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Bio-clusters as Co-evolutionary Developments of High Tech, Venture Capital and Socio-Political Institutions: A Historical Perspective of Cambridge and Scotland

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Abstract: Bio-clusters have been at the centre of regional dynamics in the last ten years. The fact that they allow innovation and competitiveness to emerge through intense interactions between various agents in close geographic proximity has stimulated the interest of policy-makers with aspirations to establish biotechnology presence in their regions. However, this paper conceives bio-clusters as historical developments of the social division of labour which co-evolve with biotechnology, venture capital (VC) and socio-political institutions. In doing so, it focuses on the empirical cases of Cambridge and Scotland, critically taking on board a recently developed industry life cycle model. The argument is that co-evolutionary development of bio-clusters is not static but dynamic, involving, nevertheless, certain pre-conditions, discontinuities and contradictions.

Keywords: Bio-clusters, Innovation, Regional Dynamics, Division of Labour, Public Policy

1. INTRODUCTION

Bio-clusters have been at the centre of regional dynamics in the last ten years. The fact that they allow innovation and competitiveness to emerge through intense interactions between various agents in close geographic proximity (Rychen and Zimmerman, 2008; Cooke, 2007a,b; Asheim and Coenen, 2005; Niosi and Banik, 2005; Morosini, 2003) has stimulated the interest of policy-makers with aspirations to establish biotechnology presence in their regions. Indeed, this is not surprising since as Cooke (2004: 915) stresses '…biotechnology is seen as a *sine qua non* of regional economic development'. What is surprising is that bio-clusters are either considered to be linear developments of Porter-type policies which seek to stimulate innovation flows and learning (Mcdonald et al, 2007) or a-historical phenomena, occurring and evolving by accident when an innovation problem sequence arises (Metcalfe et al, 2005; Coombs et al, 2003; Foster and Metcalfe, 2001).

This paper conceives bio-clusters as historical developments of the social division of labour which co-evolve with biotechnology, VC and socio-political institutions. In doing so, it focuses on the empirical cases of Cambridge and Scotland, critically taking on board a recently developed industry life cycle model (Avnimelech and Teubal, 2006). The argument is that co-evolutionary development of bio-clusters is not static but dynamic, involving, nevertheless, certain pre-conditions, discontinuities and contradictions.

The paper is structured as follows. Section 2 critically reviews current approaches to bio-cluster development, stressing the importance of historical pre-conditions in the life cycle of biotechnology geographical agglomerations and regional innovation systems (RIS). Section 3 presents the methodology of empirical research. Section 4 examines the cases of Cambridge and Scotland bio-clusters. Section 5 builds on empirical evidence to point out the co-evolutionary process of bio-cluster formation and the historical role of the social division of labour. Section 6 concludes that this dynamic and historical process involves pre-conditions but also discontinuities and contradictions.

2. CURRENT APPROACHES TO BIO-CLUSTER DEVELOPMENT

In the growing literature of regional innovation and competitiveness, two schools of economic thought have been having an arguably prominent impact on policy-makers. The first is static and derives from the view of Michael Porter on clusters (Porter, 1990, 1998, 2000, 2003). According to this school of thought, bio-clusters are major policy tools for producing high value products and health-related services that support high wage jobs in regions. Therefore, the focus of governments should be on encouraging the development of networking between dedicated biotechnology firms (DBFs) and research institutions, facilitating interactions for new knowledge generation and innovation. The Porter school of thought has been influential among policy-makers and opinion formers (McDonald et al, 2007). Thus, for instance, in an early report on *Biotechnology Clusters*, Lord Sainsbury (1999) offers a number of policy recommendations for removing the barriers to bio-cluster development. Among them, the development of a strong science base in regions, the facilitation of entrepreneurial culture, and the provision of incentives to venture capitalists (VCs) and the improvement of infrastructure.

However, despite its influence on innovation policy, the Porter school of thought on bio-clusters has been severely criticised for its tendency to treat all kinds of regions in an undifferentiated manner and ignore the importance of institutional development and learning. This critique has led to the development of a second school of thought that is dynamic and derives from the innovation systems (IS) theory (Nelson, 1993; Lundvall, 1992). According to the IS school of thought, bio-clusters are phenomena which emerge and evolve in a systemic way, following different stages of development. In each stage, different conditions influence their performance.

For neo-evolutionary economists (Foster and Metcalfe, 2001; Metcalfe and Ramlogan, 2005; Pelikan, 2001), the IS approach to bio-clusters seems to imply an innovation problem sequence process '…akin to random mutation or copy-error processes' (Foster and Metcalfe, 2001: 9). These economists clearly propose a three-stage evolutionary framework of analysis based on variation, selection and development (ibid: 6). Therefore, they also use concepts of knowledge ecology and innovation ecosystem to explain the regional environment within which interrelations between different actors are developed (Papaioannou et al, 2009). For instance, Metcalfe and Ramlogan suggest that 'Innovation systems do not occur naturally, they self-organise … around…the problem of sequence that defines innovation opportunity. Hence, innovation systems are emergent phenomena, created for a purpose, they will change in content and pattern of connection as the problem of sequence evolves and they are constituted at micro scale' (Metcalfe and Ramlogan, 2005, page 20). This argument implies that knowledge ecologies at regional level are spontaneously transformed into RIS within which bio-clusters emerge.

On the other hand, for economic geographers the IS approach implies that bio-clusters emerge and evolve when major innovation interactions between knowledge generation actors (public research laboratories, leading edge universities, etc) and exploitation actors (DBFs, pharmaceutical companies, VCs, hospitals, etc) take place in a specific geographical and political unit e.g. region. The emphasis of economic geographers such as Cooke et al (1997) and Asheim (1996) is not on abstract socio-biological processes of selection and development but on the role of 'localised knowledge spillovers' and the significance of social and political environment of innovation. For instance, as Rosiello (2007) and Cooke et al (1997) show, in Scotland and Wales, shared culture, territory and devolved administrative and political governance provide important dimensions of institutional set up for innovation.

In the present paper, we intend to form another school of thought (e.g. the Innogen school of thought) that is interdisciplinary and builds on the economic geographers' view of RIS. The main argument is that bio-clusters are, in fact, historical developments of the social division of labour and co-evolve with biotechnology, VC and socio-political institutions. This argument deviates from the Porter school of thought and some neo-evolutionary interpretations of IS theory because, despite their differences, they both seem to abstract from the historical pre-conditions, discontinuities and contradictions involved in the whole of process of bio-cluster development. Specifically, as O'Shaughnessy (1997: 73) observes, Porter encourages the belief that cluster related problems '…are soluble exclusively through economic policy measures. This view underplays the role of history, politics and culture in determining competitive advantage, so that as a result of defining the problem incompletely, he offers an incomplete solution.' Indeed, Porter (1990, 2000) distinguishes between established and deep clusters, stressing the importance of established local supply chains and deep collaborative networks for competitive advantage. His main hypothesis is that 'The relevant knowledge spillovers that affect innovation and performance should be strongest within cluster and among related industries' (Porter, 2003: 562). Thus, Porter clearly fails to explain how research and capital intensive industries such as biotechnology influence the tendency of firms to increasingly locate near public research laboratories and universities, forming bio-clusters which display a full range of networks and knowledge spillovers (Cooke, 2005).

In order to provide explanation, one needs to investigate the different historical phases of the process through which the social division of labour influenced the emergence and co-evolution of bio-clusters. As has been pointed out elsewhere (Papaioannou et al, 2009: 4), '…the division of labour as such is not biological but social, expressing social relations of production (e.g. private property) and power (e.g. ideology and politics)'. In this sense, it is a historical pre-condition of development of a *background phase* in which separations of the social division of labour become geographical, explaining why science, technology and higher education activities at universities expand in some regions and not in others. The role of economic policy in the background phase of development of bio-clusters may be not as crucial as the Porter school of thought might think. However, this does not imply that a regional environment of knowledge and innovation emerges spontaneously as an ecology that includes '…those organisations that store and retrieve information as well as those that manage the general flow of information in multiple formats but the principle actors are usually for-profit firms, universities and other public and private specialist research organisations' (Metcalfe and Ramlogan, 2005, page 19). Rather, the historical process is holistic, including both the social division of labour and public policy as determinant factors of bio-cluster development.

The explanation of bio-cluster development in terms of different phases is also proposed by Avnimelech and Teubal (2006) who construct an *extended* Industry Life Cycle (ILC) model of VC-led cluster dynamics based on the Israeli experience. In this model, VC is seen as a higher form of organisation, industry and/or market, which materialises not only through *background* conditions but also through *pre-emergence*, *emergence*, *crisis and restructuring* and *consolidation* stages. Thus, the extended process of *VC emergence* is defined as a cumulative, autocatalytic process involving a few phases and interconnected sub-phases that run throughout time. A central element of such process is that VC co-evolves with the expanding group of high-tech SUs, so that demand and supply of VC interact and stimulate each other in a dynamic fashion, rather than the former being taken as a given. However, emergence would never take place, unless 'appropriate *Background* and *Pre-emergence* conditions prevail or are created by policy' (ibid: 1483) At that point, VC could become 'a driver or central vector in the transformation of existing high tech clusters (towards a more 'entrepreneurial' mode) or in the creation of new clusters' (ibid: 1484). Innovation policy can play a key role by supporting emergence and/or creating the appropriate set of pre-emergence conditions. Thus, it would appear that emergence needs not to resemble the preordained outcome of a biological process.

At this point we accept Avnimelech and Teubal's (2006) argument that a pre-emergence phase exists. According to them, this phase is characterised by the following conditions:

- Rapid technological change that assures a continued stream of new business opportunities for SUs.
- A significant increase in the supply of potential high tech labour.
- Increasing number of SUs leading to the creation of excess demand for VC.
- Growth of informal VC-related activities; and some formal VCs.
- Experimentation (variation) and learning by SU, VCs and policy-makers.

We assert, however, that the pre-emergence phase of bio-clusters is not without fragmentations, discontinuities and contradictions. Indeed, as has been shown elsewhere (Papaioannou, 2009: 4) '…a historically developed environment of knowledge and innovation does not evolve through a functional process of adaptation but through an uneven and contradictory process of co-operation and conflict generated by the separations of the social division of labour'. It is this process that drives the emergence of bio-clusters within RIS. Again, Avnimelech and Teubal (2006: 35) are right that, generally speaking, in the *emergence phase* there is high rate of growth of VC and SUs activity as well as large numbers of new companies. However, the dimensions of specific RIS might influence differently the emergence phase of bio-clusters. According to Cooke (2001: 953) these dimensions include: region (e.g. a political and administrative unit); innovation (e.g. commercialisation of new knowledge); network (e.g. trust and co-operation-based linkages among actors); learning (internalisation and externalisation of knowledge, skills and capabilities); and interaction (e.g. formal and informal communication focused on innovation). The politics of specific regions, the pace of innovation, the quality of networking and the dynamism of learning, all these have impact on the rate of growth VC and SU activities as well as on the numbers of new companies.

Avnimelech and Teubal's (2006) analysis of evolutionary processes is close to Foster and Metcalfe's three-stage evolution scheme and therefore appears to be relatively linear and unable to take fully on board political, historical and cultural dimensions of specific RIS. This is not surprising since, as Papaioannou et al (2009) show, specific RIS dimensions are difficult to be captured by evolution schemes based exclusively on variation, selection and development. Foster and Metcalfe rather condense the evolutionary phenomenon of innovation into a socio-biological process of adaptation. Thus, they tend to move away from Schumpeter who, in his *Theory of Economic Development* (1983) criticised the reduction of evolutionary thought into social Darwinism. Indeed, as Papaioannou et al (2009: 4) point out, '…they seem to be closer to thinkers such as Polanyi (1951) and Hayek (1978) who conceived the social environment as a spontaneous order in analogy with the growth and form of plants and animals. For those thinkers, evolution was a matter of cultural selection and unconscious adaptation to spontaneously generated rules of conduct'.

Certainly, because of the various references to pre-emergence conditions, the role of policy in creating markets and that of external factors (such as technical change and global financial trends), the approach adopted by Avnimelech and Teubal (2006) remains visibly distinct from the strict socio-biological approach to bio-cluster development. What they seem to do is rather to overlook the role of historical[1] political and cultural dimensions of RIS in phase transitions. Thus, they argue 'A major condition (phase transition) to the second, pre-emergence phase is significant diffusion of R&D and associated innovation capabilities throughout the business sector…A related condition is an ongoing *technological revolution* that would make the pool of technological opportunities continuously renewable …. Transition to a successful VC emergence process (phase 3) involves two groups of conditions: first, those underpinning early phase

[1] However, it ought to be noted that the Avnimelech and Teubal (2006) extended ILC model is used by Rosiello et al (2008) to propose a new system-evolutionary approach to VC policy which takes into full account history and systemic idiosyncrasies.

3 *demand* for VC services; second those underpinning rapid growth of VC *supply*. The appearance of adequate demand for VC services during early phase 3 is result of the appearance of critical mass of SUs during late phase 2' (ibid: 1487). As our empirical cases of Cambridge and Scotland will demonstrate, at times diffusion of R&D and innovation capabilities presupposes politics to deal with certain separations of the division of labour (for instance bridge the gulf between direct production and academia) and individual initiatives of entrepreneurship at regional level.

3. EMPIRICAL RESEARCH METHODOLOGY

Empirical research for this paper has been carried out in the UK since January 2005. The focus has been on the RSI of Cambridge and Scotland. Two methods of data gathering have been used: firstly, documentary analysis that includes academic journal articles, policy papers and reports, DBF websites, company brochures and press articles, including historically relevant materials from a previous study (Massey et al, 1992); secondly, in depth interviews (based on a semi-structured questionnaires) with a range of public and private actors such as high level managers of DBFs and industry stakeholders, policy makers and scheme managers, scientists and life science consultants, VC firms and business angels.

Since January 2005, recent relevant documents have been collected and 64 face-to-face interviews have been conducted in both Cambridge and Scotland. Textual representations of these qualitative data have been analysed and interpreted in such a way that provide an in-depth understanding of the unevenness and contradictions of the historical process of development of bio-clusters.

The general aims of the survey were to map the recent history of the two clusters, understand the drivers of bio-cluster development within the two different socio-economic contexts, assess the impact of innovation and technology policy both at a regional and at a national level, and explain the modes of interaction among public and private actors. In order to achieve these goals, three different questionnaires have been employed. The first questionnaire was directed to 18 DBFs located in Scotland and operating in therapeutics and diagnostics. They were approached for two reasons: firstly, they were created after 1994 and were more likely to have been affected by Scottish innovation strategy; and secondly, they had core scientific and technological competences in molecular biology. The main objectives were to investigate the location choices and research and business strategies of DBFs; and find out whether policy played any significant role in supporting innovation and growth.

A second questionnaire was employed to examine the role played by VC in the emergence of the Scottish and Cambridge bio-clusters, considering the question whether the characteristics of the local clusters, including their stage of development, have any effect on the frequency of knowledge transfer, ways of interacting, and the extent to which VC networks are regionally bounded. This phase of the survey involved 10 DBFs and 10 VC firms, equally shared between Scotland and Cambridge.

Finally, a third questionnaire was used to investigate the role of the Scottish and Cambridge bio-clusters in developing complex public-private collaborations and building innovative capabilities at regional level. This final phase of research involved 26 organisations, including DBFs and regional development agencies in Scotland and Cambridge.

In order to process the information gathered during the interviews we used NVivo software and referred to the grounded theory method (Strauss and Corbin 1990). Various coding techniques have been employed to (i) label conceptual categories and properties and unveil logical connections; (ii) identifying, categorising and describing phenomena found in the text; and (iii) distinguish between core and non-core categories and phenomena, which helped to synthesise ideas and identify possible answers to the research questions.

4. THE CASES OF CAMBRIDGE AND SCOTLAND BIO-CLUSTERS: A POLITICAL AND HISTORICAL PERSPECTIVE.

Cambridge

Background Phase

The background phase of Cambridge's bio-cluster development is characterised by the gap between direct production and academia, originated from the industrial revolution. According to Massey et al (1992: 7) '… this gap … has been interpreted, from the 1960s of Harold Wilson to the recent decade of Margaret Thatcher, as a crucial problem which it is essential to resolve'. Therefore, it might be argued that during the background phase two breakthroughs in the development of Cambridge's knowledge and innovation environment took place: firstly, big public investments in science and technology, including the building of the Medical Research Council (MRC) laboratory of molecular biology; secondly, the realisation that the university's own vitality would depend on the benefits of technological revolution. These two breakthroughs were politically justified in the so called Mott Report published in 1969. The report '…addressed directly the need to strengthen the interaction between teaching and scientific research on the one hand and its application in industry, medicine and agriculture on the other' (SQP, 1985: 19). The report led to policies of industrial development and the SU of new high-tech firms in computing. In 1979, a number of these firms founded the Cambridge Computer Group while earlier formations such as the Cambridge Consultants (ibid: 26; Athreye, 2001: 8) played a crucial role in transferring knowledge from the university to companies and in spinning out new ventures. As one interviewee said:

> 'If you look back … forty five years there was nothing other than a great university … In the 1960 a bunch of courageous young men with the Columbus spirit … formed a company called Cambridge Consultants, [they] went to the University and said right … we are here to commercialise [research] … The University said thanks a lot but that's not what we do… But they kept going and they got corporate business …' (Extract ..).

Pre-emergence Phase

Parallel to all these developments, the lending policies of financial organisations such as Barclays provided informal VC for SU and young companies in high-technology. As another interviewee said:

> 'What Barclays did was to provide effectively equity through overdraft in a number of cases for which [bank] managers would have been sacked today …and the number of companies grew from twenty in 1978 to around three hundred sixty in the mid 1980s' (Extract ..).

Some of these companies grew because of their formal and informal collaborations with the University of Cambridge and research laboratories such as the MRC laboratory of molecular biology. The newly developed Cambridge Science Park (CSP) also facilitated university-industry collaborations.

All these bottom-up institutional initiatives in the pre-emergence phase have to be seen in relation to the wider economic and political context of the United Kingdom (UK) in the 1980s. As has been stressed elsewhere (Papaioannou et al, 2009), due to neo-liberal interventions of the Thatcher governments, a lot of big traditional companies such as Cambridge Scientific Instruments were acquired and downsized (Garnsey and Heffernan, 2005). This resulted in a pool of highly qualified individuals with both scientific and managerial know-how to SU new technology-based firms. It is not exaggeration to say that the emergence of the Cambridge bio-cluster is due to those individuals as well as to facilitators of informal networks. The latter promoted entrepreneurship and development of connections between different public and private components of the RSI. As one individual facilitator confessed:

> '…the thing we had to do was to try help create a culture of entrepreneurship and we did that by identifying and promoting role models…and also by doing a lot of press releases and going around and talking to encourage people, as I say using role models about the benefits of entrepreneurship …' (Extract ..).

Of course, economic liberalism and entrepreneurship also continued to be central ideological and political convictions in the New Labour era. The Blair government in the end of 1990s introduced a number of policies to promote competition and entrepreneurship. As one interviewee pointed out:

> '… with the advent of the Blair government there became a competition to set up entrepreneurship centres so all universities were allowed to bid in this competition…' (Extract ..).

However, it becomes clear that the background and pre-emergence conditions of the Cambridge bio-cluster formed a bottom-up innovation process that is in the core of the RSI of Cambridge. The latter is founded upon a combination of the social division of labour that strengthen the university R&D and the wider economic and political situation of the UK in the 1980s and 1990s e.g. neo-liberal ideology and New Labour politics.

Emergence Phase

The emergence phase of the Cambridge bio-cluster is characterised by high rate growth of VC and SU activity. Specifically, more than 200 DBFs and 350 biotech expertise service providers locate in Cambridge. Also there are more than 30 research institutes and universities, 20 multinationals in pharmaceutical, agro-bio and food, and 4 hospitals involved in biotech research (ERBI, 2005). The University of Cambridge is at the centre of this bio-cluster mainly because '…twelve different university departments were the source of forty two companies in biotech recognised by the university as spin-outs' (Garnsey and Heffernan, 2005: 22). Formal interactions between all these public and private actors are established in order to support the incubation of new DBFs, generate new IP, and facilitate professional networking. As one manager of a formal network said:

> '…[the network] it started off purely with public funds … and not a lot of money, essentially to help…the network activities not quite in the same format as we now do it and there were aspects in the original work which was looking to try and help companies…' (Extract…).

As another manager of DBF stressed formal collaborations depend on the needs of companies for IP generation. Thus:

> 'Small companies may sub-contract work out to universities on needs they have' (Extract …).

Formal interactions within the bio-cluster are complemented by informal interactions between public and private actors. Geographical, organisational and technological proximity plays important role in this respect. According to Knoben and Oerlemans (2006), the geographical dimension of proximity has to do with the fact that small geographical distances mainly facilitate face-to-face interactions while the organisational dimension of proximity refers to public-private actors that belong to the same space of relations. Technological proximity then is based on shared technological knowledge and experiences. All dimensions of proximity are undeniable facts for Cambridge. Thus, for instance, as one interviewee said:

> '…you know you are in buildings, you are in science parks, you are going to the sandwich bar, these are all places where things happen because Cambridge is not a big place and there is a high concentration' (Extract…).

The global dimension of proximity is also crucial. As another interviewee put it:

> '…the whole of the East of England is London because there isn't a part of the East of England that isn't more than two hours away. If you are a Japanese business person and you flew into London to see somebody at the university there, …you are not going to miss the opportunity to jump on the train for fifty

> minutes to go to Cambridge…to find out what's going on up there…' (Extract…).

Both formal and informal interactions constitute social relations which are influenced or facilitated by non-economic values such as mutual trust and communication culture and regional identity. In Cambridge, a number of social networks are in fact spin-out networks. According to one interviewee, this means:

> '… people who have left another company, they will still have ties with their former colleagues, they will still phone them up when they have a problem, there is this continual e-mailing and phoning going on between people asking for information, asking for various contacts. And there is no better way building up trust than having worked with somebody before …' (Extract …).

Trust is indeed a crucial non-economic value and as another interviewee clearly put it:

> '… a cluster is not about the number of biotech companies, its about the bio-community that is knocking around and that's the key aspect of how that bio-community interacts … the biotech companies by themselves would fail because they need a lot of assistance and its that community which makes it work and that's what Cambridge has … (Extract ..).

Our empirical data suggests that people mainly identify with the city of Cambridge, the university and the culture of academic excellence. For instance, consider this extract:

> '…'There is a strong identity with Cambridge and people like it … there is a lot of heritage and culture around … as well as in terms of being an on going centre of excellence …' (Extract…).

This extract clearly implies that there is some kind of symbolic embodiment and therefore people are more likely to trust people associated with Cambridge than any other substantial region.

However, despite the various formal and informal interrelations in Cambridge, there are also fragmentations, discontinuities and conflicts. These phenomena take place not within but between different networks, the university and/or research institutes and companies. For instance, as one manager of network said:

> '…academics tend to have little interaction with the network, there are a few literally a small number who do get involved but the only way academics get involved is if we are really specifically trying to put on some event which will attract them. I think it is always an issue trying to get academia and industry together…' (Extract…).

Although in Cambridge there are a number of individuals and organisations that play the role of network broker (ERBI, The Cambridge Network, St John's Innovation Centre, etc.), the problem of fragmentation cannot be easily resolved, due to conflict of public-private interests and different agendas. This fragmentation implies certain discontinuities and contradictions at the level of RSI. Such discontinuities and contradictions mainly concern the spread of new knowledge and information across the system. Conflicts of public-private interests determine who benefits from the new knowledge and information.

Scotland

Background Phase

The background phase of Scotland's bio-cluster is characterised not only by the gap between direct production and academia but also by the North-South divide of the UK. However, political interventions that aimed to resolve the problem of economic and social separations of the division of labour in Scotland resulted in a rather top-down institutional development. Specifically, in the years after World War II, the region faced the severe decline of traditional heavy industry such as ship-building and the lack of new technology based entrepreneurial activities. Also, a number of people emigrated to England or went overseas. Thus, according to Mitchison (1982: 411) 'The industries entering Scotland tended to be either pushed in by the government or American in origin and native enterprise remained poor'. At the same time Scotland witnessed the excessive concentration of development in the South-East England. As Campbell (1980: 185) observes '…by the late 1950s further delay was no longer such an easy option. The growth of the Scottish gross domestic product lagged behind that of the UK from 1954 and seriously from 1958'.

Pre-emergence Phase

It might be argued that the pre-emergence phase of Scotland's new knowledge and innovation environment began in the 1960s. According to Campbell (ibid) 'The signs of deteriorating industrial conditions, most evident once again in some of the old specialist producers, were partly responsible for an appraisal of regional policy accompanied by massive injection of government assistance to industry in the 1960s rising from £18 million in 1961-62 to over £96 million in 1969-70…'. It might be said that the crucial aspect of this pre-emergence phase was the establishment of the Scottish Development Agency (SDA). The SDA was established in 1975 in order to attract an already developed hi-tech sector (Massey et al, 1992: 200). However, despite certain improvements in the region's knowledge and innovation environment, the SDA failed to provide an essential foundation for the change of the Scottish industrial structure and development of a critical mass of new-technology based firms. In comparison to Cambridge's pre-emergence phase, Scotland lacked individual champions of entrepreneurship and network brokers as well as financial organisations which could provide informal VC for high-risk investments. In addition, there was a little local ownership and therefore R&D in Scotland was very restricted (ibid). Given the ideological and financial constraints of the Thatcher neo-liberal policies in the 1980s, R&D in Scotland were further restricted (Hickie, 2003: 66). Thus, for a number of years the Scottish economy was influenced by the role of multinational corporations (MNCs) in financial services, gas, oil, transport, electronics and utility sectors (Rosiello, 2005: 4). Nevertheless, as Rosiello points out '… the downturn of the global economy and the difficulties faced by some MNCs led to the shutting-down of some plants … with negative implications for the whole economy….As a result, in the late nineties the focus of policy interest shifted towards possible ways of stimulating entrepreneurship and the creation of locally anchored business with high growth potential'.

Emergence Phase

The aforementioned failure of pre-emergence phase constitutes a set back or discontinuity that explains why the actual emergence of the Scottish bio-cluster only took place in the late 1990s as a clear top-down initiative of the Scottish Executive and the Scottish Enterprise (former SDA). According to Rosiello (2007) 'SE's Framework of Action for biotechnology originally consisted of a £40m investment and it included organisations engaging not only in advancing knowledge in bioscience and exploiting the technological outcomes, but also in producing medical devices and providing general support and supplies'. Targets of the SE's Framework of Action included substantial increase in the number of DBFs and support and supply firms located in Scotland as well as doubling employment figures and developing international networks. These targets were in line with the 2001 integrated science strategy of the Scottish Executive. The main objectives of that strategy included: maintenance of a strong science base and international networking; increase of effective exploitation of scientific research and provision of cutting edge science (SE, 2001: 4-5).

Scotland is today the third largest cluster of DBFs in the UK while more than 550 public and private organisations are directly involved in life sciences related activities (Rosiello, 2008). The Scottish universities and research institutes (HEIs) play a central role in this cluster. For instance, according to the Scottish Executive (SE, 2005) in 2002-03, 17 spin-off companies were established by Scottish HEIs. Also, Scottish HEIs filed 212 new patents and granted 131 licences for the use of IP. Most of these patents and licences concerned innovations in life sciences and biotechnology. Our empirical data shows that interactions between different (public and private) actors within the Scottish bio-cluster are mainly formal and aim either at creating new IP or at facilitating networking. In the case of new IP creation, the newly established Intermediary Technology Institute (ITI) for life sciences plays a crucial role. ITIs are specific innovation policy initiatives. They were set up by the Scottish Executive to bridge research and development in Scotland. Within the bio-cluster, ITI operates as a broker of formal public-private collaborations which have the potential to commercialise research. As one ITI manager stressed:

> 'We go into programmes having identified at least one Scottish route to commercialisation for a main IP output' (Extract …).

In the context of these programmes, ITI manages all collaborations between DBFs and research institutes, appropriating new IP. Despite criticisms (Rosiello, 2007), licensing out IP is one of the main functions of ITI. As another ITI manager said:

> 'We license and we know this is particularly true in life sciences. You are not going to invest the kind of money that is needed to be invested to bring a life science product to the market unless you can get exclusive rights. So we recognise that we will license exclusively …' (Extract …).

Apart from the establishment of ITI Life Sciences, various government bodies in Scotland, including the Scottish Enterprise, have developed organisations that play the role of collective broker of public-private networks and collaborations.

Our empirical data suggests that there may be also ethical-political values that influence the Scottish bio-community. According to one interviewee:

> 'North of the border we have traditionally as a community voted for labour government, a community such as Cambridge might not have that political orientation or at least not predominantly, there has been and behind that there is a culture of more socialistic aspirations then so yes that might be well embedded in the culture and that may well interact' (Extract …).

Certainly, whether deeply political or not, this bio-community might not always be open to international collaborations with other companies and/or bio-communities. As one interviewee said:

> '… there is an advantage of having a vibrant community … and we have productive interactions with companies which are local versus ones which are based elsewhere in the world' (Extract …).

However, despite the fact that formal and informal collaborations in Scotland are influenced by strong ethical-political values such as public-interest, mutual trust and Scottish identity, there are also conflicts and fragmentations. Although these phenomena may be marginal, comparing to Cambridge, they take place in the formal relations between HEIs, research councils, DBFs and government initiatives such as ITIs. Specifically, as one interviewee said:

> '… for some of the work that the university researchers take part in, it is funded by a research council who retain their intellectual property rights over that money, if that project overlaps with money that is coming from a company, the academic then has a conflict of interest …' (Extract …).

As another interviewee confirmed:

> 'There is a conflict on the academic pursuit of science and the production of a product that a company wants and where we benefit is if we can be involved at the first bit, the development bit …' (Extract …).

Although our data suggests that initial contractual agreements between public and private organisations in Scotland aim to prevent such conflicts, the latter, when they arise, are resolved even with withdrawal of HEIs from particular collaborations.

5. BIO-CLUSTER DEVELOPMENT FROM AN ECONOMIC AND CO-EVOLUTIONARY PERSPECTIVE

Having looked at the emergence of the Cambridge and Scottish bio-clusters from a historical and political perspective, in this section we are going to use our findings to enhance our understanding of the scientific, economic and institutional drivers of such process of emergence. Our perspective is inherently systemic and evolutionary. A central lesson that is crucial to appreciate our standpoints is that bio-cluster emergence seems characterised by idiosyncratic and context-specific patterns. Thus, on e ought to be extremely careful when making any sort of generalisation.

The mainstream economic theory on clusters explains geographical agglomeration as the result of static conditions, including strong science base, entrepreneurial culture and VC (Porter, 1990; Krugman 1991; Fujita and Thisse (1996). Other approaches, however, lay more emphasis on evolutionary and dynamic agglomeration. This stream of research tends to consider the meso-level (a cluster or a network of firms) as the unit of analysis, with a focus on the structural and institutional features of the RIS. The process of emergence is seen as self-reinforcing and as a direct outcome of the progressive materialisation of positive externalities (Cooke 2007b). Because of the focus on the meso-level, useful clues are often provided to policy-makers to develop effective policy frameworks (see for instance, Breshnanan et al 2001; Orsenigo 2006). However, as argued by Giuliani, (2004), less research has been directed to the understanding of how such meso-level characteristics come into being or evolve as a results of micro-level, non-structural characteristics.

Other interpretations still stress the cumulativeness of innovative processes and related spin-off processes from incumbent firms and/or HEIs. In addition to Avnimelech and Teubal (2006), some accounts of the rise of the Silicon Valley (Moore and Davis 2004) stress the role played by a few events and actors in spurring the processes of agglomeration. The implicit suggestion is that it may be a core innovation that creates clusters. Similarly, Feldman and Francis (2003) account of the development of the bio-cluster in Washington DC show that unforeseeable events - sometimes prompted by public policy and wider political decision-making - can be at the origin of the cumulative process that leads to emergence. These arguments suggest that perhaps more attention should be paid to firm-specific features and the role of various regional/national players, including HEIs and policy-makers.

Not surprisingly, most of the recent literature on bio-clusters points to the existence of meso-level commonalities as regard the process of emergence. The progressive strengthening of the scientific base, the presence serial entrepreneurs, VC inflow, the establishment of links to large firms and global markets, institutions and policies that define and appropriate infrastructure of innovation, expanding networks, are all important ingredients for the commercial exploitation of science. Yet, as these observations often refer to emerged cluster, they tend not to reveal how these ingredients have come into existence and accumulated within the cluster (Rosiello and Orsenigo 2008).

Europe is characterised by a wide range of bio-cluster structures and growth trajectories[2]. However, in Cambridge, various studies show that the bio-cluster has managed to breed, attract and exploit science, know-how and VC like no other European bio-cluster. Also, unlike US clusters Cambridge does not grow many large companies with a global reach (Pacec 2003; Casper and Karamanos 2003). The majority of local emerging DBFs are sold to foreign multinationals; among the recent examples there are *Cambridge Antibody Technology (CAT)* and *Arakis*.

Consequently, our study has aimed to (i) identify meso-level drivers of cluster emergence as well as to highlight (ii) key differences in the trajectories followed by different clusters (in this case Scotland and Cambridge), (iii) the nature of the pre-emerging conditions that contribute to explain the origin of the process and, finally, (iv) crucial elements of discontinuity and conflict (perhaps the result of individual action and political decision-making) that characterised the process in the two different contexts. We think these observations have important implication for regional innovation policy. Indeed, in some cases awareness about existing and/or emerging weaknesses has motivated policy action in Scotland.

Our empirical evidence confirms the significance of the local science base in both locations, with which many companies retain very strong links in terms of formal and informal collaborations, legal agreements to gain access to new scientific developments and representation in the board of directors. In the overwhelming majority of cases, our interviewees agreed that the characteristics (strength, reputation and areas of specialisation) of the local bio-science shape the direction and intensity of the process of emergence. As discussed by Rosiello (2007) in relation to Scotland, the geography of knowledge transfer seems characterised by a combination of "close conduits" and "open pipelines" (Owen-Smith and Powell, 2004), a result corroborated by the evidence gathered in Cambridge. One interviewee notes:

> 'There is a strength in and around Cambridge, that is something with universal reputation in terms of biotech and pharmaceuticals, principally because of the proximity to the markets, the proximity to very excellent research (in London, Cambridge and Oxford), Cambridge led itself to biotech companies being set up, being established, being replicated and being close' (Extract…).

With regard the wide range of structures and trajectories, our study stresses the existence of heterogeneous patterns of bio-cluster emergence. The emergence of Cambridge was clearly characterised by the central role played by technology consultants, easier access to managerial skills, closer links to VC located in London and its nodal position inside

[2] Rosiello's (2008) study of the Scottish, Swedish and Danish biotech industry suggests that Denmark and Sweden are shaped by a higher proportion of industrial spin-offs and R&D investment by incumbents, Denmark and Scotland have higher intensity VC per € invested in R&D, in Sweden and Scotland public development agencies play a more prominent role.

UK VC syndication networks (Rosiello and Parris 2008). The same conditions did not exist in Scotland. For instance, the manager of a DBF observes:

> 'Being in Northern Ireland or in Scotland makes it not as easy to grow a biotech company as being in Cambridge. Because, I think, the investors are in London, so the closer you are to London, the easier it is going be to attend meetings, to have network, to come up and go there to see them.' (Extract …).

At the same time, in both Cambridge and Scotland DBF lamented a paucity of VC, a higher risk aversion compared to US bio-clusters, and the excessive geographical distance from the deal-making head-offices of big pharmaceutical corporations (often located in North-America) which, in their view, prevent local ventures from exploiting their complete growth potential:

> 'If you want to be successful, you have to have a successful drug in the US and you need to access a large amount of capital, which is in the US.' (Extract…).

Scotland occupies a more peripheral position within UK VC syndication networks. Further, the role of technology consultants seems less significant and the cluster currently experiences a lack of managerial capability (Rosiello 2008). Our interview-based study clearly shows that in evolutionary terms these dimensions are clearly linked to each other, in that not only VC tend to invest in close geographic proximity, but also they prefer to invest in "investor-ready opportunities" (Mason and Harrison 2003). As one manager of a VC firm said:

> 'If you are an investor and something is long away, you feel less comfortable about it because it is harder to detect problems, influence, impact, and help, harder to bring the rest of your network, which is why clusters work.' (Extract…).

According to Avnimelech and Teubal (2006), this could mean that a full cycle of variation (experimentation), growth and selection has not taken place. Thus, a critical mass of technological and managerial capabilities, VC and complementary services is yet to emerge. In Cambridge, some of these key assets were already been available before emergence, because of the proximity to the financial community and R&D pharmaceutical facilities located in London, and the previous existence of an ICT cluster. These represent (alongside the strong science base) crucial pre-emergence conditions. An additional reason for the different stage of development reached by the two clusters is probably that biotechnology in Cambridge started earlier, partly thanks to the vital role played by some early pioneering and visionary individuals:

> 'Why did it start here? First of all there was a little bunch of entrepreneurs, the medical research council, an agriculture science based company set up by a government decision, then there was a source of techno-commercial people in the consultancies, there was a source of industrial scientists close-by in the pharmaceutical companies and there was intellectual property inside

> and coming out from university and it was a nice place to live and it was close to London, which is close to the money. Not just the university.' (Extract…).

At present, Cambridge seems capable to sustain its own growth and attract assets and skills from the outside (Casper and Karamanos 2003). Yet, some of the professional and financial networks span the regional dimension, and our study includes DBFs with collaborations and R&D facilities in both locations. Further, as most investments are syndicated, an emerging (although more peripheral) cluster may be able to grow local investors with good connections in place such as London (Rosiello et al 2008).

Scotland on the other hand, despite its strong networks and powerful infrastructure for public-private collaborations and knowledge transfer seems unable to attract assets and skills from the outside. This is one important reason why Scottish DBFs do not grow substantially. As has been shown elsewhere (Papaioannou, 2006), shortage of skills such as management of innovation and intellectual property has negative implications for regional development and maintenance of high employment figures.

Whatever their differences, both the Cambridge and Scottish bio-clusters constitute historical and co-evolutionary developments which followed *background*, *pre-emergence* and *emergence* phases. Certainly, our empirical data could not reveal that these bio-clusters also entered *crisis and re-structuring* and *consolidation* phases. Therefore, Avnimelech and Teubal's (2006) *extended* ILC model cannot be entirely applied in explaining the phases of bio-cluster development in Cambridge and Scotland. However, we propose that this *extended* ILC model could be further extended beyond the dimension of the VC-SU interaction. In so doing, it can be used to capture the empirical fact that all historical phases of bio-cluster development have been determined by certain separations of the social division of labour, micro dynamics and individual actions which have aimed at dealing with those separations in a beneficial way. The lending policies of Cambridge financial institutions and the biotechnology investments of the Scottish Enterprise during pre-emergence and emergence phases respectively are examples of such actions.

6. CONCLUSION

Our interview-based study examined the process of bio-cluster development in Cambridge and Scotland, two of the three major poles of agglomeration to biotechnology-related activities in the UK. Some elements of regularity have emerged. For instance, the attractive power of knowledge seems to be stronger than in other technology sectors such as ICT. Industrial and scientific networks frequently help the search for potential partners and can be conducive to critical information, know-how and reciprocal trust. As far as the relationship between HEIs and the DBFs is concerned, these networks tend to be local (Rosiello 2008). The recycling of know-how, VC, consultancies, suppliers, customers and so forth, wherever it starts, allows a cluster to develop. Areas that benefit from these clustering effects become more geographically bounded, as positive externalities materialise. Regions at an earlier stage of cluster development, such as Scotland, appear less geographically bounded, in that the paucity of local opportunities pushes local actors to link with external players to access complementary assets and opportunities.

Processes of cumulative and collective learning are clearly at work: formal and informal networks and knowledge flows, collective adaptation to changing conditions, forms of coordinated behaviour to deal with transactional problems (dilution and internal conflicts), technical challenges (moving compounds through R&D stages) and managerial risks (high attrition rates and regulatory uncertainty). All of these mechanisms allow learning through direct interaction and apprenticeship.

Despite such regularities, this study also shows idiosyncratic patterns of emergence. These are to a certain extent due to different pre-emergence conditions (Avnimelech and Teubal, 2006) in that clear divergences exist in relation to the industrial structure, institutional settings and social fabric of the two systems. This translates into diverse patterns of co-evolutionary experimentation, growth and selection. For instance, concerning the relationship between the public and the private sector, DBFs are dedicated to activities that reflect the specialisation of the local science-base, which often entails the adoption of different business models. Further, reliance on public schemes is more evident in Scotland, where distinctive forms of knowledge translation have been attempted. These include the ITI life science but also the Translational Medicine Research Collaboration (TMRC). Launched in 2005, this schemes involves four Scottish Universities and the NHS and a number of collaborative activities: (i) setting up a centre for the development of biomarkers; (ii) developing and coordinating clinical trials on defined disease populations; (iii) linking with the *Scottish Clinical Research Network* to deal with ethical approvals, data collation and statistical analysis of results; and (iv) coordinating research on collected samples (www.wyeth.co.uk–translational research).

Even among the interviewees contacted in the same location, fundamentally different views emerge as regards the role and direction of regional innovation policy in supporting the birth and growth of the local cluster. Nevertheless, especially when we look at VC as an accelerator of bio-cluster emergence, our results are more in line with demand-side arguments stressing the attractive power of “investor-ready” opportunities (Mason and Harrison 2003) than supply-side approaches that take VC presence at the core of high-tech clusters for granted (such as Gilson 2003). Given the proportion of deals taking place within the “golden triangle” (Cambridge-Oxford-London), the chances other clusters have to attract significant inflows of VC depend on their ability to grow a significant number of investor-ready DBFs. In turn, achieving this goal entails acting on various pre-conditions, especially the local science-base and infrastructure of innovation which allow for cumulative learning, variation in business approaches and development of critical skills (Rosiello and Parris 2008).

These findings have important policy implications. By and large, they call into question the Porter line of argument but also the Bresnahan and Gambardella (200: 357) position concerning the suitability of policies that have 'elements of benign neglect' and a focus on 'enabling conditions' in the general sense of 'creation of a suitable demand …openness, education, competition to encourage the success of skilled people with entrepreneurial ambitions, and policies focused on key-supply side factors and institutions'. In line with Avnimelech and Teubal (2006), our study stress the effects of a long-term term commitment to develop a research, physical and institutional infrastructure that supports knowledge *exploration* and *exploitation* (Cooke 2007b), and allows private investors to invest in early stage venture that operate in a highly uncertain environment (Rosiello and Parris 2008).

Another policy implication of this study is that *one fits all* approaches are unlikely to work. The dynamics revealed by our survey can be hardly characterised as homogenous across locations or as the outcome of a linear biological process. Like other bio-clusters, Scotland and Cambridge are becoming the epicentres of path-breaking research efforts within specific domains, with the potential to attract a growing number of skilled people, sponsors, and organisations with an interest in those areas. The direction taken by this flow of financial and human resources is often the result of personal and political decisions. Such decisions contribute to explain the sudden acceleration in the process of knowledge accumulation in certain location, the relative geographical division of labour and the emergence of conflicts and discontinuities.

In particular, we observed that the rules which govern the interaction among scientists and DBFs are increasingly replaced by formal exchange mechanisms through which explicit or formalised knowledge is transferred to potential exploiters. Thus, despite extensive cooperation, some cultural and interested-related conflicts are coming to the surface. The theme of the potential conflict between the basic principles of open-science and market incentives is of course reflected in various academic works who discuss the possible negative consequences of the spreading of a utilitarian, self-interested, and sectarian attitude among bio-scientists (Heller and Eisenberg 1998).

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