Oxford and Grenoble: multiple anchors, strong dyadic relationships and national policy in fostering cluster architectures

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ABSTRACT

This paper explores the divergence in patterns of regional development in twin towns, one in France, Grenoble and one in the UK, Oxford. Since the early 2000s a number of changes in national policies in each country have had a direct effect on the dynamics of local technology-led economic development. Here the particular interest is in those which relate to inter-relationships (dyads) between anchor organisations (public sector research laboratories)

and major local firms. The paper's focus is on how changes in policy have an effect on strong local relationships and how multiple anchor organisations drive cluster development.

INTRODUCTION

Many studies highlighted the role of knowledge organisations, such as national laboratories and research universities, in innovation-led regional economic development. Their role includes contributing both to the building of clusters and to improving local economies (Feldman, 2003; Lawton Smith, 2003; Smallbone et al., 2015). As national innovation policies change over time, there are consequences for the engagement of science base organisations with industry (Autio, 2014) and for the spatial organisation of those formal and informal relationships. Although there is great heterogeneity in the institutional and organizational context of different territories, the role of anchoring knowledge organisations appears to be quite distinctive in local development (Feldman, 2003). This is because anchoring knowledge organizations create different forms of innovation-based relationships with other key organisations - laboratories and major local firms.

Previous studies have put forward the single anchor hypothesis (Feldman, 2003), examining aspects such as the process and interaction channels (Bekkers and Bodas Freitas, 2008; Dutrénit et al., 2010), knowledge flows (Tether and Tajar, 2008) and benefits between public research organisations and industry (Arvanitis et al., 2008). However, it is empirically observed that in knowledge intensive clusters, there is seldom only one such pivotal anchoring organization (Lawton Smith and Assimakopoulos, 2020). Cluster evolution is based on a tightly knit core of key organizations in the cluster, acting as multiple anchors that connect peripheral actors (e.g. SMEs) to the cluster core, fuelling innovation and collective learning (Tsouri and Pegoretti, 2020). The innovation-based relationships, multi-stranded and strong ones, that connect the multiple anchors to each other, have not been elucidated. Although national policy has been observed to determine the forms and strength of these relationships, questions remain open on how changes in policy have an effect on such strong relationships, and how multiple anchor organisations drive cluster development.

The aim of the paper is to identify and assess such strong relationships among multiple anchor organisations and how policy changes affect their development. Our contribution lies in relaxing the "single anchor" hypothesis (Feldman, 2003), and, in exploring the character of innovation processes when multiple anchors, both public research organisations and firms, are strongly inter-related with dyadic relationships nurtured by national (and regional) policy rather than just by opportunity for participation in collaborative research.

The key question explored is how national policies (top down vs. bottom up) foster the buildup of clustering in the presence of multiple, rather than a single, anchor(s). Examining specific relationships between public research and large enterprises helps in understanding that this is more than the application of research in polycentric cluster development. Such relationships may initiate and drive particular research in Key Enabling Technologies (KETs); allow for socio-economic development with SMEs engagement with public research; and contribute to innovative processes of large enterprises, global pipelines and value chains linking local knowledge organisations with places elsewhere (Bathelt et al., 2004).

We draw from two case studies, Grenoble (France) and Oxfordshire (UK) to answer the research questions: "*To what extent do dyadic forms of innovation-based relationships between key organisations arise from differences in national policy?*" and "*How do dyadic relationships in each location connect multiple anchors to the main anchor organisation sustaining collaborative innovation at the cluster level?*". We postulate that a major difference in relationships lies in the "purposeful" brokerage of research-based networking in Grenoble as a consequence of French national cluster policy (top down), whereas in Oxfordshire, the national government's funding of the science base provides the basis (bottom up) for diverse forms of relationship between local firms and nearby research laboratories.

The paper is structured as follows. The next section critically reviews the literature on clusters, cluster architectures, innovation and networks from different perspectives. The third section presents Grenoble and Oxfordshire, and the data and methods employed in the analysis. The fourth section explores and compares the dyads developed between key actors in each cluster. The last section presents conclusions.

CLUSTERING AND CLUSTER ARCHITECTURE WITH MULTIPLE ANCHORS

Clusters, anchor firms and institutions, cluster architectures

To position the study with the inter-connected literature, key terms are first defined. The definition of cluster provided by Porter (2000: 254) is "a geographically proximate group of interconnected companies and associated institutions" in the same or related sectors. The basic argument for geographical clusters is that they foster innovation levels, efficiency and productivity - with which participating companies can compete at regional, national, and global scales (Baily and Montalbano, 2018). Relational forms and governance of cluster have also been extensively discussed (Bell et al., 2009), as well as explicit top down vs. implicit bottom up approaches (Fromhold-Eisebith and Eisebith, 2005).

The concept of 'anchor firms' was introduced to explore the regional concentration and specialisation of emerging industries (Feldman, 2003). Such firms facilitate and strengthen the clustering around them as they attract government funding, cause skilled labour pools, and absorb and produce knowledge and spillovers that benefit the regional firms and related actors active in KETs development (Niosi and Zhegu, 2010). They also have a key role as technological gatekeepers, acquiring knowledge outside cluster boundaries and contributing to diffusing knowledge to other local firms (Giuliani, 2011). In many industries, knowledge flows in innovation processes retain a distinct localized nature, focused on the knowledge mediating roles of focal 'anchor firms' in industrial districts, as technological 'gatekeepers' (Munari et al., 2011). Another important element for clusters' development is anchor institutions. Anchor institutions, like public research organisations, can play a crucial role in bringing about different kinds of interconnectivity in cluster architectures (Tsouri and Pegoretti, 2020). Their characteristics include spatial immobility, local embeddedness, and a large resource base manifested in institutional forms of cluster promotion, including employment, purchasing and business support.

Drawing on the language of social networks, we define cluster architectures as polycentric structures with particular keystone 'anchor' organisations tightly connected to other knowledge institutions and place-based anchor firms, via patterns of strong dyadic relationships encompassing multi-stranded project-based networks. Dyadic relationships, the smallest possible social group of collaborative relationships (strong ties), include mobility of talented personnel, connecting the main anchor (keystone or orchestrator) with other anchors. The concept of dyadic relationships has long been used by economics of innovation and management literature, in collaborative knowledge intensive structures (Rowley, 1997; Hite, 2008; Tortoriello et al. 2012).

In this context, cluster architectures not only have to do with the keystone organisation, but also with the sets of dyadic relationships connecting it to other focal anchors (Doloreux and Turkina, 2021; Denney et al, 2021). We posit that dyadic "strong" relationships among multiple anchors drive performance locally, for example in new technological advances in

KETs. These highly innovative technologies are knowledge and capital intensive, strongly linked with high intensities of R&D in focal organizations.

The role of national policy in fostering such "strong" dyadic relationships is a new phenomenon calling for further study in context sensitive case studies. For a cluster to host successful innovation activities, its knowledge organizations (research laboratories, private firms) have to embrace all kinds of institutional arrangements, talent, knowledge and capabilities needed to re-combine expertise and deliver high value to customers with respect to emerging technologies (Assimakopoulos et al., 2016; Evangelista et al., 2018).

National policy sustaining R&D in multiple anchors may therefore contribute to place based clustering of innovation and can provide connectivity to the cluster's SMEs, and thence rapid and integrated innovation cycles via collaborative research projects and mobility of human capital, including high skill employment (Cova et al., 2010; Robinson et al., 2013).

Clustering, cluster architectures, brokerage and innovation

Why technological clusters develop successfully in certain regions but not others (Cainelli and Iacobucci, 2012; Casper, 2013) relates to their particular cluster architectures. Clusters are not just agglomerations of opportunities, but may also inhibit some opportunities for developing emerging technologies and initiating innovation processes, empirically divergent from others. Innovation involves multiplex and complex phenomena of knowledge flows and externalities within innovation networks, some are in clusters (Quatraro and Usai, 2017; Doloreux and Turkina, 2021), and are evidence of brokerage through a variety of mechanisms.

Knowledge networks, as the backbone of innovation cluster architectures, involve a plethora of actors, knowledge organizations and firms whose embeddedness in the cluster may vary and demonstrate discontinuities. Scholars argue that the development of clusters, apart from the network embeddedness, rests on geographical proximity, intertwined with other dimensions of proximity incorporated into entrepreneurial initiatives (Boschma, 2005). Both proximity and advantaged position inside the knowledge network (e.g. brokers, gatekeepers), could generate externalities, by creating new opportunities for effectively combining and absorbing knowledge (Cohen and Levinthal, 1990). However, closer geographical proximity may not benefit the knowledge transfer inside the cluster, implying a paradoxical relationship between co-location and effective knowledge spillovers (Broekel and Boschma 2011). In the ongoing debate on whether co-location of knowledge organizations and firms in clusters leads to innovation-led economic development (Huber, 2012), there remains scope for exploring the conditions under which co-location may matter.

Knowledge networks are multi-directional in their brokerage capacity. For example, informal relationships or weak ties (Granovetter, 1983), developed out of working on joint projects in anchor firms and/or public research laboratories may lead to more formalized, longer term strong ties building on accumulated knowledge and trust (Tsouri, 2019). This allows innovation in a network of agents, including public research and anchor firms involved in the creation and diffusion of technology both locally and across large geographical distances. Differences in network architectures and in knowledge flows within and across regions are significantly associated with regional rates of economic growth (Huggins and Thompson, 2017). Network architectures are heterogeneous in their timing and function, with sometimes short-term goals and sometimes long-term network establishment.

Knowledge organisations therefore produce highly localised conditions for knowledge accumulation through four activities that form cluster architectures (Cooke, 2007; Christopherson and Clark, 2007). These are: creating and sustaining innovation-led places through opportunities for developing science and technology frontiers with cross- and trans-disciplinary projects and teams; brokering relationships between two and often more organisations at local level; brokering relationships external to the region; and responding to policies that attract talent and generate entrepreneurship. These activities describe the various roles of 'anchor' institutions and how they contribute in defining cluster architectures and increasing (or decreasing) the regional embeddedness of all actors.

Autio (2014) categorised the missions of big-science facilities into research-oriented or service-oriented missions, and fundamental research or solutions-oriented missions. In practice, while many big-science facilities exhibit elements of each, a mission's emphasis varies over time, and can fit the 'anchor institution' roles and categorisation. Thus, these 'anchor' organisations provide knowledge resources which produce spillover effects, because of dyadic relationships with other public research facilities or/and large infrastructure of private companies that carry our research and development in KETs. Such research organisations, deeply involved in knowledge generation, also engage in knowledge-exchange processes and may possess more privileged (broker) positions within regional innovation networks, than do private firms.

Labour markets and brokerage

Clustering is found to matter in relation to the process and outcomes of local labour pooling and mobility, and the attraction of global talent for knowledge generation locally and across large geographical distances. Clustering impacts might vary by job role, sector, cluster culture and technological traditions of practice shaping new communities and innovations (Assimakopoulos, 2007); and knowledge networks might be more important at different stages in the development of agglomeration economies (Huber, 2012).

Labour markets thereby have a key role in brokering knowledge flows and coordinating activity. They are constantly changing especially in clusters dominated by major organizations, as then local and global labour markets co-exist and the labour is mobile. Park et al. (2019) argue that geo-industrial clusters exhibit a stronger association between the influx of educated workers and financial performance, compared to traditional aggregation units. Moreover, while clusters attract new sets of skills and talent, older skills are displaced as activity changes. These changes are a consequence of innovation occurring through an inter-relationship between technologically – related knowledge in different organizations and presence of a highly skilled workforce. Both the quality of the labour market and inter-organisational mobility are fundamental for network development, because of their coordinating roles in regional innovation (Lawton Smith and Waters, 2011). Specific human capital refers to skills or knowledge that increases a worker's productivity in all tasks, possibly differentially. The concept of human capital has been broadened to competences as well as knowledge and skills (Gillies, 2017). Thus, anchor organisations often facilitate the mobility of innovation knowledge in clusters through their recruitment and exit of staff (Kasabov and Sundaram, 2016).

Public policy and brokerage

Knowledge institutions and anchors have multiple roles so are often funded from different agencies for different policy objectives. One possibility is funding for research at the edge of technology frontiers designed to improve the capacity of focal organisations to appropriate or internalize benefits from knowledge investments that they encounter (McCann and Ortega-Argilés, 2013). Another is funding to develop local infrastructure e.g. science parks as is the case at both Grenoble and Oxfordshire (Lawton Smith, 2003). While all funding may impact on cluster architecture, the overall effect on cluster building may be inhibited by poor alignment of institutional incentive structures, or by there being insufficient pathways for rapid knowledge transactions and transfer.

Three competing technology transfer policy paradigms are described by Bozeman (2000). They highlight how government might stimulate brokerage to improve internal research effectiveness and external cooperation. These are: the market failure paradigm, the mission paradigm, and especially the cooperative technology paradigm which relates closely to technology transfer. The last involves active participation between various actors in the region, who develop and transfer technology. Government's role includes new knowledge production, supplying applied research and technology to industry, acting as a purposeful broker, and developing policies contributing to industrial technology development and innovation and to the quality of the business environment (Lefebvre, 2013; Ketels and Protsiv, 2021).

Changes in national (and regional) policy may explain how and why anchor institutions develop new regional collaboration networks and improve relatedness of knowledge (Balland et al., 2015; Boschma et al., 2014). For example, if a policy objective is improvement in the application of scientific or technological excellence, then in principle network stimulation will bring together those actors and competences with potential for scientific advance and thereby economic development. Consequently, synergy effects can be realised through joint efforts over the longer term as well as through short-term gains (Klaster et al., 2017). Science policy (as in the UK) is not a single, comprehensive programme, nor have its science policies been aligned with other policy goals (British Academy, 2019). France traditionally has not had a coherent national research strategy (Casassus, 2019). Different types of cluster architecture are therefore required both taking advantage from and affecting the broker linkages developed for knowledge, talent and capabilities in emerging technologies, such as KETs (Assimakopoulos et al., 2016).

It is thus the regional cluster architectures for knowledge in the form of networking, particularly pairs of strong (multi-stranded) relationships (dyads) that explain country differences in how interaction is organized and brokered among multiple anchors. A key point of comparison is how network architectures are configured and change in the presence of multiple anchors and strong dyadic relationships connecting the multiple anchors to the keystone anchor. We now draw on evidence from the two regions in order to identify differences both in substance and style of approach of public policy and its effects.

DATA AND METHODS

This study draws together and contrasts the Grenoble region in France and the Oxfordshire region in the UK. A multi-pronged methodology includes an array of data sources (network and interview data as well as extensive documentary and archival sources) facilitating cross-case analysis and triangulation. We consider underlying factors, which explain how and why inter-relationships have formed and evolved since the early 2000s. The focus is on multiple anchor institutions, knowledge exchange and labour market dynamics, and public policy. Since we are exploring the changes in public policy affecting the innovation-based relationships between public research institutions and industry, the selection is largely based on public research institutions because they are supported and influenced by local and national governmental policy. Both regions have a high density of public research laboratories and clusters of major firms in KETs supported by public funding for research (Table 1).

<Table 1 about here>

Policy context 2003-2015: France and UK

Differences in national policy remain and continue to have pronounced spatial outcomes (Lawton Smith, 2003). In France, this is deliberate. There is an aggressive national cluster policy, including the creation of global competitiveness clusters. In 2005 the French government rolled out a new competitive cluster policy 'inspired by Grenoble's legendary innovation environment and community' in KETs. National government-certified competitive clusters were designed to bring together research organizations, businesses of all sizes, and educational institutions and training providers in order to develop synergies and collaborative projects in a given geographical area. These clusters are eligible for specific government financing for the projects they select to coordinate under the aegis of a cluster management organisation, such as MINALOGIC[1] .

In the UK, the government is a major funder of knowledge creation (£5.85bn for science and research in 2015-16). However, the country has a long-term lag in R&D investment with public sector funding slipping increasingly behind the EU average since 2010. The science base had already begun to change by 2003, with the moves to privatize many public laboratories, signalled in the 1994 Multi-departmental Scrutiny of Public Sector Research departments and the introduction of the successful Public Sector Research Exploitation Fund in 2001. Having abolished the nine regional development agencies (RDAs) in 2012, the UK does not have regional or cluster policies. The recent national Industrial Strategy that is aimed at boosting productivity (Department for Business, Energy & Industrial Strategy, 2019) has a place-based element, but the sixty or so public sector research institutions are not primary actors. As the British Academy (2019) highlighted, there is need for alignment of science policies with policy goals in other areas rather than science policy being a substitute for industrial policy.

[1] See: https://www.minalogic.com/en/

The Grenoble case

The rationale for choosing MINALOGIC is that in the Grenoble region, it is the strong cluster of some 400 organizations specializing in ICT development, focusing on micro/nanoelectronics, photonics, software, content and uses.[2] Its mission is to foster collaborative R&D project networks among world-class public research laboratories, large manufacturing companies, universities and entrepreneurial startups, in order to undertake research and bring to market key technologies and products. Over the last decade, the emphasis of MINALOGIC's strategy has shifted from hardware to software and support of the development of novel products and services that are near market and commercialized by innovative companies. Since creation, nearly 600 projects have been certified by MINALOGIC. These projects are financed equally from public / private sources with a total R&D budget of over two billion euros. MINALOGIC – ICT development currently has more than 400 institutional members; the majority are private companies (89% are SMEs).

Four anchor research institutions in Grenoble known to have strong ties with the French Atomic Energy Agency (CEA) were identified. These are the keystone state funded laboratory 'Laboratoire d' électronique des technologies de l'information' (LETI), part of the CEA, plus the three focal anchor organisations : the Centre National de la Recherche Scientifique (CNRS); the Université Joseph Fourier (UJF) ; and STMicroelectronics (STM), see Table 2 below. These organisations form major dyads (strong relationships) for the creation, sharing and diffusion of knowledge, in particular within the MINALOGIC cluster. Since 2005 the cluster has given birth to emerging technologies, fueling growth for both large and small companies. Associated with this concentration of expertise, Grenoble has a very highly skilled labour market. The Grenoble science base employs more than 10,000 public

[2] See: https://www.minalogic.com/en/le-pole/

researchers. Over time, universities, laboratories and firms have increased their demand for and supply of labour, thereby increasing the quality and diversity of the local labour market.

The Oxfordshire case

Oxfordshire anchor institutions include Oxford University, with world leading research and teaching, as well as a unique grouping of ‘big science’ and other research facilities (Table 1). These include nuclear energy research and civilian research activity. Nuclear energy research is now confined to nuclear fusion. From 2000, an anchor actor in Oxfordshire, UKAEA Harwell, was converted to civilian commercial activity and is now Harwell Science and Innovation. It hosts the Rutherford Appleton Laboratory (RAL) funded by the Science and Technology Facilities Council (STFC) - a government research funding body, the Diamond Light Source (2007), the UK’s synchrotron facility and the ISIS Neutron and Muon Source. There are a number of other research laboratories on site or close by.

The pattern of high-tech activity in Oxfordshire is one of specialization or clustering in a relatively small range of sectors. Currently its bioscience area is at the forefront, but of particular relevance to this discussion is the exceptional concentration of cryogenics, a KET that evolved around Oxford, unmatched elsewhere in the world with sought-after specialists at all levels. Oxfordshire, which has pioneered cryogenic-enabled developments such as MRI scanners, plays a leading role in the new technology.

The county has an above average proportion of higher and intermediate managerial / administrative / professionals and its workforce has a very high percentage with higher education and professional skills. Oxfordshire is England’s third most qualified county. By 2016 about half the county’s workforce had degrees. That year the largest industry group in Oxfordshire was professional, scientific and technical, accounting for 22% of all enterprises and 12% of all employees. Nearly 11% of the workforce is employed as scientific, research, engineering and technology professionals, nearly double the national average. In 2016 the two universities in Oxford and seven public sector laboratories collectively employed 18,500 people, nearly twice as many as in Grenoble. However, Grenoble had 55,000 students compared to Oxfordshire's 35,000. In Grenoble the laboratories contribute to local capacity by training graduates while working with firms and universities. In some cases, post-graduates were working with firms whilst completing their theses so both forms of engagement play a central coordination role (Lawton Smith and Waters, 2011).

Methodology

We adopt a cross comparative case analysis recognizing differences in kinds of data available (Yin, 2017). This approach offers in-depth insights and understanding of commonalities and differences across locations. There is considerable policy interest in comparative research. Krehl and Weck (2020) note that in regional and urban studies, the 'traditional' comparative case study approach is deductive and variable-centric aiming to empirically test ex-ante propositions, while a 'relational' approach focuses more on inductive process, describing causal links or configurations within a specific context or understanding the formed structures and elements of the cases. This means that the units of analysis should not be clearly bounded with exactly the same variables (Bartlett and Vavrus, 2017), and that research questions are employed as an analytical framework to analyse each case. Then, similarities and differences across compared cases or locations are drawn from observed case-specific insights, rather than cataloguing similarities and differences based on defined variables (Elwood et al., 2016). We explore the relationship between public research and knowledge organisations and processes of innovation-led regional development. The relational approach is deemed suitable for analysing and comparing the Oxford and

Grenoble cases because there are sufficient similarities to enable an analysis of what underpins the success of each region. Hence, we summarise the findings of each case instead of showing measure-for- measure comparison.

Grenoble has a detailed mapping of all actors and their collaborations in the MINALOGIC cluster through Social Network Analysis (SNA) and visualization (Assimakopoulos et al. 2016). This is done at inter-organisational level for all actors that have participated in MINALOGIC supported projects from January 2005 up to December 2012 (some funding is for 3 years so results were published up to 2015). We collected relational (network) data from 107 projects during this period (2005-2012). Extracting the consortium data we defined collaboration between two actors as their co-participation in a project funded by MINALOGIC.

Overall, 383 actors were identified and categorized into public research centers, universities, large companies / groups, SMEs and others. The actors are represented as nodes and the collaborative relationships between them as ties. Mapping the MINALOGIC cluster as a network, we focused on one keystone anchor organization: CEA-LETI dominates the MINALOGIC cluster based on its centrality measures (see Assimakopoulos et al., (2016): for a discussion of centrality measures and Table 2 below). We focused on three major long-standing relationships with other focal anchor organisations, according to the centrality measures (degree and betweenness centrality) and the weight (frequency) of the tie (collaboration). The three organizations are: the national research institution (CNRS); a large university (UJF) that is now part of the University of Grenoble Alpes; and a major firm (STMicroelectronics).

<Table 2 about here>

Oxfordshire is much less managed, looser in structure and less recorded. Accordingly the data are less structured - highlighting the differences in political culture (top down versus bottom up). The focus here is on three major long established firms and their dyadic relationships with the science base which (like Grenoble) consists of state funded research laboratories and local universities, and on changing relationships with other local firms. A series of studies on the Oxfordshire high-tech economy dating back to the mid-1980s, with follow up studies in the mid-1990s and mid-2010s, forms the basis of the Oxfordshire evidence. In 1985, 182 local firms were identified as advanced technology firms. Of these, 164 firms agreed to be interviewed. We explore what has happened to the 182 firms by tracing and collecting the data from the periods of 2010-2015.

In all, 170 companies were traced due to some firms having closed, merged or been acquired. Out of these, 15 companies were available for interview. Senior managers were interviewed using an updated version of the original semi-structured questionnaire to find out what had changed in their operations, growth, innovation activities, links with universities / research institutions and inter-firm networks. For this comparison, the three largest were chosen as being the closest equivalents to firms in Grenoble and potentially fulfilling similar roles. During the interview process, we discovered that in most companies, the dyadic relationships with PRIs have been changing and in many cases fading over time. The three examples illustrated in Oxfordshire were selected based on continuing relationships with the PRIs since their inception until 2015. Oxfordshire has no cluster management organization to collect and publish the complete directory of membership and activity. From the outset we focused on the cryogenic innovations as part of KETs and local anchors' knowledge assets, and labour skills development as evidenced and underpinned by the strong dyadic relationships.

ANALYSIS

In both our cases, we focus on the three most important dyads that focal organizations form with the keystone anchors in Grenoble and Oxford (CEA-LETI / Oxford University). While both illustrate the results of multiple anchors, we draw conclusions on the differences between them and on the network architectures emerging in the two clusters.

Grenoble

CEA-LETI is the dominant actor (highest centrality see Table 2) and keystone anchor for the most significant dyads (two thirds of all actors are directly connected to CEA-LETI, see Table 2 for Ego-Network) inside the MINALOGIC cluster (Assimakopoulos et al., 2016). Its main objective is the maximization of the research impact of public research for KETs in the Grenoble cluster. Valorization of research outputs and opening CEA-LETI's world class knowledge assets and research infrastructures to industry and local firms facilitates the formation process of the cluster as well as production and transfer of knowledge in the cluster (Feldman, 2003). The other regional actors are positioned around this large public research laboratory, forming a cohesive sub-group of focal anchors forming the core of the local cluster architecture. Consequently, the knowledge that this keystone anchor generates or acquires can diffuse quickly to other anchor organisations and vice versa, facilitating knowledge transfer between actors overall (74.63% of the initial graph's edges are part of CEA-LETI's Ego Network, see Table 2). This is mainly achieved by strong (multi-stranded) cooperation with different anchors, as well as extending the CEA-LETI's reach to SMEs and all kinds of actors in the cluster network. If we remove CEA-LETI then three quarters of all actors -edges would disconnect from the main actor in the graph. More importantly, as the keystone anchor, CEA-LETI controls 60% of the knowledge flow in the cluster, and its betweenness centrality is three times higher than the second anchor (CNRS).

We also observe a star structure in the tightly knit core of the network, having as centre the keystone anchor (CEA-LETI), while we focus on the dyadic relationships of this anchor organization with the three other central anchors. All these relationships have CEA-LETI as one half of the dyad. CEA-LETI creates strong dyads with CNRS, showing how French state and regional agencies cooperate to promote innovation in KETs in the Auvergne-Rhone-Alps region, with STM, demonstrating knowledge creation and transfer flows to industry and vice versa, and with UJF, showing the application and diffusion of scientific knowledge in strategic areas of interest.

Dyad no.1: CEA-LETI and CNRS

CNRS is active in maintaining partnerships in projects with important proximate knowledge creating institutions (such as the University of Grenoble Alpes and its various joint research laboratories with the CNRS). Its EU and international partnerships are part of the portfolio of wider CNRS research organization at national and European levels. CNRS is an integral part of the national research centre, while CEA-LETI is the dominant keystone regional anchor, fairly independent from other parts of the CEA (specialized in other types of KET). CNRS research activities and projects are often complementary to those of CEA-LETI. As a result, they inter-changeably lead and co-ordinate numerous collaborative projects under the MINALOGIC aegis. They also participate in many EU and international projects and in the diffusion of scientific knowledge within the cluster. This allows them to cooperate, coordinate and participate in collaborative projects independently from each other.

While CEA-LETI intensively promotes the cooperation with local SMEs within MINALOGIC, CNRS cooperates more with big industrial groups and private firms. CNRS appears as the representative of the national innovation system in the region, concentrating knowledge from big firms. CEA-LETI includes more local SMEs, fostering further development of the cluster architecture. When these two research organizations cooperate, they create and share expertise for the production of new knowledge in KETs. As they cooperate widely, their direct dyadic ties are surrounded by a large number of additional ties (34% of the cluster), facilitating knowledge flows and connecting an array of other players in the cluster via multiple paths.

Dyad no.2: CEA-LETI and STM

STM has established a strong culture of partnership and a far-reaching network of strategic alliances with important customers, suppliers, competitors, and universities and research institutes worldwide. Although it owns a wide product portfolio with customers across the spectrum of micro- and nano-electronic applications, and strategic partnerships and manufacturing strengths worldwide; its largest research and new product design and development facility remains in Grenoble with over a thousand scientists and engineers. STM has recently focused its product strategy on sensor and power technologies, automotive products and embedded processing solutions. Its Grenoble division is the largest industrial employer in ICT in the region. The cooperation of CEA-LETI and STM ensures encouragement of the private sector in knowledge production with a clear orientation for developing knowledge near to the market and commercialization of products. The participation of local SMEs and smaller industrial groups in MINALOGIC cluster activity is further enhanced because CEA-LETI supports local firms, and STM's business units in Grenoble outsource the development of designs and components to local SMEs.

The long-standing collaboration between CEA-LETI and STM demonstrates how this dyad encourages knowledge transfer between private and public institutions in a bi-directional flow through multiple paths, thus changing the structure of public private networks and the positions of actors within them (Ferraro and Iovanella, 2017). Various programmes have enabled employees to start their own firms, receiving initial support from STM. In case of failure, they are offered their previous job back. Its existence facilitates the creation of knowledge flows inside the region and also connects it extensively outside the region. This can increase local firms' participation in knowledge creation and can reinforce CEA-LETI as a knowledge broker. Without this dyadic relationship, potentially private actors would be excluded from the knowledge production and transfer process. Another possible consequence could be an isolation of entire industrial projects.

Dyad no. 3: CEA-LETI and UJF

UJF is one of the leading French universities in science, technology and healthcare related disciplines. UJF is now part of the University of Grenoble Alps (UGA). UJF has fifty laboratories in fields related to medicine, science and technology and close partnerships with national and international universities. It promotes their research outputs through a private subsidiary, which manages university-industry relationships. In the last fifteen years, 35 start-ups have been created by UJF scientists and researchers. In this dyad are CEA-LETI as public research centre and UJF as leading academic institution, UJF adds co-operations with national and international academic institutions and some local SMEs, thereby constituting a broker for academic knowledge in the region. It encourages flows towards research centres and from them to industry or directly to local firms. Projects involving both include local firms (SMEs or industrial groups), and other French universities. UJF is thus an indispensable node and a collaborator of CEA-LETI, facilitating knowledge produced in academia to be diffused in the local cluster, and in strengthening human capital.

In sum, the linkages within the dyads of these public actors, either with other research centres or universities, produce expanded networks that reach almost 80% of the entire cluster network. The combination of a research centre and a university produces networks that connect the more peripheral parts of the initial network. However, the cooperation of research centre directly with university only happens occasionally - but is then rich in participants. The dyad between research centre and industrial group appears more frequently. Taken together these findings suggest that the industrial group gives trust to the knowledge produced by the research centre.

Oxfordshire

In Oxfordshire the focus is on the changing forms of dyadic relationship that Oxfordshire research laboratories form within our first two dyads and on Oxford University in the third. Contrary to Grenoble, the anchoring activity in Oxfordshire shows a mixture of stability but also considerable change in the nature of the strong local dyadic relationships. This reflects differences in the policy contexts in the two countries which are then influential in creating and sustaining different kinds of cluster architectures.

Dyad no. 1: Oxford Instruments' dyadic relationships

Oxford Instruments was established by an Oxford University academic in 1959. It is a leading provider of high-technology tools and systems for industry and research. It is the industrial founder of the Oxfordshire cryogenics cluster, 'cryogenics valley' and is continuously reinforced over time (Lawton Smith, 1991). It has spun-out a number of companies and has contributed to the region's dynamism of innovation through new products and services. Design is mainly local but now one third is not in Oxfordshire. The firm's role as a driver of the local production system in Oxfordshire has largely disappeared as production has ceased and local subcontracting, very important initially, has effectively ended. Links to some local firms, including SMT, remain. Although the dyadic relationships of Oxford Instruments have changed over time, the company makes a significant contribution to the regional high-tech economy and reinforcing the cluster architecture around KETs, particularly cryogenics. Relationships with individual research laboratories comprise labour market exchanges, customer-suppliers, and knowledge generation and exchange. The main two dyads are strategic couplings with several laboratories based on knowledge exchange and on inter-changes of skilled labour.

Oxford Instruments and the STFC including RAL have collaborated for over 40 years on the development of many KETs including superconducting wire and magnets, particle accelerators and applications of cryogenic technology (Science &Technology Facilities Council, 2012). Research and business relationships with the local research laboratories began with the atomic energy laboratories, then with RAL. The current Oxford Instruments CEO has driven links with RAL, sharing knowledge and employees. The company and the research labs sit on each other's management committees. Links with laboratories have increased in importance over time. Oxford Instruments staff identify themselves as belonging to the same 'research community' as staff at the ISIS Neutron and Muon Source based at RAL.

The dyadic relationship between Oxford Instruments and Oxford University began when the then CEO was employed in Oxford University's Clarendon Laboratory (physics) and recruited Oxford University academics to its Board. That link has been lost. While the overall importance of links with universities as a whole has remained, the links with Oxford University have declined. Collaborations now take place with a wide range of universities but only one project is with Oxford. This is indicative of how strong dyadic relationships can weaken and evolve over time.

Underpinning these changing dyadic relationships and contributing to the local cluster architecture is exchanges of skilled labour. This has played a key role brokering knowledge flows and coordinating activity (Kasabov and Sundaram, 2016). Indeed, the most important relationship is that of local recruitment. Oxford Instrument's workforce is highly skilled: over half have first degrees. A recent interest in a different KET, life sciences, has changed the profile of the company's workforce. It recruits strongly from the local labour market for both technologies, especially for production skills having a stable local recruitment pattern (Gillies, 2017). The company also has a graduate programme designed to encourage mobility within the firm, increasingly bringing overseas talent to Oxfordshire where poaching from the local laboratories is common. Harwell laboratory's apprentice programme was a major source of technicians for Oxford Instruments. Later RAL has also been a supplier of technicians to the local economy.

Dyad no.2: Siemens Magnet Technology, (SMT) and Oxfordshire Research Laboratories

In 1989, Oxford Magnet Technology (OMT), a spin-out from Oxford Instruments, became a joint venture between Siemens (51%) and Oxford Instruments (49%). In 2003, Siemens bought the remaining 49% and it became Siemens Magnet Technology (SMT). SMT is the world's leading designer and manufacturer of superconducting magnetic resonance imaging magnets for medical applications. SMT's dyadic relationships take the form of market relationships with its former parent company, as well as local recruitment and knowledge exchange with local research institutions.

R&D covers all aspects of product design, including materials, mechanics, software, system co-ordination and project management. The Oxfordshire site is the design authority for all of them: 70 scientists and engineers work on R&D. Products are wholly designed in Oxfordshire. Company policy emphasizes the effectiveness of having R&D and manufacturing co-located. The firm holds more than 100 patents. The workforce is highly skilled. In 2015, 40% had at least a first degree (10 had PhDs and 60-70 MSc). The company recruits undergraduates as interns, and many are subsequently employed permanently. It also recruits 10-15% of its engineers and cryogenicists from overseas, while 75% of the shop floor and white-collar staff are recruited within Oxfordshire. The impact on local production systems arises from being a centrally important company in the Oxfordshire cryogenics cluster. The company benefits from this knowledge excellence and access to skilled labour.

Dyad no.3: Sophos and Oxford University

Sophos, established by two post-docs in the Department of Engineering, Oxford University, became a PLC in 1993 part-owned by a private equity company, and in 2019 was acquired by Thoma Bravo. Sophos has grown continuously over three decades to become a multinational data security company producing anti-virus software. Its dyadic relationships within the county are more to do with recruitment than other forms of engagement. Other cluster benefits involve branding and reputation.

The underlying driver for the firm's growth has been innovation. Innovation has enabled Sophos to introduce new products, often based on new technologies, into the market. They have more than 11 patents with more than 50 patents pending. Their R&D expenditure has increased from 12.9% in 2004 to 26.9% in 2009. The Sophos site in Abingdon remains its largest location although its share of the operation has declined: in the mid-2000s, Abingdon accounted for over half of the Sophos workforce (around 300 staff). Most future physical growth is now likely to be outside Oxfordshire.

The company has an important relationship with the University of Oxford and to a lesser extent with Oxford Brookes University. In the former case, the dyadic connection is that of enduring network relations (Klaster et al., 2017), based on the company founders' links with academics, on part-time lecturers working in the company, and on the presence of academics on the board. In the case of Oxford Brookes, the connection is shorter-term being based on links with the university career service. Sophos has no formal collaboration with Oxfordshire-based firms. The prestige and the innovative environment of Oxfordshire has been an important enabler for Sophos' innovation. Research links, the international reputation of Oxford and the attractiveness of the county seem to be the main reason for Sophos being embedded in the region. Moreover, since 2004 the firm has expanded R&D operations and markets outside the UK increasing its overseas offices from 4 in 1999 to 13 in 2009. As a result the revenue from international operations almost doubled between 1999 and 2009.

The evidence here suggests that for all three anchor firms, more staff are recruited from outside the UK as the local economy becomes increasingly internationalized since 2005, thereby weakening knowledge flows with other local organisations (Bathelt et al., 2004). This is especially true of Sophos.

CONCLUSIONS

The paper set out to re-think the single 'anchor-tenant' hypothesis (Feldman, 2003) and make a contribution in relaxing the single 'anchor' hypothesis when we observe multiple anchors in data collected over a period of nearly 20 years. We identify significant differences in how policy affects strong relationships between the keystone anchor knowledge organization and other anchors driving cluster development in two regional clusters in Oxford and Grenoble (Lawton Smith, 2003). Indeed the context is how different national policy priorities have provided incentives for the continuity or change in the territorial roles of the anchor public research organizations (Oxford University and CEA-LETI) in each place. We observe that although the 'rules of the game' have changed in the UK, they are nevertheless nowhere near as pronounced as those in France.

Drawing on multiple data sources, including data from different points in time, we have illustrated changing cluster architectures within two context sensitive case studies (Ferraro and Iovanella, 2017), showing a divergence in patterns of collaboration for innovation. While having some disadvantages, the adoption of two different approaches has enabled several insights into the changing internal dynamics of clusters and their architectures. It has enabled a closer perspective on the functions of multiple anchors, the kinds of interconnectivity in dyadic relationships, and how relationships are brokered and in some cases reconfigured over long periods of time. It has also enabled key similarities as well as differences in brokerage to be highlighted, thereby giving tools for the comparison of other clusters.

What is different is the density of relationships in Grenoble compared to Oxfordshire. The character of the cluster architecture in Grenoble is purposely brokered around CEA-LETI the keystone anchor and electronics laboratory with high embeddedness of the additional key anchors to the cluster networks. This is a result of French cluster policy introduced in 2005. We observe that while the importance of knowledge and information resources is similar in each location, only in Grenoble are those resources locally orchestrated by a dedicated publicly funded Cluster Management Organization (CMO), i.e. MINALOGIC. This is through strong relationships among key multiple anchors, particularly through the purposeful brokerage role of MINALOGIC which has built long standing relationships between regional anchors that benefit from co-location (Boschma, 2005). This is a de facto cooperative technology paradigm (Bozeman, 2000; Doloreux and Turkina, 2021) enacted at the local level with funding and institutional support from government. While there are elements of this in the UK, there is no equivalent policy or CMO.

Instead, the UK has continued to provide extensive funding for scientific research which has underpinned concentrations of expertise (cryogenics, bio and med-tech) providing high-level knowledge and information resources. In Oxfordshire, the world-class cryogenics cluster has been strengthened but it has not been underpinned by the same set of national policy brokered relationships. Hence while the state is of paramount importance as a research funder, in Oxfordshire there is little evidence of strong relationships, (for example with RAL), for explicitly linking the science base to the cryogenics cluster development. The continuing importance of national science funding leads to varied and often opportunistic knowledge exchange relationships, a pattern reinforced by the successive siting of new research infrastructure, for example of the new Vaccines Manufacturing and Innovation Centre located at Harwell, announced in April 2020, following Oxford University's development of a major Covid-19 vaccine.

Rather than knowledge and information resources being the dominant feature, in contrast with Grenoble, local recruitment is the main underlying "free labour market" broker of dyadic relationships in Oxfordshire. The dominant model is of mobility within local, national and international labour markets, as well as sustained concentrations of skills in technologies such as cryogenics. As with Grenoble, links with the group of research laboratories have remained important for two of the leading firms (Oxford Instruments and SMT), based on relevant local concentration of expertise. The primary underpinning of dyadic relationships is the quality of the local labour market, which is being reinforced over time enabling local exchanges of skilled labour (between firms and between firms and the laboratories). For example, the apprentice training role that at Harwell ended when research ceased, was continued by RAL (Lawton Smith, 2003) and strengthens the local labour market. The overall effect is that the county maintains its position as a world leading centre of research and innovation, with local spillover effects through local recruitment (Niosi and Zhegu, 2010). In order words there is an association between the presence of high skill/high wage employees, the sophisticated business environment and cluster development (Ketels and Protsiv 2021).

Noticeable in Oxfordshire is the strong personal relationships which foster networking between anchor firms and research institutions in dyadic relationships (weak ties, Granovetter 1983). These may well exist in Grenoble but are not visible in the data, mainly provided by the CMO at the project and organizational levels of analsysis. While Oxford Instruments and Sophos have their origins in Oxford University, early strong personal links have become relatively less important over time. We suggest that the explanation for these differences is found in a combination of perspectives (Casper, 2013) related to how dyadic relationships between anchor institutions and firms (Smallbone et al., 2015; Denney et al, 2021) are formed and purposely brokered leading to changing characteristics of the individual places. We show that the importance of place and proximity (Boschma, 2005) in clusters is sustained, but for different reasons.

Even though France remains characterised by top down big spending, public sector-led development, taking advantage of government labs as ‘anchor institutions’ (Feldman, 2003) it has reinforced their territorial role. At the local level, different organisations have been co-opted into processes of technological innovation via purposeful brokerage. The dyadic relationships created between key influential anchors and the keystone anchor institution create a polycentric core of ‘local anchors’ in the network, connecting different and distant parts of it. This process in Grenoble case is orchestrated to a large extent by MINALOGIC, the local CMO, and the high centrality of CEA-LETI as a keystone anchor. Continuing cluster funding sustains these “strong” dyadic relationships, hence cluster competency (Baily and Montalbano, 2018) as well as purposeful brokerage and networking, shifting the emphasis over time from hardware to software and services near to the market, and from large players to SMEs and their variegated collaborative project networks. The CEA remains the dominant anchor and recipient of public funding in Grenoble, even though it is its civil arm, CEA-LETI that is the key anchor and orchestrator in the local cluster architecture.

Rather differently, Oxfordshire's dyadic relationships are coordinated more by public-private partnerships and privatisation of national assets. This is alongside the strong effects of highly skilled labour markets particularly within such specialised clusters which serve to interact with other processes in the evolution of the locality. Dominant national research funding has maintained the science base and knowledge and information resources continue to be shaped by previous local and national developments rather than a coherent regional strategy. For example, nuclear fission research was of primary importance in the cluster architecture in Oxford not least because of the supply of technicians to firms such as Oxford Instruments.

The Grenoble / Oxford comparison highlights both the differing relative importance of the multiple anchors and that some "rules of the game" are more important than others and have differing outcomes in terms of the underlying cluster architectures. Even though the kinds of data available differ, the evidence shows that both regions are the national hubs for advanced technology. In Grenoble, public funding directed at cluster development is crucial to the future, while in Oxfordshire public money sustains the science base. In both places, however, strong dyadic relationships between anchor organisations and firms would be unlikely to be sustained without ongoing public policy intervention nurturing big science, KETs and regional innovation for a competitive future.

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