), through its international research and industrial contacts and the mobility of its staff (Waters and Lawton Smith 2012). Its technology system, characterised as a passive regional system (Perry and May 2007) is underpinned by the dirigiste national government and to some extent by EU research funding (HealthTies 2013). The science base is reinforced by significant national and EU research awards to Oxford University and to the county's research laboratories. Through Oxford University, Oxfordshire is a growing focal point of the UK national innovation system (Lundvall 1992, Nelson 1992) in biomedical research. It has been estimated that £1.2bn has been invested in the Oxfordshire biotech sector.

Recently, weaknesses in the local sectoral system of innovation are demonstrated by the need to push for a bioescalator on Oxford university-owned land in an Oxford hospital and research complex at the edge of the city. The County has a lack of dedicated incubators. Its one small incubator (Diagnox) (12 tenants, 279 m^2 letable space) is full. Although there are other incubators in the county, bioincubators do not form a significant element for inputs into support for the life science sector as the case in other regions (Mobius Life Sciences Fund 2010). The plan for the bioescalator emphasised facilitating new models of business growth, lower running costs for businesses, proximity to world class research and clinical excellence, an ethos to drive innovation and economic growth and collaboration between key partners. It has now assumed political significance, and is included in the Oxfordshire Innovation Support programme being led by the Local Enterprise Partnership, the body responsible for policy coordination and action, and includes public and private sector organisations[5].

Output metrics

An indicator of the region's strength in knowledge is the number of professors with an H-index of 30 and above[6] and the number of scientific papers they publish. The HealthTIES study identified that Oxford University's academics published more papers in the peiord 2001 to 2010 in health related subjects than the three other main European regions: Oxford 2264, Biocat 789, Medical Delta 1171 and Zurich 1190. This represents high levels of scientific activity (Autant-Bernard et al 2006).

Networking metrics

It is also necessary to specify components of the system under consideration, other than the presence of the research base and the growing number of firms (Carlsson et al 1999, Malerba 2002, 2005). Examples of network metrics in Oxfordshire relate to the formal networks that have contributed to the density and effectiveness of system networks. Co-existing with strengths in research and skills but only in part related to biomedical research at the local level (national but working at the local level, Carlsson et al 1999) are output indicators which demonstrate the growth of a cluster of biotech research and biotech firms. Networking activities have contributed in part to some elements of systemness. Two formal networks have been particularly important. The first established in 1997 was the Oxfordshire

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[5] http://www.oxfordshirelep.org.uk/cms/ (accessed November 10 2014)

[6] The H-index is a measure which combines publication output and impact through the number of citations of an academic paper.

BiotechNet. This was founded by the Oxford Trust with national government funding (initial funding of £20,000 from the Department of Trade and Industry in 1997, followed by £400,000 from the Biotechnology Mentoring and Incubator Challenge fund in 1998) as well as national and local private sector support (including that from local firm Oxford Instruments, and nationally from Barclays Bank and 3i). It's aim was to double the number of jobs to 2000 by making it easier for scientists to exploit their ideas through interactions between firms and the university/science base (Lawton Smith et al. 2000). This organisation folded in 2005 when funding dried up. Since then the OBN (formerly the Oxford Bioscience Network) has taken over the role of being the focal point of networking in the sector in Oxfordshire.

OBN started as a region-specific sectorally focused institution but is increasingly connecting the Oxfordshire biotech cluster to a more national and international sectoral system of innovation (Malmberg 2005). It is through OBN acting as a convenor of firms, investors and suppliers that the HealthTIES project is making a difference, most immediately through inter-regional, inter-firm linkages contributing to what exist as components of Oxfordshire's sectoral innovation system.

OBN achieves this by networking, holding events and coordinating elements in the supply chain. Between 1999 and 2010, OBN hosted around 150 networking events for the bioscience industry in and around Oxfordshire, including networking events in London and elsewhere in the Thames Valley. OBN argues (OBN 2011) that these have contributed to the Oxfordshire Life Sciences cluster's development as a social entity and therefore as a fully functioning cluster. Networking outcomes include gaining new business, obtaining funding, acquiring competitor intelligence and scientific knowledge. Clustering around Oxford has also led to the OBN Purchasing Scheme. Agreements with 25 suppliers have been made by OBN to reduce margins to gain a larger share of available business, for example, in couriers, recruitment, IT services and financial services. This Scheme has now been extended to OBN members elsewhere in the UK (Lawton Smith 2011).

However, UK and the Oxfordshire Life Sciences system is weak with respect to inputs in the form of there being a financing gap in 'innovation capital' for early-stage companies. This restricts the progression of companies that are creating the innovations which big pharma will develop through in-licensing and acquisition, and is a particular problem in the UK compared with the rest of Europe (OBN 2011). In order to overcome this gap, OBN has started its own fundraising advisory service, OBN Capital Advisors. It organises match-making meetings with investors at BioTrinity (below) and at regular networking meetings to which investors are invited.

Its major event, BioTrinity, is an annual trade fair which has grown rapidly over the years, and in 2014, was held in London, reflecting both its growth and international focus[7] as well as the need to be close to the venture capital community. The event brings together SMEs with big pharma and their corporate ventures. In 2014 1000 delegates from over 625 companies from 34 countries across Europe, Asia and North America took part with a strong attendance from investors and pharma partners. In a sector such as the life sciences/healthcare sector, the organisation of a sectoral innovation system (from research through to healthcare delivery) takes place within an international context. Big Pharma firms are global players with developments in many countries. Hence, any region with a cluster of biotech firms has to be seen within that context and BioTrinity puts Oxfordshire firmly "on the map" internationally.

Outcome metrics

The indicators of outcome metrics used here relate to the number of biotech companies established since the early 1900s, the start-up rate, the status of firm, the size distribution, rate of formation by product group, number of employees and turnover.

Oxford University has been a source of system development through the incubation of new firms in the cluster. Isis Innovation, Oxford University's technology transfer company, has incubated several biotech companies in Oxfordshire since it was formed in 1997. However, other companies started in Oxfordshire that were independent of the university (Lawton Smith 2005, Lawton Smith et al 2008). This dynamism has been encouraged during the second part of the 2000s and the period between 2010 and 2013.

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[7] http://www.obn.org.uk/press-release/biotrinity-establishes-itself-as-the-leading-biopartnering-and-investment-conference-in-europe-2/

Identification of the evolution of the sector establishes the basis for the emergence of a system. The HealthTies database is composed of 211 companies and records in Oxfordshie the date of formation. The oldest company, in terms of date of incorporation, is Sucampo Pharma, established in 1903. The second oldest company, Baxter Healthcare Ltd, was established in 1948. The number of companies incorporated between 1948 and 1989 remained low as showed in Figure 1.

Figure 1 here

The biotech sector in Oxfordshire started to take shape during the 1990s as was highlighted in studies undertaken at the end of 1990s. It was, however, during the period 2000-2009 that its cluster of firms became a recognised worldwide biotech hub, comprising mostly small local firms but also a number of international companies which acquired local firms (Lawton Smith et al 2008). As shown in Figure 1, almost 100 companies were established during that period. The period 2010-2013 continues that pattern with 36 companies established in four years.

Figure 2 shows the incorporation ratio by period. The ratio has been calculated as a ratio between the total number of companies established during the period and the number of years of the period.

Figure 2 here

Figure 2 confirms the performance of the biotech sector in Oxfordshire in terms of newly formed companies during the period 2000-2009 with a ratio of 9.9. The period 2000-2013 shows a similar trend, 9 companies per year. However, not all the companies of this group are still active. 27 of them have been dissolved or are along the process of insolvency. It is also important to highlight that 35% of these companies have been acquired or have merged with other companies as showed in Figure 3. This is a normal pattern in the evolution of the biotech sector, particularly in the UK (Kowelle 2011). The Oxfordshire cluster, however, shows remarkable stability.

Figure 3 here

Of the population of firms, 65% of all companies remain independent and 30% have been acquired by international biotech companies. Only two companies went through a merger process. The acquired firms still possess their own brand name but they are branches of medium-sized and large-sized biotech companies. As a third of companies were acquired by international biotech companies, this is sign of how Oxfordshire is an attractive location for the biotech sector internationally. It also indicates how the cluster is changing with inputs to the local technological/sectoral system (Edquist 1997) increasing from outside the UK, in the form of ownership changes particularly by US companies (Lawton Smith et al 2008), and the investment that brings as the change in components of a sectoral system of innovation (Carlsson et al 1999, Malerba 2002, 2005).

The growth of the biotech cluster in Oxfordshire is also due to the presence of innovative small-sized companies, often spin-outs from universities and research centres. Using employment data for 172 companies (81.5% of all companies), the number of small enterprises (less than 50 employees) is 130, being 75.5% of all companies, as is shown in Figure 4.

Figure 4 here

The companies analysed can be classified into two main groups of research and product lines: Life Science and Medical Technology. The Life Science group accounts for 56% of all companies. The Medical Technology group accounts for the remaining 44%. Looking at the evolution of these two groups over time in terms of company formation, it is possible to note that the Life Science group, initially the largest one, becomes progressively less dominant as is shown in Figure 5. This also indicates how the characteristics or attributes of the system are changing (Carlsson et al 1999).

Figure 5 here

Figure 5 shows how the formation of medical technology companies started to increase during the 1990s. That trend continued during the 2000s and, grew stronger during the period 2010-2013. Since the late 1990s, the contribution of information and communication technologies and electronics into the medical sector has strongly shaped research and product development in the sector, hence the sectoral system of innovation (Malerba 2002, 2005).

The increase in the of formation of medical technology companies reflects that phenomenon and also highlights the innovative capacity of the entire system to adjust to being always at the cutting-edge of the research trends, essential following the technological trajectory of the sector (Edquist 1997). Moreover, as a large percentage of firms have international markets (Lawton Smith et al 2008), it emphasises this key characteristic of the cluster.

The 172 companies for which data was available in 2011, accounted for 12499 employees. In 1996, it was estimated that 2500 people worked in the biotech sector. Therefore, the compound annual growth rate of the sector employment was 11.3% between 1996 and 2011. This significant growth in employment is shown in Figure 6.

Figure 6 here

The concentration of firms reached its peak performance in 2008 when there were 13474 employees. This favourable situation is reflected in the number of companies formed in 2007, 12, the second most dynamic year in terms of companies newly established. In fact, in 2012, 16 companies were incorporated. It is further reflected in the growing number of employees in 2012, 13083. It is also important to highlight that the sector has not been immune to the worldwide economic crisis. The overall number of employees decreased during the years 2009 and 2010. However, the effect of the economic crisis has not been dramatic as is shown above and in Figure7.

Figure 7 here

The total turnover carried on increasing from 2001 to 2011 with a weak decrease between 2009 (£2.33bn) and 2010 (£2.31bn). This is a sign of a resilient system, a resilience that lies in its maturity and innovation capacity – for example in its university research (as a potential source of new technology and firms) and the skills base.

A further component of any system of innovation is the knowledge and learning links between firms and the local research base (Lundvall 1992). However, in spite of the co-location of the exceptionally strong research base and a growing number of university spin-outs as well as other firms, the pattern of university-industry interaction is mixed (Lawton Smith and Bagchi-Sen 2010). While Oxford’s universities are a key locational factor and advantage, proximity has been found not to be a main source of interactions other than those of an informal nature. Most formal links between the firms and Oxford University were with university spin-outs (51 out of 142 firms in 2008).

5. CONCLUSIONS

This paper explores the extent to which the biotechnology sector in the Oxfordshire-Thames Valley region has evolved as a geographically focused sectoral system of innovation. It has drawn mainly on systems of innovation literature as a research compass (e.g. Carlsson et al 1999, Malerba 2002, 2005, Edquist 1997). Empirically it has done this through the use of a series of metrics as indicators for innovation drawing on Grupp et al. 2004, and Smith 2001).

Using these metrics to measure some indicators of sectoral systems of innovation, the paper shows how there are some elements of an interconnected system of different players – academia, government, and businesses – within Oxfordshire that have enabled the continuous growth of the biotechnology sector as in becoming a sectoral system of innovation in the geographic area under scrutiny. These indicators, as exemplified by the case study would allow comparison of best practice in other areas.

One of the contributions of this paper is to record the performance of the sector over time. It has been shown that since the establishment of the first company in 1903, the sector has grown in number of companies, number of employees, and turnover becoming a very important biotech hub for the UK and Europe. The sector has demonstrated its resilience and robustness being almost untouched by the economic crisis which started in 2007-2008. It has also shown that a private sector organisation, rather than one in the public sector, can drive productive interconnections. In Oxfordshire OBN represents and drives interaction between local, national and international actors.

However, after establishing the components of the local system (Carlsson et al., 1999), it has demonstrated that there are weaknesses that limit performance of this sectoral system of innovation (Malerba 2002, 2005) as it is localised in Oxfordshire. These are in part related to it being a cluster that is underpinned by national funding rather than there being an orchestrated RIS (Cooke 1992) in which local administrative bodies influence both public and private investment decisions. Missing also are big pharma firms whose presence in other regions provide opportunities to biotech firms for local networking and learning from an anchor firm (Feldman 2003). However, Oxfordshire is shown to be staying at the leading edge of science and technology through the formation of university spin-out companies and the publication performance of its world leading professors.

The implications of these findings are therefore, that in spite of this strong evolution, the policy question that requires debate revolves around how to ratchet up the ambitions of the actors who might influence local sectoral performance. The HealthTIES project explored this theme by identifying the strengths and weaknesses in the local area where attention needed to be focused to particularly in terms of entrepreneurial capability of the sector: on increasing the growth in the number of start-ups and their survival. Also needs to be addressed is what seems to be a major inhibitor to the sector's development as mentioned above – that of a lack of large enterprises' R&D centres in the county.

In order for policy to be effective, further research is needed that informs decision-making such as on the intended and unintended outcomes of the national and local policy framework. This should reflect on what have been the past outcomes of measures to capitalise on both the private sector and universities.

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