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Distributed innovation processes (DIPs) and the dynamics of knowledge tradability

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Distributed Innovation Processes (DIPs) and the Dynamics of Knowledge Tradability

Sally Gee

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Abstract

This paper draws on two extensive case studies to explore how the co-production and exchange of knowledge is organised during innovative activity. In the empirical cases multiple, transient innovation systems emerge, and self organise, around a particular problem. The emergence and evolution of these innovation systems involves the mutual intrapenetration of market and non-market forms of exchange. The cases suggest that economic markets and knowledge acquisition networks are not alternative forms of economic organisation but are co-dependent and mutually embedded.

Keywords

markets, networks, evolution, innovation, systems

JEL Classification

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1.0 Introduction

Innovative activity is characterised by dynamic processes, often involving a wide range of economic agents and institutions. The systemic nature of innovation is well discussed in the literature and authors have drawn the boundaries of innovation systems in different ways in order to emphasise particular characteristics. By discussing sectoral, national or technological systems we are able to identify features peculiar to a given domain. Bounding systems in this way has many advantages but also some key disadvantages. Sometimes (and only sometimes), in order to emphasise the key characteristics of an innovation system, the literature focuses on identifying and defining the important institutions and economic agents in a spatially or technologically bounded system at a particular point in time. As a system is defined by 'connectedness', i.e. the interdependence and organisation of system participants for a specific function, research concerned with economic agents and institutions rather than relationships could be more accurately described as studying 'ecologies' of innovation. The 'naming of parts, although useful, fails to capture any both the connections and the system dynamics¹. Another disadvantage of bounding a system spatially, sectorally or even technologically is that we miss certain elements of the innovative process, for example in emergent systems which transcend given boundaries. The position taken here is that innovative activity is characterised by multiple, transient systems which are organised around, and defined by, a given problem or function. So innovation systems transcend national and sectoral 'ecologies' of innovation yet are affected by, and embedded in, them. In summary, this paper assumes the innovation system is transient, dynamic, embedded in multiple ecologies and emergent around a given problem. The system as a whole evolves, and elements of the system emerge, stabilise and disintegrate over time. It is the nature of these system dynamics which are discussed in this paper.

In an evolving system, boundaries, agents and interactions are continually being defined and redefined. In order to explore the dynamic nature of linkages within an innovation system we use the distributed innovation processes (DIPs) approach. The DIPs framework is primarily concerned with the processes of instituting/re-instituting/de-instituting relationships and facilitates a more fine-grained analysis than much of the systems approach². The DIPs approach identifies three aspects of 'distributedness' (Coombs et al, 2003) or connectedness; the forms or *modes* of relationships, the *dynamics* of inter-agent relationships and the *scales* of the distributed relationships. By using case studies of protracted innovation processes it is possible to explore what forms of relationship are exhibited in an innovation system and how these evolve over time. As the creation and exchange of knowledge is central to innovative activity we focus the analytical lens on the inter-organisational linkages employed for these activities, particularly collaborative relationships and licensing activity. The decision to focus on collaboration and licensing is partly empirically driven; these formal relationships are more visible. However, there is also a puzzling theoretical aspect to studying these two types of relationships; namely, the empirically observed increase in collaborative relationships and licensing agreements is used as evidence by two 'competing' theories of economic organisation (networks

¹ This is not to say that all systems approaches are non-dynamic. For example, McKelvey et al (2006) provide a wonderful evolutionary analysis of the pharmaceutical industry.

² It should be noted that when the level of analysis is a 'competence bloc' Carlsson's technological systems approach is similar to the DIPs approach (Coombs et al, 2003).

and markets). On the one hand, network proponents focus on collaborative relationships to argue that the co-production and exchange of knowledge for innovative activities is organised in networks, rather than in hierarchies or markets (Powell, 1990; Powell et al, 1996). On the other hand, market proponents focus on the increase in licensing agreements to argue that scientific and technological knowledge is increasingly subject to market-based transactions (Arora et al, 2001). Although the emphasis in each approach is different, i.e. the network literature focuses primarily on collaboration and the markets literature focuses primarily on licensing agreements, both approaches include collaboration and licensing agreements in their analysis, either as a type of network 'tie' or a 'market transaction'. As collaboration is broadly agreed to be a longer-term learning-based relationship in the innovation literature, the most obviously puzzling aspect of this is the inclusion of licensing in both approaches. The markets for technology approach rests heavily on the premise that licensing agreements can be defined as relatively discrete transactions for technological knowledge yet the network literature views them as relatively stable organisational linkages. We ask how these competing frameworks are effectively used to analyse the same phenomenon; collaborative relationships and licensing agreements. We consider how the focus of analysis differs in each approach and what is not captured. How can collaborative relationships be effectively characterised by the network approach, yet also described as transactions for technological knowledge? How can licensing relationships be effectively characterised as network ties yet provide the empirical evidence for the markets for technology framework, which promotes discrete, as opposed to relational, transactions? Is it possible that the two approaches are suited to different time scales? Is there a broader issue with the categories of collaboration and licensing agreements? Are the network and markets literatures complimentary rather than competing? Is there a more useful analytical tool for understanding the creation and exchange of knowledge? We tackle these questions by following the unfolding of two broad innovation processes and providing a detailed analysis of exchange in terms of market and non-market processes. We hope to move beyond the overly dichotomous perspective of economic organisation as markets *or* networks. This dichotomous perspective tends to promote one form of organisation at the expense of the other, resulting in an incomplete understanding of exchange processes and ineffective/inefficient interventions by policy makers and other institutional actors.

The paper draws on original empirical research in the field of scientific instruments. Two large case studies are outlined. The first discusses an instrumentation company, Amersham Plc. (now part of GE Healthcare), and their involvement in the development of automated DNA sequencers. This empirical case covers a period of 18 years. The second case is centred on the pharmaceutical company GlaxoSmithKline (GSK) and their involvement in the development of protein crystallography instruments. This empirical case covers a period of 7 years. In each case study, as the innovation process unfolds, a variety of inter-organisational linkages emerge, stabilise and disintegrate. The length of the cases, the methodology used, and the number and variety of involved agents, enables us to observe the emergence and evolution of two innovation systems and facilitates an analysis of the mechanisms employed by organisations for the co-production and exchange of knowledge.

The remainder of this paper is organised as follows; in Section 2 I review the positions taken in the ‘network’ and ‘markets for technologies’ literatures on the co-production and exchange of knowledge, focusing primarily on collaboration and licensing agreements. In Section 3 I provide an overview of the methodology and the empirical case studies on which this analysis is based. In Section 4 I analyse the fit between the empirical cases and the network and markets approaches. In Section 5 I conclude by discussing the contributions and limitations of this paper.

2.0 The co-production and exchange of knowledge

The increasingly networked organisation of innovative activities has received a great deal of attention in the literature over the past two decades. There is a strong link between the increasing complexity of technologies, the distribution of knowledge necessary to innovate and the empirically observed increase in inter-organisational relationships. Innovative activity draws on multiple sources of knowledge embedded in multiple organisations, and this necessitates some kind of inter-organisational involvement. The nature of this involvement, or exchange, is usually either defined as market-based or network-located. The increase in collaborative relationships is of interest to economists as transaction cost analysis (Williamson, 1975, 1985) tends to predict a low relative efficiency of this arrangement. Researchers drawing on transaction cost theory discuss the networked form of organisation as a hybrid to either the market or the hierarchy. Collaboration at one extreme is viewed as quasi-vertical integration or at the other as an alternative to pure market transactions (Barbanti et al, 1999). Despite the limitations of using transaction cost theory to explain collaborative relationships and networks forms of organisation it is often invoked as a framework for discussion. In contrast, interdisciplinary and sociological studies tend to argue that networks represent an alternative type of economic organisation, distinct from markets or hierarchies, used for exchanging resources and value-creating assets (Powell, 1990; OECD, 1992).

2.1 Networks for learning

Powell (1990) compellingly argued that networks are not a hybrid form of economic exchange but a distinctive, and increasingly dominant, way of organising economic activity. The crux of Powell’s (1990) argument is that discrete market exchanges only play a marginal role in the economy and that organisations increasingly enter into long-term interdependent relationships where the outcome of the exchange is not easily measured and the organisational boundaries of the participants are relatively permeable. Additionally, Powell and colleagues argue that relational ties, and social networks, enable and embody the exchange process. That it is not sufficient to discuss a market or a hierarchy as this fails to encapsulate the social (individually centric) element of exchange, or economic organisation generally.

Powell and colleagues (1996) stress *learning* as the dominant characteristic of the co-production and exchange of knowledge process and argue that when knowledge is broadly distributed the locus of innovation is the network. Learning is a process that involves relatively long-term iterative exchange, trust and reciprocity; characteristics not associated with economic concepts of market transactions. Knowledge sharing, and learning during knowledge transfer or creation, involves tacit as well as codified knowledge. As tacit knowledge is person-centric, personal interaction, or mobility, is

(for the most part) the only channel by which tacit knowledge can be transferred (Senker and Faulkner, 1996). The conversion of tacit to explicit knowledge is a critical mechanism underlying the link between individual and organisational learning (Nonaka and Takeuchi, 1995) and new knowledge creation is a dynamic process involving personal or social interaction, as well as individual and collective interaction with explicit, or codified, knowledge (Nonaka, 1994). It is the importance of personal interaction over a relatively long period of time during the knowledge creation process that motivates organisations to form collaborative relationships.

Collaborative relationships are the primary focus, and main empirical evidence, of the network approach; however other types of organisational linkage are described as network 'ties'. These linkages serve to strengthen network structures as organisations establish patterns of repeat trading and access to the network becomes restricted. However, other inter-organisational linkages, such as licensing agreements and the acquisition of partial equity are not given as much analytical attention as collaborative arrangements in this literature; as previously discussed, licensing is generally referred to as a type of network 'tie' (for example, Chesnais, 1996, Powell et al, 1996) or grouped under the umbrella of collaboration and alliances (for example, Hagedoorn, 1993, Stuart et al, 2007, Lowe and Taylor, 1998, Rasmussen, 2002). Authors tend to incorporate a wide variety of organisational linkages into network analysis, or alternatively focus specifically on relational collaborations. Despite, or possibly because of, the inclusion of a wide variety of these 'ties' there has been little detailed analysis of non-collaborative arrangements within this stream of literature.

Additionally, although the increase in patenting and licensing behaviour is invoked as evidence that organisations are increasingly inter-linked, very little is discussed about the tradability of patents. In lieu of this gap in the network literature some economists have argued that the increase in patenting and licensing agreements demonstrates that knowledge is increasingly subject to market-based exchange. Arora et al (2001) refer to the increasing codification of technological knowledge in patents, and argue that this facilitates the exchange of knowledge as a market transaction. Patenting and licensing agreements provide the main empirical evidence for the 'markets for technology' approach.

2.2 Trading technological knowledge

As previously emphasised, a number of authors have argued that stronger and clearer intellectual property rights have facilitated the development of a market for the acquisition and sale of industrial technologies (Mowery and Rosenberg, 1998; Arora *et al*, 2001; Granstrand, 2004). Arora, et al (2001) argues that there has been an increase in market transactions for technologies, ideas, knowledge and information, demonstrating that a 'market for technology' is emerging. The crux of this perspective is that a 'market for technology' exists due to the increasingly codified nature of scientific knowledge, and that this presents firms with new strategic decisions: licensing or self exploitation (Arora et al, 2001), or 'make or buy' (Lowe and Taylor, 1998). The Arora et al (2001) study presents a simple typology of 'markets for technology', defining markets for existing technology (e.g. licensing) as well as future technology (e.g. collaboration) and then categorises these in terms of horizontal or vertical transactions.

This approach stresses the increasing codification of technological knowledge which enables economic exchange as a discrete market transaction, most visibly in the form of licensing agreements. In comparison with collaboration, licensing is a relatively arms-length and discrete form of exchange between agents (Tidd et al, 1997), mainly because the exchanged knowledge is pre-existing and explicit. The knowledge is codified in a patent and the licensing agreement confers the right to use that knowledge. A licensee will usually possess 'absorptive capacity' enabling them to both identify the licensing opportunity and effectively transfer the technology(ies) in-house. Within this broadly economic perspective licensing relationships are often discussed as relatively simple and uniform agreements between organisations. This definition of licensing agreements conforms to market-centric analysis as the patent is defined as a tradable object and the license as a single (or short term) transaction³.

A tentative definition of a transaction for technology is given in the Arora et al (2001) paper. The authors state that "strictly speaking, market transactions are arm's length, anonymous and typically involve an exchange of a good for money" (p422). The authors acknowledge that transactions for technology usually fail these strict criteria as they often involve quite detailed contracts and may be embedded in technological alliances. This relates to "the peculiar nature of technology as an economic asset and as a potential object of exchange" (Arora et al, 2001, p422). This seems to indicate that when technological knowledge is exchanged it cannot be wholly described within the transaction economics tradition, yet despite this definitional problem a stream of literature refers to licensing as a market-based transaction between firms, for example, Grandstrand (2004) defines technology trade as the buying and selling of technology in some kind of market.

Outside the network literature, yet within innovation studies generally, a number of authors have demonstrated that licensing cannot be characterised simply as a market-based transaction. For example, Howells et al (2003) argue that although licensing is perceived as relatively straightforward contractual agreement, technological knowledge sourcing is not simply a serial, stand-alone process, but more frequently a simultaneous or parallel process. Often licensing relationships are embedded within collaborative relationships or other categories of inter-organisational linkage. Other research supports this; Anand and Khanna (2000) found that licensing agreements in some industries are more likely to be signed with firms with whom the licensor has prior relationships, established either through alliance activity, common board membership, or personnel histories. These observations demonstrate the contextual background to exchange and emphasise the multi-faceted and dynamic nature of relationships. Relationships in this context evolve over time and if licensing is primarily a market-based based transaction, these transactions are embedded in some kind of pre-existing network. This echoes Powells ascertain that networks 'crystallize' as a result of persistent communications (or types of exchange) that become self-replicating, and enable other forms of relationship to develop. Despite the reservations of researchers sympathetic to the network approach there is, to my knowledge, very little explicit consideration of license agreements as a mode of exchange for scientific and technological knowledge outside the market-orientated

³ At least in the negotiation stages; the license will often persist for some time and link (or tie) the organisations together.

literature. Broadly licensing is referred to broadly as a type of network tie, or considered as a transaction for knowledge in a technology market.

3.0 Methodology and empirical cases

In order to further explore the nature of exchange during the innovation process I use two large meta-case studies following the development of two different families of technologies at two large firms. A variety of economic agents were involved in these protracted innovation processes and each of the relationships is treated as a mini-case study within a larger meta-case. At least one participant at each organisation involved in the innovation process was interviewed, and secondary data was collected from a variety of sources, including Investext plus, FACTIVA, internal documentation, the U.S. Securities and Exchange Commission (SEC) and the internet. Primary data was collected by semi-structured interview over an hour and a half using a snowball interview technique starting at the two central firms. In total 27 individuals were interviewed and each of the key informants held a senior R&D and/or management position, for example, they included inventors, intellectual property lawyers, company founders and departmental heads. This data was triangulated to present two overall 'stories'. The depth, breadth and time covered by the empirical data enables us to focus in on the detail of the different exchange processes, whilst providing a dynamic perspective on system emergence and evolution. These stories are introduced in this section and the evolution of the innovation system is demonstrated by diagrammatic representations of the inter-organisational linkages at different time points. The advent of molecular biology provides the backdrop to these two stories and I briefly review this context before outlining the case studies proper. However further detail is withheld until the next section; a discussion of knowledge creation and exchange.

The emergence of biotechnology has had a profound effect on the structure of the pharmaceutical industry⁴; both transforming the division of labour within the industry and impacting on internal processes. Molecular biology offered firms an opportunity to move from the traditional chemical paradigm of drug discovery characterized by 'brute empiricism' (Nightingale, 2000) to a more 'rational' process. This journey began with researchers comparing maps of genetic sequences with good clinical characterizations to identify the relationship between genetic markers and disease states. This process was referred to as 'reverse genetics' and was facilitated by advances in automated DNA sequences technologies in the mid-1980s (Nightingale, 2000).

⁴ Much has been written about the impact of biotechnology on the pharmaceutical industry, see for example, Mangematin et al (2003), McKelvey et al (2006), Orsenigo (1989), amongst others.

Automated DNA Sequencing

DNA sequencing is one of the core techniques in molecular genetics. It is a method used to decipher the inheritable information that is encoded within deoxyribonucleic acid (DNA) that is present in the cells of all multicellular organisms in structures called chromosomes. Contained within chromosomes are lengths of DNA known as genes. Genes are transcribed into messenger ribonucleic acid (mRNA) molecules which are in turn translated into proteins that form the basis of biological life,

DNA sequencing is usually carried out by dideoxy chain termination method (invented by Sanger). Crudely, this involves marking genes, separating them by gel electrophoresis, using a detection tool and 'reading' the results. In the original Sanger method radioactive phosphorus was used as a marker to identify the segments of DNA; the process was manual, time consuming and required skilled technicians. In automated DNA sequencing the basic principle remains unchanged but radioactive markers are replaced by fluorescent dyes able to be read by lasers; the electrophoresis of DNA and the detection and analysis of sequencing reactions is carried out by instruments controlled by computers.

During these early advances in genomics, there were corresponding advances in proteomics. Proteins, rather than genes, are typically the targets of pharmaceuticals. Proteomics is the large scale analysis of proteins and has become one of the most important disciplines for characterizing gene function, for building functional linkages between proteins molecules and for providing insights into mechanisms of biological processes in high through put (HTP) mode (Zhu et al, 2003).

In traditional drug discovery, scientists identify new drugs either by 'tinkering' with existing drugs or by screening thousands of compounds in the laboratory. Scientists can use an entirely different approach to identify new drugs if they can determine the structure of the target molecule (often a protein). Once the three dimensional structure of the protein has been determined scientists can use molecular modelling on a computer to investigate their target molecule. The target is often an enzyme and by determining the structure it is possible to see the 'active site' of the enzyme (often envisaged as a 'lock'). Some molecules have the potential to block this active site and can be envisaged as specific 'keys'. In theory, once a molecule, or key, has been identified that fits the lock, scientists use it as a lead molecule in the discovery search, or at least vastly reduce their search area. This process is referred to as structure-based drug discovery (SBDD) and has to the potential to revolutionise the drug discovery process⁵.

⁵ Although the author agrees with Nightingale and Martin (2004) that biotechnology has not revolutionised the drug discovery process to the extent expected by key industry participants, these high expectations do underpin the innovative activity outlined in the empirical cases.

Protein Crystallography

By the early 2000's a major bottleneck in structure-based drug discovery was determining the structure of proteins. The main technique for viewing protein structures is x-ray crystallography. Broadly speaking this requires a protein to be grown, crystallised and then x-rayed. However, producing sufficient quantities of materials (crystallised proteins suitable for x-ray) and finding appropriate crystallisation conditions was problematic. The instruments in the GSK case study were developed to automate the protein crystallisation process and overcome these bottlenecks.

The instruments developed for automated DNA sequencing and protein crystallography are complex, modular, pieces of equipment. The automation process necessitated the production of new knowledge, and the combining of existing knowledge, in the fields of chemistry, biology, physics and electronics. This complexity is captured by the highly distributed innovation processes, and variety of actors involved in them.

Two diagrammatic overviews of the meta-cases are shown shortly. By choosing to organise the empirical cases around specific innovative activity at given firm(s) it is possible to explore how the innovation system emerges around a particular problem and when that problem changes, or is solved, the system responds accordingly. As emergence and evolution of a system involves a process of self organisation it is useful to explore the internal processes and motivations for engaging in inter-organisational linkages for knowledge creation and exchange. Although these diagrams do not capture the internal processes (these are discussed in the main body of the paper) they providing representations of the innovation system at different points in time and demonstrate that relationships emerge and evolve. Additionally, we can see that some relationships are fairly stable yet others are relatively transient and unstable.

The two cases are summarised briefly below:

- In the Amersham meta-case the company used a variety of organisational arrangements to assemble the competencies required to enter a new market, and strategically re-orientate the company. Amersham entered into collaborative relationships with Bertin (a French defence company), Hitachi (a Japanese instrument company) and Molecular Dynamics (an American instrument company). They negotiated or inherited licensing agreements with Harvard Medical School, the University of California, Berkeley and ABI (the world leader in automated DNA sequencers). Amersham also used acquisition (including of partial equity stakes) as a tool for accessing strategically important externally located knowledge and reinforcing existing relationships, for example with USB (an American reagent company) and Molecular Dynamics.
- In the GSK meta-case the company used a variety of organisational arrangements to gain access to strategically important research tools. GSK developed a prototype instrument in house and out-licensing the patent to an

American instrumentation company (Cartesian) so they could access (i.e. buy) a well developed and commercial product. GSK entered into collaborative relationships with DCA (an American instrument/computation company) and Fluidigm (an American instrument company) to co-develop protein crystallography instruments for their internal drug discovery process. GSK also used the acquisition of partial equity stakes to reinforce strategically important relationships.

These two cases emphasise the dynamic nature of inter-organisational relationships; demonstrating how they evolve as links form, stabilise and are disrupted over time. We can see how systems self-organise around particular problems and are adapted to the needs of the participants. This detail enables us to explore the process dynamics of the co-production and exchange of knowledge (the primary motivation behind the formation of these systems) and this discussion forms the main body of this paper

Figure 1: The emergence of the innovation system in the Amersham case study

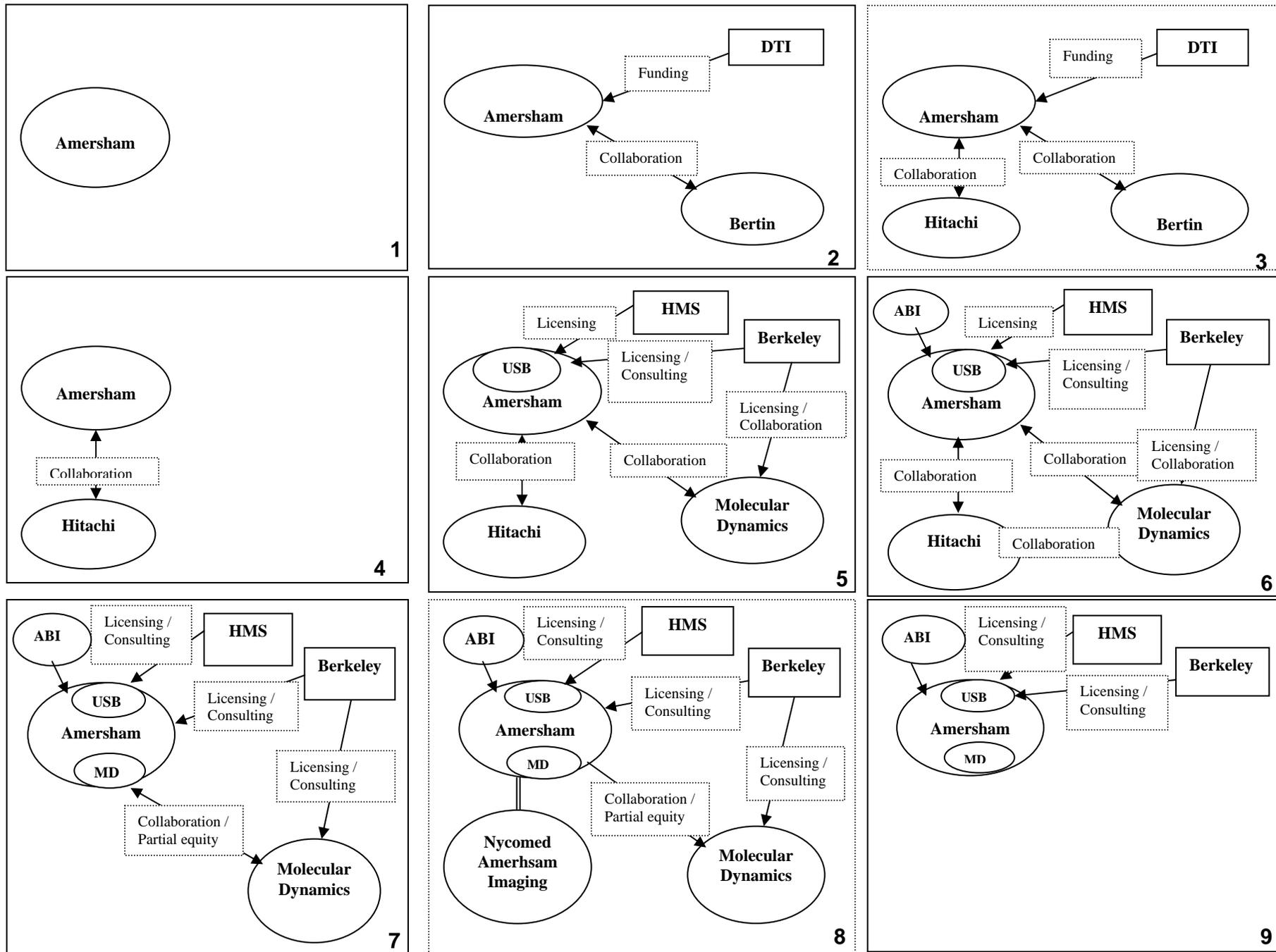
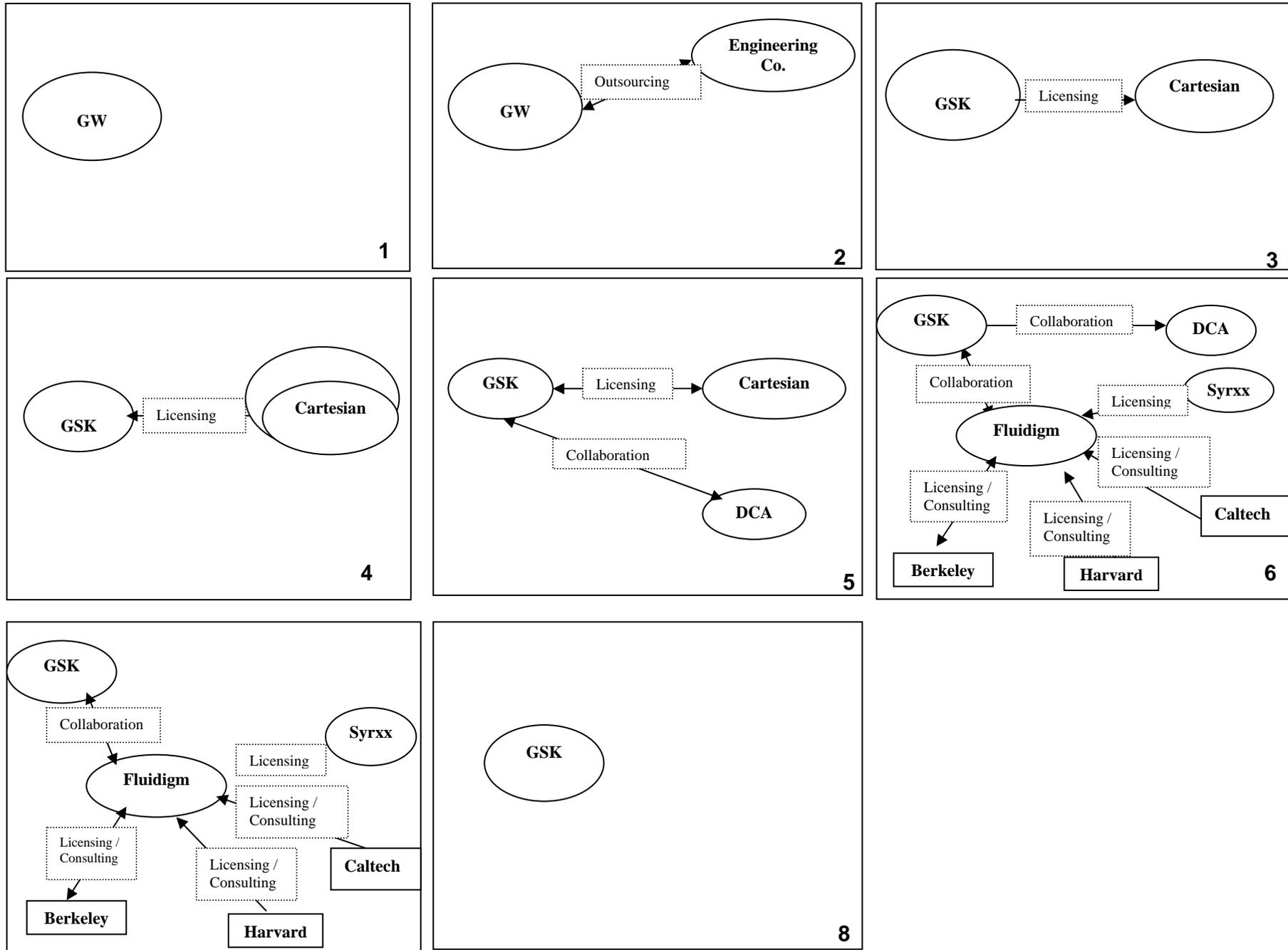


Figure 2: The emergence of the innovation system in the GSK case study



4.0 Discussion

The empirical cases demonstrate how, during a protracted innovation process, inter-organisational linkages change over time and range from relatively discrete, short term linkages to longer term relationships, often embodying a variety of linkages. Three main categories of linkage are observed in the case studies; collaboration, licensing agreements and the acquisition of partial equity stakes. Two full acquisitions are also observed in the Amersham case. Many of the links persist (stabilise) over time though relationships and configurations change. In this discussion we tackle two main issues; 1) a detailed examination of two categories of co-production and exchange; 2) an analysis of the dynamics of the exchange process. In the first instance, we discuss collaboration and licensing agreements as types of network ‘tie’ or market ‘transaction’. In the second, we discuss how linkages between organisations emerge, stabilise, re-stabilise or disintegrate over the lifetime of the empirical cases. This analysis refers to the acquisition of partial equity stakes and full firm acquisition.

4.1 Collaborative Relationships

This paper distinguishes between the myriad of relationships referred to as collaboration in the innovation literature. I define collaboration as a relatively long-term and close relationship with partners dependent on each other’s complementary skills and assets (Chesnais, 1988). There are six examples of close relational collaboration between organisations in the case studies: Amersham-Bertin; Amersham-Hitachi; Amersham-Molecular Dynamics; GSK-DCA; GSK-Fluidigm; and Berkeley-Caltech-Fluidigm, the last being an informal collaboration. Each of these relationships was formed to co-develop a technological artefact(s) defined as complex, multi-disciplinary and emerging. The creation of the artefact involved the co-production, as well as the exchange, of knowledge. The following sections discuss the main features of the collaborative relationships in the case studies and each of these features represents characteristics of the co-production and exchange process.

4.1.1 Collaboration:

All of the collaborative relationships in the empirical cases last for a number of years and characteristics of the exchange process identified in the network literature are found in most of the individual examples. Firstly, personal relationships underpin many of the relationships in the empirical cases, and often preceded and facilitated organisational linkages: relationships between individuals provided opportunities to foster linkages between organisations. The type of personal relationship determined the diversity and strength of organisational linkages. In turn, personal relationships were strengthened by formal collaborative agreements, and new personal relationships were formed as a result of the close interaction. Collaborative relationships were underpinned, or embedded, by social networks in many of the cases, for example Don Rose, an ex-GSK employee and Vice-President of R&D at Cartesian, played a vital role in facilitating the GSK-DCA relationship as Cartesian had worked closely with Syrx during an earlier DCA-Syrx collaboration. The personal relationship was not direct but was enabling. The GSK-Fluidigm relationship also evolved from an earlier organisational relationship, and personal contacts were central to the story both in terms of the creation of Fluidigm itself and the formation of contractual ties with

GSK. The network literature recognises that beneath most formal ties are informal relationships. Collaboration is shown to be emergent, stemming from ongoing relationships, informal and non-premeditated (von Hippel, 1988, Hakansson, 1990). Although many authors agree that markets are 'embedded' in social relationships (Granovetter, 1985) there is room for further discussion about the interaction between market and social processes during the exchange process and the impact both simultaneously have on the emergence of new inter-organisational linkages.

Secondly, the network literature recognises the role of tacit knowledge for learning and this was demonstrated by the empirical cases. Tacit knowledge is person-embodied and direct personal contact and experience is necessary for learning. As collaboration is primarily concerned with the creation and transfer of new knowledge, a significant element of the relationship involves personal interaction. Each of the collaborative relationships in the empirical cases, except the Hitachi example, involved a close working relationship where employees moved between the companies over time. The physical and relatively long-term exchange of personnel is one element of the collaborative relationship which makes it a suitable organisational form for the co-production and exchange of knowledge. Knowledge creation and exchange is clearly a longer term, close and iterative process rather than an arms-length transaction.

Thirdly, the Amersham case study demonstrates the importance of learning *how* to collaborate. Although the Amersham-Bertin collaboration was widely regarded as a failure, Amersham learnt a great deal about collaborating with instrumentation companies. They developed absorptive capacity and managerial skills which benefited future relationships. The Amersham-Hitachi relationship was also regarded internally at Amersham as a failure. Amersham reported that they were unable to fully develop any internal technical capabilities during the relationship, and this contributed to the breakdown of the relationship. Rather than evolving into the collaborative relationship envisaged by Amersham the relationship embodied characteristics associated with outsourcing. Despite the relative 'failure' of the relationships, both the Bertin and Hitachi relationships enabled Amersham to develop the basic level of internal expertise and the organisational skills necessary to successfully collaborate with Molecular Dynamics. This data broadly supports Powell's (1990) argument that experience is necessary to manage inter-agent relationships, as organisations must learn how to transfer knowledge across alliances and how to function in relationships (Powell, 1990; Powell et al, 1996).

Finally, experience also enables firms to develop a good reputation as a partner, which in turn encourages future collaborations (Powell et al, 1996). The cumulative affect of collaborations encourages organisations to treat them as long term relationships rather than opportunistic transactions. This is especially apparent in the case of GSK, where each collaborating organisation described the company as a good partner, even going so far as to describe them as "almost a business incubator" (DCA interview, 2005). The positive impact of reputation cannot be underestimated and is closely related to perceptions of trust and reciprocity. Without trust the collaborating organisations cannot easily work closely and share knowledge. The association between trust and the successful outcomes of collaborations (Dodgson, 1996) was demonstrated by the GSK-DCA and the GSK-Fluidigm relationships. It was also conversely evidenced by the demise of the Amersham-Bertin relationship, which was

expedited by a breakdown in trust, as each organisation perceived that the other was not contributing fairly. This suggests that the cumulative affects of learning and trust impact on the longevity of relationships and the dynamics of the exchange.

A particular feature of the collaborative relationships, not discussed in the network literature, yet observed in the GSK case study is that longer term close relationships facilitate the iterative process of technological and organisational change. The two instruments developed by DCA and Fluidigm drew on the new biotechnology paradigm of drug discovery and had the potential to impact on the drug discovery process itself. GlaxoSmithKline were motivated to collaborate in the development of these technologies not only to gain early access to technologies, or to develop a technology that would help remove a bottleneck, but also to simultaneously re-assess and, if necessary, re-structure their internal drug discovery process. Innovation was therefore taking place at a technology level but also, in parallel, at an organisational level. This necessitated a close collaborative relationship for both partners to get maximum benefit from the technology. A more arms-length relationship could not have facilitated the co-evolution of the technology and the organisation.

The characteristics identified from the empirical research and discussed above emphasise the relational and temporal aspects of collaborative arrangements. These features demonstrate that the knowledge creation and exchange process requires long-term relationships based on reciprocity and trust (social ties are also shown to be a central feature of this type of inter-organisational relationship). Broadly speaking these findings support the perspective that networks are a distinctive way of organising economic activity especially suited to knowledge creation and exchange. However economic/market processes *are* embedded in collaborative relationships and this analysis is missing from the network literature. The ‘markets for technology’ literature argues that collaboration is a type of transaction for future knowledge (Arora et al, 2001). Using this perspective the transaction is concerned with formal intellectual property rights, rather than other economic processes, such as the co-funding of joint activity. In the empirical cases the intellectual property is often contractually divided prior to its creation, as in the GSK-Fluidigm, Amersham-Bertin, Amersham-Hitachi and Amersham-Molecular Dynamics relationships, or jointly owned as in the GSK-DCA relationship. Cross licensing may, or may not be exhibited. And if not, what is the technology transaction? Yet licensing agreements are created during some of the collaborative relationships and exclusively licensed to the other organisation, e.g. the GSK-Fluidigm relationship (discussed later). It could be more accurate to describe technology trading, or market-type exchange, as one component of collaborative relationships (Granstrand, 2004) rather than a tool for explaining the relationship itself. In which case, we see a double embedding of knowledge creation/acquisition networks and market networks⁶. The role of market-based exchange in collaborative relationships is discussed next.

4.1.2 Collaboration and the ownership of knowledge

⁶ It could be argued that all markets exhibit network characteristics, for example, even the trading of equity shares can occur within closed networks, and personal relationships are important for many direct sales relationships (for example, medical equipment sales). To take that argument a step further we could suggest that markets actually *are* networks, albeit a type of network.

The codification of knowledge into tradable entities, patents, is of primary importance to the collaborating organisations in the case studies. During the collaboration provisions are made for ownership. Prior to creation it cannot definitely be known whether the knowledge will be deployed internally or made available externally; in many cases both mechanisms will be employed. However it is the allocation of ownership, through property rights, which enables exchange via economic processes. Conversely knowledge creation can motivate the emergence of a relationship and the process of allocating ownership can facilitate collaboration by forming a basis for negotiations. This demonstrates that market processes, including the creation and division of IPRs, are embedded in social processes, and *vice versa*.

In each of the case studies bar one (discussed shortly) a contractual agreement was drawn up to assign ownership over the resulting knowledge. The division of intellectual property was usually based on the complementary strategies of the collaborative partners, for example, in the GSK-DCA and GSK-Fluidigm relationships any resulting instrumentation intellectual property was assigned to the instrumentation partner and any pharmaceutical intellectual property was assigned to the pharmaceutical partner. In the Amersham-Hitachi and Amersham-Molecular Dynamics relationships the intellectual property was also divided this way according to reagents or instrumentation. The complementarity of business strategies facilitated this division. However, in the Amersham-Bertin relationship intellectual property rights were assigned based on who invented the knowledge first. This was due to the emerging competitive position between the two firms, as both wanted to market scientific instruments, i.e. were to compete as producers of the artefacts. The ability to clearly demarcate knowledge ownership in the GSK-DCA, GSK-Fluidigm, Amersham-Hitachi and Amersham-Molecular Dynamics collaborations facilitated the relationships and contributed to the development of conditions necessary for successful joint knowledge creation. Even when the division of IPR appears to be clear the actual outcomes of the collaborative process are not always as expected. In the GSK-Fluidigm collaboration, the pharmaceutical company patented some knowledge related to the instrument primarily developed by Fluidigm which was then licensed back to the firm. This example demonstrates how it is difficult to clearly divide IPR before the knowledge is created, and how economic considerations can cause tension in relationships.

This is perhaps most apparent when considering university-industry relationships. Negotiations over the appropriate division of IPRs (usually patents) are cited as the most problematic issue in securing a collaborative agreement, especially in university-industry-government collaborative projects (Carayannis and Alexander, 1999). Collaborative agreements between public and private organisations have an added complexity due to the public dissemination mission of the university. An informal collaboration, as opposed to a formal contractual collaboration, was employed by Berkeley-Fluidigm-Caltech in order to circumvent this problem. This decision enabled the collaborators to avoid a primarily market-mediated relationship and allowed the scientists to work across universities without imposing restrictive working practices or raising ownership issues at the administrative level. From an administrative perspective, university-university collaboration is more straightforward than university-firm collaboration as both academic institutions have a knowledge creation and dissemination objective. In practise this makes university-university collaboration less complicated: IPR agreements can be worked out retrospectively and

informal collaboration is standard working practise. Informal collaboration between a university and a firm is less common and actively discouraged by the technology transfer offices of the universities interviewed. The reason cited was that if a collaborating company has ownership rights but a different strategy they may not out-license resulting innovations, conflicting with the university mission to promote 'public good'. Because of this strategic conflict informal academic-firm collaboration is reported as rare, or happens as a university is developing its technology transfer function. The decision to avoid a formal collaboration prohibited Fluidigm from directly funding the laboratories, but enabled the company to provide hardware for experiments without involving the university administration or gaining ownership rights. In this case the exchange of money for knowledge ownership rights during a collaborative relationship was explicitly avoided. Learning was central to the relationship and payment-in-kind did occur, however there was no formal, or market, transaction during the collaboration. The institutional considerations influenced the knowledge ownership outcome and affected the system evolution; once a patent had been filed by the universities, it was licensed out to Fluidigm. So a market mediated transaction occurred after the collaboration phase and influenced the relationships between the organisations. This example again demonstrates how economic networks are embedded in knowledge acquisition networks, and *vice versa*.

4.2 Licensing Agreements

The discussion above demonstrates how collaborative relationships embody both market and non-market processes, and that these mutually embedded processes drive organisational linkages in a number of different ways; exerting pressures and providing opportunities simultaneously. This section explores the detail of the licensing agreements in the empirical cases. As previously emphasised, licensing agreements are regarded as a form of 'tie' in the network literature; yet underpin the central arguments in the 'markets for technology' literature. I discuss the market and non-market processes related to the exchange of knowledge by first differentiating between licensing agreements for 'freedom to operate' in a market, and licensing agreements which involve an element of knowledge transfer and learning. The following section explores the prevalence of consulting relationships associated with licensing agreements in the empirical cases and discusses the importance of non-market processes for learning. Finally, I discuss the heterogeneity of licensing agreements. This analysis provides further evidence that market and non-market processes are interdependent.

4.2.1 Licensing relationships for knowledge transfer

Licensing relationships are utilised for a variety of reasons in the empirical cases, including the creation of spin outs, accessing knowledge and/or markets. Although each of these inter-agent relationships is unique, they can be grouped according to whether the licensing is motivated by firms' need to use the knowledge or not. The licensing relationships engaged in to access markets, i.e. 'freedom to operate' (ABI-Amersham) and 'defensive licensing' (Syrxx-Fluidigm) are arms-length agreements with limited interaction. The inter-organisational ties are maintained by flows of licensing revenue rather than knowledge, as the licensor does not intend to use the knowledge but to gain rights over the knowledge. In both of these examples the firms who hold the patents are competitors. These licensing agreements loosely correspond

with an orthodox view of economic exchange, because there is limited sharing of knowledge and the exchange process is relatively discrete. To clarify, when licenses are used to gain ‘freedom to operate’ in the empirical cases they are predominantly market-mediated. However, when licensing was motivated by an organisations’ need to use the knowledge, non-market exchange processes were observed. In the case of university spin-out (USO) licensing relationships (Caltech-ABI, Caltech-Fluidigm), close social and working relationships were maintained between the organisations. Prominent examples of this are the formal consulting relationships accompanying each of the university-USO and the university-firm (Berkeley-USB and Berkeley-Molecular Dynamics) licensing relationships. The prevalence of consulting relationships in the empirical cases is explored next.

Many of the licensing agreements found in the case studies were complemented by related consulting agreements (USB-Berkeley, USB-Harvard Medical School, Molecular Dynamics-Berkeley, Amersham-Berkeley-Harvard Medical School, Fluidigm-Stanford, GSK-Cartesian). These consulting agreements were explicitly intended to facilitate the transfer of knowledge. In the case of academic-industry knowledge exchange the academic inventors formed consulting relationships with the companies who had licensed their inventions from the university. Consulting relationships have to be formed independently from the licensing agreement because of the academic’s contract with their employer (the university), but it was generally agreed by interviewees that it was preferable, in terms of technology transfer, for the academic inventor to engage in a consulting relationship with the licensee. Sometimes the consulting relationship will precede the licensing agreement, as the academic inventor will suggest the company (s)he is consulting for as a suitable licensee. This was seen in the Berkeley-USB, Berkeley-Molecular Dynamics, Harvard-USB relationships. In other cases the consulting relationship arose as the result of the licensing relationship in order to facilitate the transfer of knowledge. The use of consulting relationships for knowledge exchange is recognised in the literature. Carayannis and Alexander (1999) found that a significant proportion of the value of the licensed knowledge is derived from consulting, training and other fees from the licensee to the licensor. Darby and Zucker (2006) note that the use of commercially available research tools (instrumentation) may be more productive through (or require) collaboration with scientists. Finally, although not explicitly stated, in one example in the Colyvas et al (2002) paper, when a scientific instrument was transferred to a private firm through an exclusive licensing agreement, it was accompanied by a consulting relationship.

The prominence of consulting relationships complementary to licensing agreements is related to the motivation for the license: whether this is for rights over the knowledge, or to use the knowledge. Neither the ABI-Amersham nor the Syrrx-Fluidigm licensing relationships involved the use of knowledge or learning, nor were they accompanied by a consulting relationship. The empirical data and relevant literature suggests that when learning is the objective of the relationship, in addition to the formal licensing agreement (a primarily economic process) a complementary consulting relationship is negotiated. Arguably this represents a tacit-knowledge market-like transaction, yet the characteristics of a consulting relationship are similar to those described by the network proponents. It is argued here that the prevalence of consulting relationships further demonstrates that market and non-market processes are central to the exchange of knowledge and formation of inter-organisational

relationships. In fact, economic processes are embedded in knowledge acquisition networks, and vice versa.

4.2.2 The heterogeneity of licensing agreements

Another way of distancing licensing agreements from the concept of market transactions is to demonstrate their non-uniformity. From the earlier discussion we can see that the licensing agreements in the empirical cases embody unique and complex relationships between organisations and are not uniform agreements. This is further demonstrated by the use of diligence provisions in licensing agreements to direct further innovative activity. A licensing agreement does not just contractualise a flow of rights or knowledge from one company to another; they involve a number of stipulations and clauses, including a level of exclusivity, fields of use, diligence provisions, mandatory sublicenses and government research exemptions. These clauses contribute to the heterogeneity of agreements. The inclusion of diligence provisions and field restrictions was less sophisticated when technology transfer offices were in infancy, for example, Amersham's license for an important enzyme from Harvard (post acquisition of USB) was an exclusive, all-fields-of-use license. However, Amersham only licensed their primary distributor⁷ to sell to the manual sequencing market. Organisations wanting to use the enzyme for other purposes have to buy the enzyme through that channel, adapt it, and then approach Amersham for a custom batch. Arguably this hinders significant investment being made for other applications of the enzyme. This example demonstrates how provisions in exclusive licensing agreements can impact on the future direction of innovative activity and the evolution of the innovation system more generally. If a license is non-exclusive, then diligence provisions have less impact on the innovation process, presuming further licenses are granted to any organisation applying for them. In the empirical cases, firms also used diligence provisions to actively exert an influence on the direction of future innovation.

Diligence provisions were used by GSK to direct the development of their internally produced instrumentation. GlaxoSmithKline maintained ownership of the original patents but exclusively licensed them out to Cartesian. Although GSK wanted to externalise development of the technology they also wanted to ensure that a product would be developed and would be commercially available to them. Instead of selling the patent and losing any rights over it, GSK licensed the patent out and included a diligence provision. The diligence provision was a developmental milestone stating that if Cartesian did not deliver a product after a specified amount of time, then the IPR would revert back to them. GlaxoSmithKline recognised that not all licensed IPR results in a commercial product. Companies can fail to get a product to market for a number of reasons, for example, they may use intellectual property to block markets, divert resources to other areas, and decide that commercialising a product is too costly or that the market is not ready. The R&D undertaken by Cartesian to create a commercially viable product from the initial prototype was significant, and GSK wanted to ensure a product was available in a timely manner. This was particularly important to GSK due to the high internal demand for the technology, and diligence provisions were included in the licensing agreement to ensure this. The example

⁷ The primary distributor is USB who re-formed after the acquisition by Amersham but now exist in a different capacity.

demonstrates how licensing rather than selling a patent enables the inventor or assignee to retain a level of control both over the patent and any innovation resulting from the patent. The licensing agreement itself can be used as a tool to direct the development of a technology and although the market-mediated nature of the transaction is transparent what is more opaque (unless we look at the details of the license) are the non-economic processes influencing the exchange. These examples suggest that rather than being the uniform tradable entities as proposed by the markets for technology approach, licensing agreements are unique, often complex, forms of inter-organisational linkage embodying the wider relationship between organisations. Perhaps more importantly the empirical cases demonstrate how the *dynamics* of the innovation process can be influenced by licensing agreements; at the extreme the licensing agreement itself can be written with the evolution of a technology, and/or organisational relationships in mind.

4.3 The dynamics of exchange; non-linear and unpredictable

Overall the evolution of inter-organisational linkages, or emergence, stabilisation and disintegration of relationships, is a central feature of the empirical cases. The co-production and exchange of knowledge for innovative activities was key to this evolution and the observed exchange involved both market and non-market processes. Although this has been discussed within the previous sections on collaboration and licensing, we now focus on the dynamics of the exchange process by analysing acquisitive behaviour in the empirical cases.

The emergence and evolution of the innovation system (or specifically inter-organisational relationships) is non-linear and unpredictable. In the empirical cases collaborative relationships evolved into licensing agreements; collaborative relationships incorporated acquisitions of partial equity stakes and evolved into full acquisitions; licensing agreements evolved into minority equity holdings followed by the sale of that equity; and sometimes collaborative relationships simply disintegrated. The empirical cases demonstrate that it is not possible to predict how inter-organisational linkages will evolve and that changes relate to a variety of internal and external factors, incorporating both market processes and network dynamics. For example, the acquisition of Molecular Dynamics by Amersham was the outcome of previous licensing and collaborative relationships. These earlier relationships were a precondition to the acquisition, and linkages developed over time, culminating in direct and full ownership of the smaller company. Molecular Dynamics instigated the acquisition as they were unhappy with the profit sharing agreement negotiated as part of the collaborative relationship. Amersham were initially unwilling to acquire the company, preferring to maintain a collaborative relationship. Only when the management of Molecular Dynamics demanded a review of the collaborative agreement did Amersham agree to the acquisition. This is one example of how a stable collaborative relationship becomes unstable and re-stabilises in a new form (in this case full acquisition); ultimately how the system self-organises. The ownership, co-production and exchange of knowledge lay at the heart of this relationship. It is clear from this example that market activity was central to the evolution of the relationship and yet this evolution cannot be described as simply a transaction, nor does the label 'network tie' capture the dynamics of the process. The acquisition of USB by Amersham was a more hands-off capital market exchange. There were no formal linkages prior to the acquisition, which was motivated by gaining access to

patents exclusively licensed to USB and not licensed on. These two examples further demonstrate that linkages emerge and evolve as a result of both market and non-market processes, whilst involving each. Ultimately it is misleading to define exchange as an economic process without considering non-market processes. This double embedding, or mutual intra-penetration, of economic networks with knowledge acquisition networks is fundamental to explaining system emergence and evolution.

These mini-cases also emphasise the heterogeneity of the overall linkages observed in the cases. This heterogeneity has implications for allocating specific linkages (or aspects of the relationship) to well defined categories. For example, the acquisition of a minority stake was a feature of a number of relationships: the collaborative agreement between GSK and Fluidigm included a provision for GSK to acquire equity in Fluidigm at a later date; GlaxoSmithKline took an equity stake in Cartesian when they exclusively licensed a patent to them; Berkeley took equity in both USB and Molecular Dynamics as part of exclusive licensing agreements. These examples demonstrate that equity was acquired in each of the inter-agent relationship categories: collaboration, licensing and acquisition. The empirical evidence suggests that each category of inter-organisational relationship, or process of knowledge creation and exchange, involves aspects associated with other categories. It is not easy to assign organisational linkages to discrete categories as by doing so we may lose significant elements of the overall exchange. The case studies suggest that the tendency of researchers to describe easily identifiable elements of overall relationships, rather than discussing the exchange process in its entirety, contributes to an overly dichotomous perspective of knowledge exchange in markets or networks.

5.0 Conclusions

The empirical cases followed the emergence and evolution of a system self-organising around a particular set of problems. The innovation systems observed transcended sectoral, technological and national boundaries. They were also constantly evolving and apparently transient; most clearly demonstrated by the GSK case study where the system fully disintegrates. To explore the dynamics of system evolution we focused on a central feature of innovative activity, the co-creation and exchange of technological knowledge, and used the DIPs approach to facilitate a detailed analysis of the processes of instituting/re-instituting/de-instituting relationships. Using the DIPs approach enables a bottom up perspective, focusing on interactions, rather than overall macro structures. The detailed analysis emphasised that organisational linkages (and the overall innovation system) emerge and evolve, partially by economic processes and partially by non-market processes. Although it has been argued that networks are a distinct form of economic organisation, different from markets or hierarchies⁸, the empirical data suggests that this is an overly dichotomous perspective. It is argued here that actually these types of organisation are not sharply distinct, instead there is an embedding of economic networks in knowledge acquisition networks, and vice versa. The system is actually a mixed system, which has important implications for explicit attempts to stimulate efficient forms of economic organisation as these currently tend to prioritise one form over the other.

⁸ A discussion of 'hierarchies' is beyond the scope of this paper but it could be further argued that the hierarchy is not sharply distinct from networks or markets either.

The inclusion of licensing agreements in the network and market literatures as both a type of 'tie' and 'transaction' can be explained because market processes and non-market processes are interdependent; both forms are exhibited because they are mutually embedded. The literatures explore different elements of the same phenomenon, often at different time points. Ultimately, a market *is* a network, comprised of inter-linked organisations and characterised by instituted economic processes, which shift and evolve over time. In response to this, network analysis would benefit from incorporating economic processes more explicitly and exploring this mutual embeddedness. Additionally, the market-orientated literature could benefit from taking account of socially mediated transactions and non-market processes. However, we have shown that a powerful analytical tool able to capture the details of market, and non market, exchange processes as they evolve over time already exists. The DIPs approach captures the strengths of both the network and markets literatures whilst facilitating an evolutionary analytical approach, essential for capturing the dynamics of innovation.

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