

Knowledge Production and University-Business Interaction in the Life Sciences



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Table of contents

Executive Summary	3
1. Introduction	5
2. Research approach: using exemplar cases to illustrate policy-relevant issues	6
3. Knowledge production in the Life Sciences	9
3.1. Connections and collaborators	9
3.2. Formalisation: the process of making a collaboration formal	11
3.3. Informal versus formal collaborations	13
3.4. Differences between academics and industry scientists' approaches to formalisation	15
3.5. Is geographic proximity important for collaboration?	17
3.6. Scientific collaboration in clusters	18
4. Policy implications	20
4.1. Do we need publicly funded initiatives to connect scientists?	20
4.2. Localised interventions to promote connections between scientists	22
4.3. Funding interventions to promote inter-disciplinary research	25
4.4. Funding interventions to promote university-business interaction	26
4.5. How can we promote informal knowledge production?	27
5. Conclusion	30
Appendix 1: Research Methodology and Analytical Strategy	32
Appendix 2: Identification of 'munificent' localities for bioscience research	37
References	39

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Executive Summary

This report presents the findings of a research project funded by the Economic and Social Research Council and by the South East of England Development Agency, conducted by Zella King of the University of Reading Business School between 2004 and 2006.

The research examined interactions between scientists involving the production of knowledge for one or both of the scientists' organisations. The objective was to understand the micro-processes whereby collaborations between scientists emerge, are made formal and resourced, and result in outcomes that create value for their organisation or the economy as a whole. By taking the individual scientist as the unit of analysis, the project aimed to offer fresh insights into policy and practice-oriented debates about effective exploitation of the UK science base by industry.

A summary of the research approach, findings and suggested policy implications is offered here. For further information, see the section of the report as indicated.

Summary of findings

The research design made an analytical distinction between collaborations exhibiting 'exemplar' process and those exhibiting 'exemplar' outcomes (for details, see section 2).

- 'Exemplar' process was deemed to be evident where a collaboration took place within a life sciences cluster, arose as a result of an intervention intended to connect scientists, or was prosecuted through a subsidised mechanism such as CASE, KTP, LINK or EU funding.
- 'Exemplar' outcomes were deemed to be evident where a collaboration resulted in a granted patent, licensing income or the formation of a new venture.

Collaborations typically begin informally and may or may not become formal. In either case collaborations unfold within a scientific and organisational context of great uncertainty (section 3.1). The formalisation process is associated with significant transaction costs and with higher exit costs once the relationship has been made formal. Expected net benefit (probability of scientific and financial gains against costs of time and resources involved in formalisation) is weighed up when a scientist considers converting from an informal to a formal relationship with a collaborator (see section 3.2).

Informal collaborations are beneficial in that they enable the parties to assess the likely benefits of formalisation, and act as a filtering process to channel time and resources to formalising those collaborations that are most likely to be productive. Formal collaborations are beneficial in that they are likely to be better managed with a clearer set of expectations on both sides (section 3.3).

Collaborations between two academics are more likely to begin with a significant period of informal knowledge production than academic-industry collaborations. The rapid formalisation often required for academic-industry collaborations increases the risk of a failed or mismatched collaboration (see section 3.4).

Complementarity and scientific need are more important than geographic proximity in increasing the likelihood of two scientists collaborating (see section 3.5). Regional clusters play a limited role in engendering collaboration (see section 3.6).

Summary of policy implications

There is limited scope for a third party to make connections between academics and clinicians on the one hand, and industry scientists on the other (see section 4.1). The problem is not making a connection but in overcoming the problems posed by a lack of informal knowledge production

- being a barrier to assessing desirability of a collaboration in the first place and/or
- reducing the likelihood of success after the collaboration is made formal.

Local science networks help to create connections between scientists. However, connections have no financial or scientific value in terms of exploitation of the science base. More important is to find ways of encouraging informal knowledge production between scientists (see section 4.2).

Funding calls in new scientific areas can engender rapid escalation to formalisation without prior informal collaboration and knowledge production. Funding decisions on inter-disciplinary projects might look for evidence of prior formal and or informal knowledge production between the collaborators as a pre-requisite (see section 4.3).

It is desirable that collaborators in different organisations produce knowledge informally together before being required to formalise their relationship. CASE and KTP projects provide a quasi-informal means to collaborate, and have an important role to play in developing an emergent collaboration into something more significant (see section 4.4). Possible means of facilitating informal knowledge production include (and see section 4.5 for further details):

- Networking meetings enabling those present to identify potential complementarity with others and to communicate scientific need
- Within universities, using pooled resources to create a formal structure that provides opportunities for academics and industry scientists to interact informally around a set of scientific problems
- Within commercial firms, providing opportunities for scientists to participate in scientific 'institutions' (such as conferences, research council committees), engage in exploratory research projects with academics and/or interactions with academics around the university curriculum
- Making technology transfer and business development officers aware of the need for informal knowledge production and developing their skills in facilitating this

From the perspective of assessing the value added by policy initiatives, policy-makers might take note of the following comments (see the conclusion for more details)

- Initiatives to engender or to accelerate collaborations in the life sciences require great sensitivity to the scientific or technological context in which potential collaborators work. Initiatives should aim not just for making connections but also providing opportunities for informal knowledge production
- For many scientists, 'markets' for potential collaborators are very thin. In the life sciences, it would be a mistake to assume that collaborators can be found nearby, and more efficient to find ways of connecting people on a national basis
- Given this market 'thinness' and the low regard that most of the scientists interviewed in this study had for regional initiatives (although with some notable exceptions), there appears to be a danger of duplication of initiatives between regions at the expense of building national capability in the life sciences.

Knowledge Production and University-Business Interaction in the Life Sciences

1. Introduction

This report is directed to the DTI in recognition of its PSA targets to

- Improve the relative international performance of the UK's science and engineering base, the exploitation of the science base and the overall innovation performance of the UK economy
- (Together with ODPM and Treasury) make sustainable improvements in the economic performance of all English regions and over the long term reduce the persistent gap in growth rates between regions

Government policy and resources are now directed toward promoting local collaboration between businesses, universities and public sector organisations, both on a national and a regional level. A range of mechanisms has been put in place with the objective of increasing demand for the product of UK higher education by increasing business R&D and absorptive capacity, promoting greater interaction between business and public science and increasing incentives for universities to exploit the intellectual property inherent in their research. These mechanisms include, *inter alia*:

- Subsidised research grants for university-industry collaborations (e.g. CASE, LINK grants)
- Subsidised mechanisms for transferring knowledge between universities and industry, such as KTP
- Funding to help universities commercialise their intellectual property and to promote enterprise and entrepreneurial activity within (most recently HEIF funding)
- Regional networking initiatives to connect scientists in industry and universities, such as Oxfordshire Bioscience Network, Thames Valley Life Science Network
- Industry-based initiatives such as Knowledge Transfer Networks (formerly Faradays)

Although these and other initiatives to promote collaboration are being widely implemented, we know relatively little about the conditions in which they are likely to be effective in generating new business-business or business-university collaborations. This research examined how scientists working in the broad areas of biotechnology, pharmaceuticals and medical devices collaborate outside their organisations. These fields of science are interesting because

- They are central to the UK's public science base, and developing them is a key element of the Government's Science and Innovation Framework
- They are cross-disciplinary fields in which networking and collaboration initiatives have been actively promoted through public policy and funding.

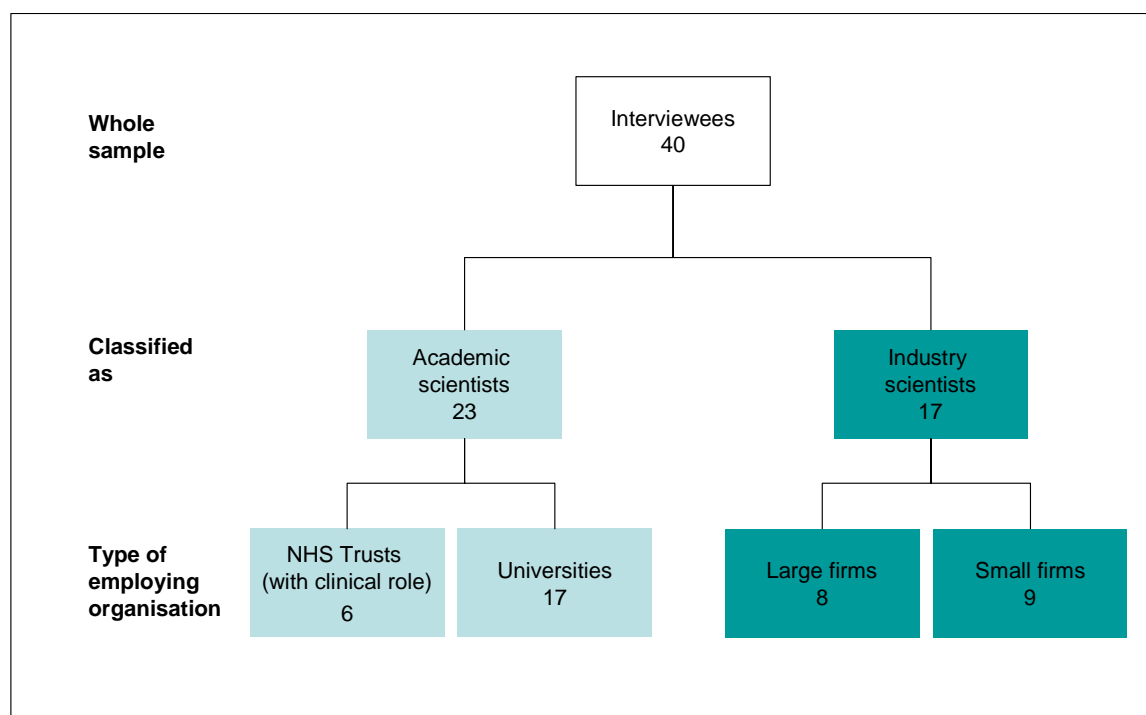
2. Research approach: using exemplar cases to illustrate policy-relevant issues

Semi-structured interviews were conducted with forty scientists, based in industry, universities and hospitals in the UK. All worked in scientific areas relevant to the biotechnology, pharmaceutical, diagnostic and agrochemical industries and/or with clinical applications. Many of the academic and clinical scientists were leading in their field, and all but six of the interviewees were named inventors on patents. Those interviewees in industrial companies were highly qualified, doing very scientific work, and most were currently or had at some time in the past been engaged with academic science institutions (14 of the 17 had PhDs and 8 had done post-doctoral work in universities).

Therefore, in considering the implications of the findings presented here for exploitation of the UK's science base, the reader should bear in mind that the project focused on science-intensive businesses and highly-skilled scientists. The industry scientists who were interviewed appreciated the value of academic science, and most were willing to pay for the opportunity to produce knowledge with academic scientists¹. The findings presented here are not necessarily relevant to companies with little or no scientific activity.

Figure 1 shows how the interviewees were divided between universities, NHS Trusts (where interviewees all had a clinical role) and industry.

Figure 1: Interviewees identified by type of organisation



From the 40 interviewees, data were collected on 130 collaborations, including their origin, knowledge production arising through them and output in the form of papers, patents etc. For 24 of these collaborations, both parties were interviewed. Supporting information was collected from other stakeholders (managers, policy-makers, regional stakeholders etc.) following a case-based methodology. Details of the methodology are given in Appendix 1.

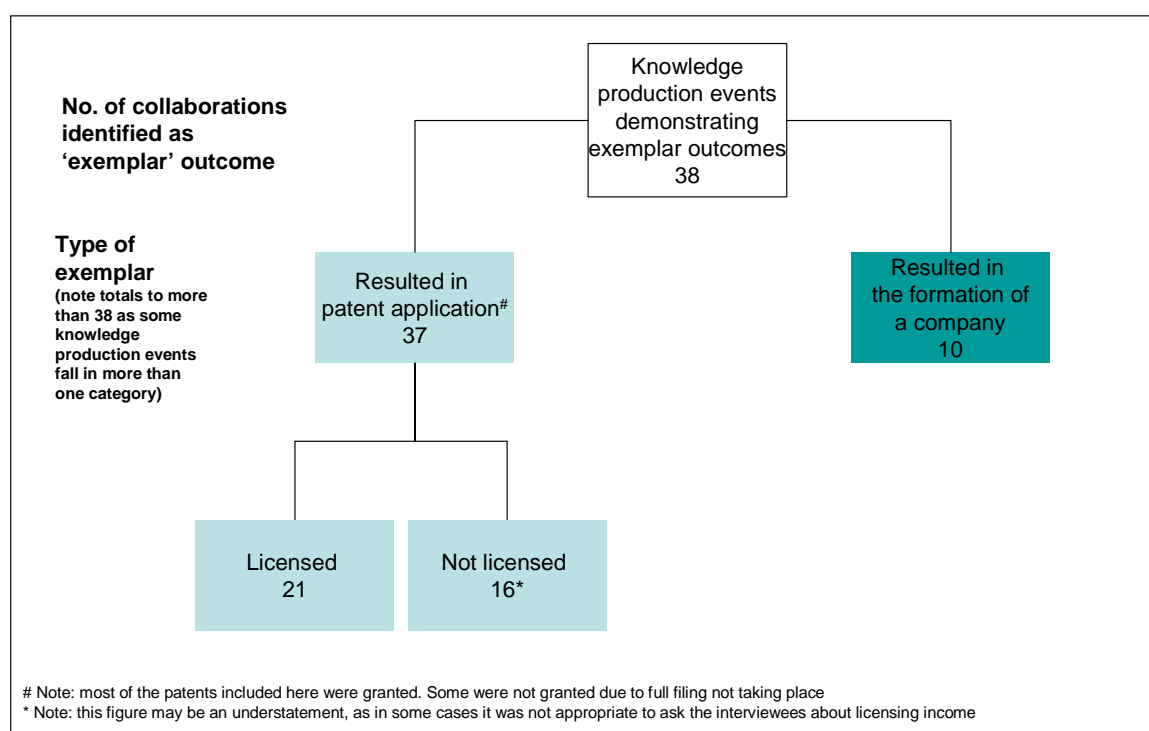
¹ The phrase 'produce knowledge with' and the term 'knowledge production' as used here are derived from Machlup's (1980: 7) definition of knowledge production as activity whereby a person learns something they did not know before - i.e. not necessarily knowledge that did not exist anywhere. Knowledge transfer is part of the process of knowledge production (transferring knowledge from one who knows - a transmitter - to one who does not).

A distinction between exemplar process and outcomes was made in order to identify how policy initiatives to promote effective exploitation of the UK science base can be most effective in generating wealth. Of the 130 collaborations studied, 38 were judged to be of significance in terms of demonstrating **exemplar outcomes** from a policy perspective, evidenced by indicators of university-business interaction²:

- patent application made (and in most cases granted)
- licensing or other IP income generated for a university
- spin-out company formed

Figure 2 shows how the various collaborations exhibiting exemplar outcomes were divided between these various categories.

Figure 2: Collaborations exhibiting 'exemplar' outcome



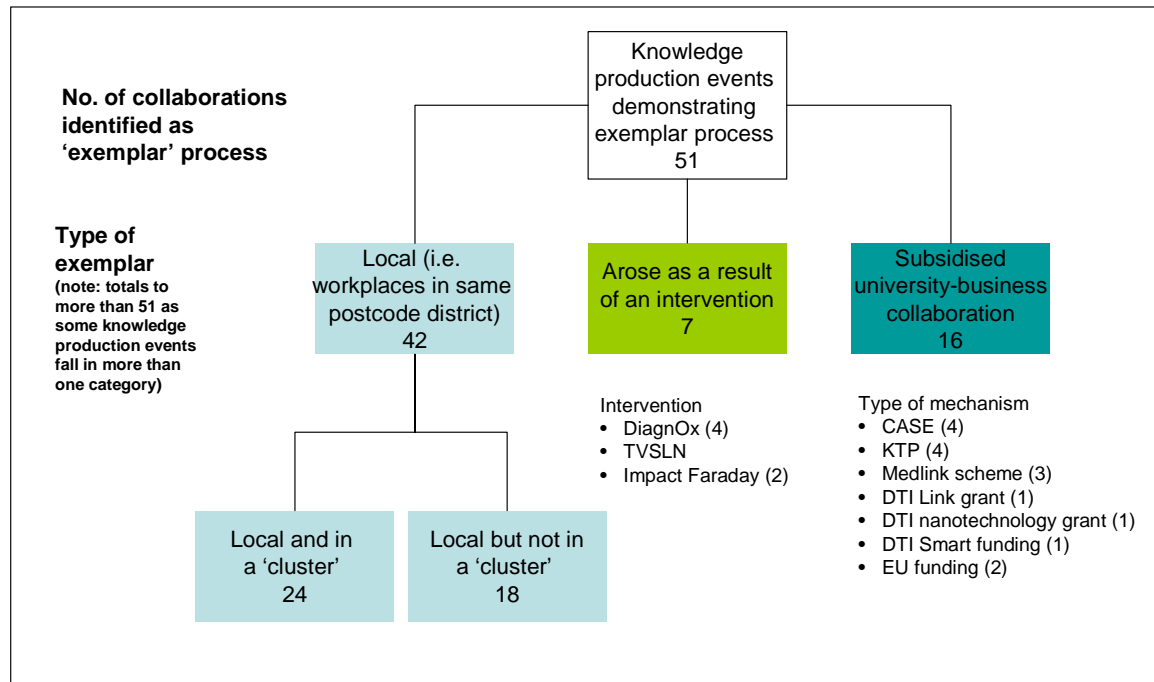
Of the 130 collaborations, 51 were judged to include knowledge production 'events' that demonstrated **exemplar process** from a policy perspective, in one of two respects.

- Both parties to the collaboration were located within the same regional cluster (the research focused on bioscience clusters in Cambridgeshire, Oxfordshire and Yorkshire's White Rose region). Appendix 2 explains how those clusters were identified.
- Some element of public funding or intervention to promote or support the collaboration was involved, such as
 - contact initiated as a result of a networking initiative (e.g. Faraday/KTN)
 - the interaction was prosecuted through a subsidised mechanism (e.g. CASE, KTP)

² These are common indicators used by policy-makers to appraise university-business interaction, as in the Higher Education Business Interaction survey

Figure 3 shows how the various collaborations exhibiting exemplar process were divided between these various categories.

Figure 3: Collaborations exhibiting 'exemplar' process



The analysis was conducted in three phases. First, the micro-processes underpinning the emergence and conduct of collaborations were identified via an iterative process that combined deductive reasoning based on insights from the economics and psychology literature with inductive insights derived from interview data and supporting case study information. The analytical framework derived from this process is set out in section 3. Second, the framework was used to interrogate the data, by analysing each of the collaborations according to the framework and recording the results in a database of collaborations. Finally, a series of propositions about the possibilities for policy intervention were developed deductively. These are set out in section 4.

3. Knowledge production in the Life Sciences

3.1. *Connections and collaborators*

A link between two scientists in different organisations can be defined as a connection. A **connection** is someone a scientist periodically interacts with. Connections are either **horizontal** or **vertical**. Horizontal connections are between peers in the same scientific field (e.g. two synthetic chemists). Vertical connections are between scientists in different fields (e.g. a synthetic chemist and a micro-biologist).

Scientists' work is divided between three overlapping sets of activities: **producing knowledge**, **securing resources**, and **generating outputs**.

- Producing knowledge refers to any scientific activity where one or more research groups learn something that was previously not known to them³. This includes basic and applied scientific discoveries, procedural knowledge of techniques or processes with potential commercial value (often referred to as 'know-how') and improved knowledge of clinical efficacy
- Securing resources refers to the process of applying for or arranging funding for research, hiring staff and equipping the workplace with apparatus, computers, reagents and consumables
- Generating outputs refers to the production of working papers, articles in peer-reviewed journals, research reports or patents. It also includes the production of reagents or artefacts for sale or exchange outside the research process, and the documentation and communication of know-how and of clinical approaches

These three sets of activities are tightly interwoven. As examples, the grant application process often coincides with making a scientific discovery relevant to the proposed research project, and outputs (in the form of reagents or patents) often help to generate resources.

Since scientists' time (their own and that of their research group) and resources (lab space, equipment and cash) are finite, they are required to make choices about how they allocate time and resources between these activities (Sharp, 1981). Scientists also make choices about whether each activity is undertaken in isolation (i.e. within the research team) or with **connections** in other organisations, forming a **collaboration**. A connection may have potential value to a scientist by providing access to complementary knowledge, skills, equipment, money or time (a 'pair of hands' to do some research). However, there is usually a cost (in terms of investment of time, money, reagents and/or equipment) associated with accessing these, and for this reason a decision to collaborate with a connection is associated with a decision to invest time and resources.

Choices about investment of time and resources, and about collaboration, are made in conditions of uncertainty. Science itself is inherently uncertain. Likewise, the chances of an application for funding being successful, the future sustainability of human resources (lab staff on contingent employment contracts), the likely outcome of submissions to academic journals and patent applications, and the future effort required to produce an output in its final form (e.g. to rewrite a paper to secure publication) are all uncertain. At the boundaries of the subject, or in inter-disciplinary collaborations, these uncertainties are magnified. The likely performance of a given connection (the extent of their knowledge, their ability to communicate and to deliver as a collaborator) is uncertain, particularly in

³ This is consistent with Machlup's (1980) definition of knowledge production, which could be considered to incorporate a uni-directional 'transfer' of knowledge (where one scientist's knowledge is transmitted to another), a bi-directional 'exchange' of knowledge (where two scientists impart knowledge to each other) and 'creation' of knowledge where a discovery new to both scientists is made. In practice of course the knowledge production process can rarely be categorised into such neat distinctions.

the early stages of a relationship. As time progresses, connections become more of a known quantity as a high-trust relationship (in which the investment of time and resources bears less risk) develops.

A connection will only become a collaborator (someone with whom knowledge production takes place through the investment of time and/or resources) if

- relative **absorptive capacity** exists - the two parties have some degree of common scientific understanding
- **complementarity** exists - each party has something different to offer the other. This may be complementary scientific knowledge and/or it may be time (e.g. access to staff) or resources (e.g. funding)
- one party has a **scientific need** of the other - one party is engaged with a scientific activity that could benefit from the knowledge of the other

As an example one interviewee (a structural biologist) described complementarity with scientists in an industrial company as follows:

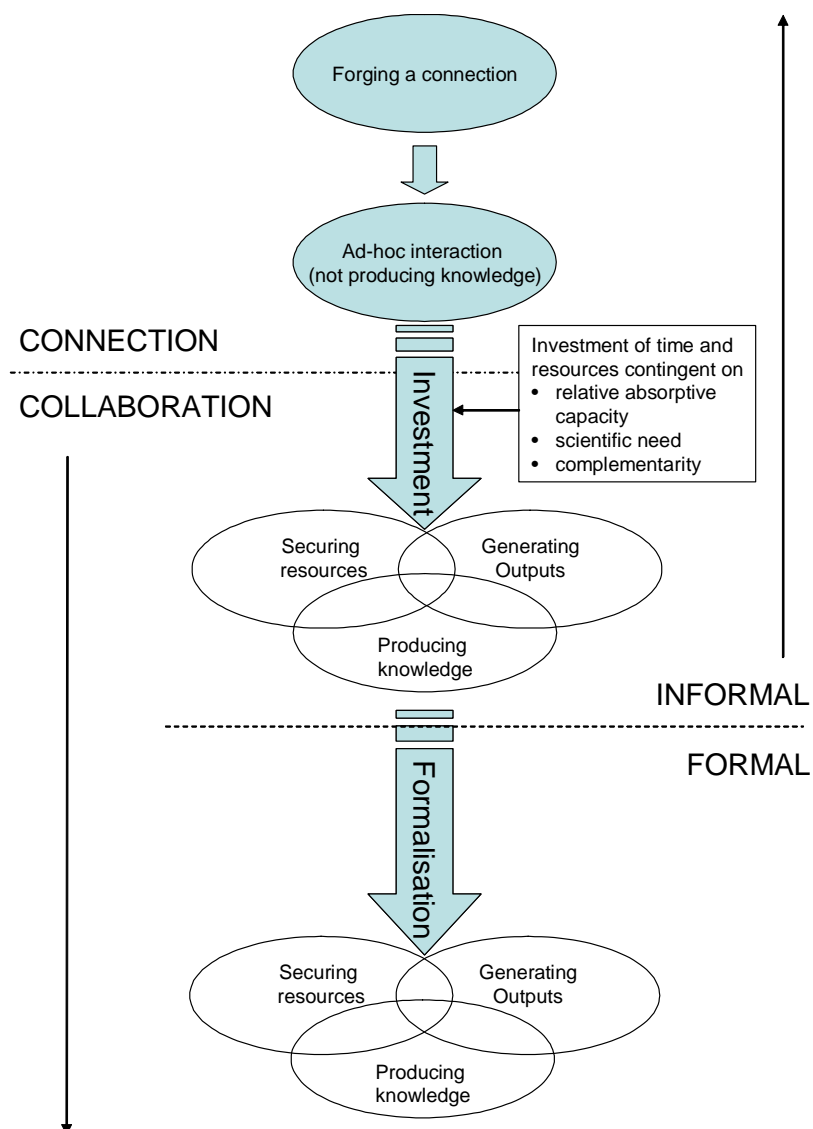
“We have been working with them for a little while now on a target, an enzyme that might form a target for development for the herbicide ... it is exactly the same type of science that you do at our end, in terms of determining the structure of the enzyme, looking at inhibitor binding, modelling inhibitor binding and trying to see what you can infer about ways in which the inhibitor might be modified. They bring to the table completely complementary skills to ours. They do more molecular modelling than we do; we are more concerned with structural determination. They bring insight of the synthetic chemistry, they bring the insights of the type of information one needs to know if one is to make a herbicide, what the characteristics of the molecule have to be like. These things work together in a complementary fashion” (University scientist)

In this example, the company’s scientific need was for the design of a herbicide which if successful would have clear commercial outcomes. The scientist’s ‘need’ was less tangible; he recognised that it was in his interest to collaborate with industry, he had the chance to be part of new developments in rational drug design and at a more basic level the collaboration provided funding for and built capability within his research group.

In making a decision about whether to commit capacity and resources to produce knowledge (i.e. to collaborate) with a given connection, a scientist (consciously or sub-consciously), assesses complementarity and scientific need, together with reputation of other party as a collaborator, costs of interaction (travel, communication issues over distance), expected additional capacity secured including income and learning (an increase in one’s own knowledge), expected outcomes from the interaction, and the value of those outcomes.

Figure 4 summarises the micro-processes involved in collaboration. The relationship is established at the top of the figure, when a connection is formed. The two parties may continue to interact without producing knowledge (e.g. via meetings at conferences or chats at social events). Once knowledge production begins, the relationship can be defined as a collaboration, even if informal. Knowledge production may continue on an informal basis for the duration of the relationship. The two parties may produce papers together without ever having a formal relationship; this is common in academic circles. They may also work together to produce know-how, or a solution to some applied problem. These outputs may increase their chances of securing further research funding. They may apply for research funding unsuccessfully; again this would mean that in the terms set out here, their relationship remained informal.

Figure 4: micro-processes involved in collaboration



3.2. Formalisation: the process of making a collaboration formal

Once joint research funding is received, a non-disclosure agreement is signed, or a contract set up between the two scientists, the relationship moves onto a formal footing (bottom of figure 1). This process is referred to here as ‘formalisation’. The same three sets of activity may continue, as scientists often continue to seek further resources even while a relationship is already on a formal footing. At the end of a period of formal relationship, the interaction may continue informally until the next funding is secured, and so on.

Formalisation is a significant activity in terms of time. It often involves negotiation of intellectual property rights and usually requires the involvement of third parties (such as technology transfer and other enterprise managers, lawyers, ethics committees etc.). Both the absolute time (hours of scientists’ time) and the elapsed time (between initiation and satisfactory resolution) are often significant. Intellectual property is a significant element for discussion in the formalisation process, and in university-industry negotiations is often the defining factor determining whether a collaboration takes place (see example 1).

Example 1: Problems with Intellectual property in the formalisation process

A small, entrepreneurial diagnostics company in the south of England is developing a device for diabetics to measure blood glucose levels non-invasively through the eye. The founders needed advice on aspects of optometry and optics. Through web searches, they found academics in Manchester and in Glasgow, whom they cold-called. They have established formal relationships with both. Their preliminary discussions with another university foundered on the issue of intellectual property, because the University wanted to own the IP. As described by one of the founders:

"That University argued that you pay for our scientists, it's their ideas, therefore we own the IP. Manchester has made a lot of money out of our company, this other University has made nothing at all. Their aim is to maximise their benefit, rather than working with us as a team. There has to be a mutual gain." (Industry scientist)

Lambert agreements (model agreements for universities and companies wishing to undertake collaborative research) are at best only a starting point for what are often detailed and lengthy negotiations.

Where collaborations with a clinical application are concerned, ethics committee approvals are another very time-intensive aspect of the formalisation process. The regulatory climate is rapidly advancing towards very stringent ethics approval requirements for clinical research. The time and resources required for this process were described by a professor of tissue engineering:

"You can't develop anything in tissue engineering unless you've got a really strong team that also involves clinicians. Now, as things are going right now [in terms of research in clinical careers], clinicians may not be part of the development team. But you need to have got something to the stage that you are pretty certain that it is going to be safe, it is going to confer benefit to the patient and then you need to have clinical colleagues who will help you get that into the clinic. And getting into the clinic early on isn't easy... the barriers have never been higher to doing clinical studies. So you really have to be incredibly stubborn. .. Until the last couple of years if I wanted to go to the clinic and we had something reasonable and I had a clinical colleague to do it with, we would always write an ethical submission. Take it through all the correct routes etc, but we would look at doing that in three to four weeks. It would be work but it wouldn't bring you out in an enormous sweat. Now, it is so bad that for the first time, I have just submitted a grant to Wellcome, just last week, and in it I said that the first landmark, the first milestone, would be getting ethical submission approved and that it would take us three months. We are in a crazy loop because nobody wants to fund the research until you've got the ethics sorted. The ethics committees don't want to give you approval until you've got the funding." (University scientist)

These 'transaction costs' involved in the formalisation process can be a disincentive, especially for academic scientists who may be able to create academic value (via publications) from an informal collaboration. The clinicians interviewed were unanimous in predicting that increasingly onerous ethics approval requirements would significantly deter clinicians from conducting research. These transaction costs can be expected to rise as universities more actively seek to exploit their intellectual property (through third stream activities) and as ethics committees' remit and requirements continue to increase. It is desirable that these transaction costs are recognised and factored into the full economic costing (FEC) of research - including the costs of 'failed' transactions.

Formalisation is also a significant activity in that it raises the 'exit costs' associated with a failed collaboration. Expectations of line managers, funding councils, university or NHS Trust management are set when a collaboration is formalised. Where a formal collaboration

does not come up with the expected results - either for scientific reasons or due to difficulties in the collaborators' relationship - the costs are more significant than for an informal collaboration (which may not be visible to anyone). Costs may be financial (in that final funding is withheld, or hoped-for economic outcomes are not forthcoming), but they may also be psychological (disappointment, failure, career set-backs etc.). For these reasons, the expected net benefit (probability of scientific and financial gains against costs of time and resources involved in formalisation) is weighed up when a scientist considers converting from an informal to a formal relationship with a collaborator.

3.3. Informal versus formal collaborations

By definition, a collaboration resulting in a granted patent, licensing income and/or a spin-out will at some stage become formal by necessity. Thus, all of the collaborations in this sample that were identified as exhibiting exemplar outcomes were put on a formal basis at some point during the collaborators' relationship⁴.

Formal relationships have a number of important advantages, which are applicable well before collaborators reach the stage of possible exploitation of intellectual property. These are the following

- Formalisation via contracts and NDAs requires a clear statement of complementarity (e.g. prior know-how brought to the relationship, what each party is expected to deliver) and mutual gain, making clear who is expected to deliver what, and making it easier to attribute contribution to particular parties later on
- Formalisation requires objectives and intended deliverables to be identified, increasing the likelihood of well-planned and targeted activity
- 'Pairs of hands' (PhD students or post-docs) - often appearing in a funded collaboration - increase capacity for at least one party and oblige interaction (e.g. joint PhD supervisions, joint papers)
- By being visible to the organisations employing the scientists, formal collaborations are more likely to be monitored and managed by the organisation for the purposes of subsequent IP generation. One scientist described the benefits of visibility from a perspective he had gained as a R&D manager in an industrial company

"I would never discourage scientists from developing links, but I would be thinking whether it was appropriate to trigger something more formal. There was an attempt to instil more control at [the company he worked for] - too many informal arrangements were being initiated. A 'green form' system tried to impose more discipline (don't give the crown jewels away) and visibility for the benefit of senior management. Encouraging people to put a formal agreement in place helps to concentrate the thinking as to what the relationship is trying to do." (industry scientist)

However, informal relationships also have important advantages. Informal collaborations provide the opportunity to

- Identify complementarity i.e. to determine whether one's own scientific need will be met by the other, and whether the other genuinely has complementary knowledge
- Appraise the likely performance of the other as a collaborator i.e. to determine how they are likely to act as regards investing time and resources, respecting,

⁴ However, 5 of the 10 companies formed as result of collaborations studied were formed independently of an employing organisation; 3 of these involved entrepreneurs and 2 involved Cambridge scientists whose companies were formed several years ago, before Cambridge University changed its policies regarding IPR

confidentiality, hiring and managing staff, target-setting and delivery, analysing data, writing papers or reports etc.

- Thereby appraise the likely benefits of having a formal relationship with a collaborator, and the net benefits once costs of formalisation are taken into account

Once a formal arrangement is in place, there is limited scope to expand or reduce the boundaries of the relationship or to change the focus of the collaboration. One industry scientist described the constraints involved in signing a confidentiality agreement

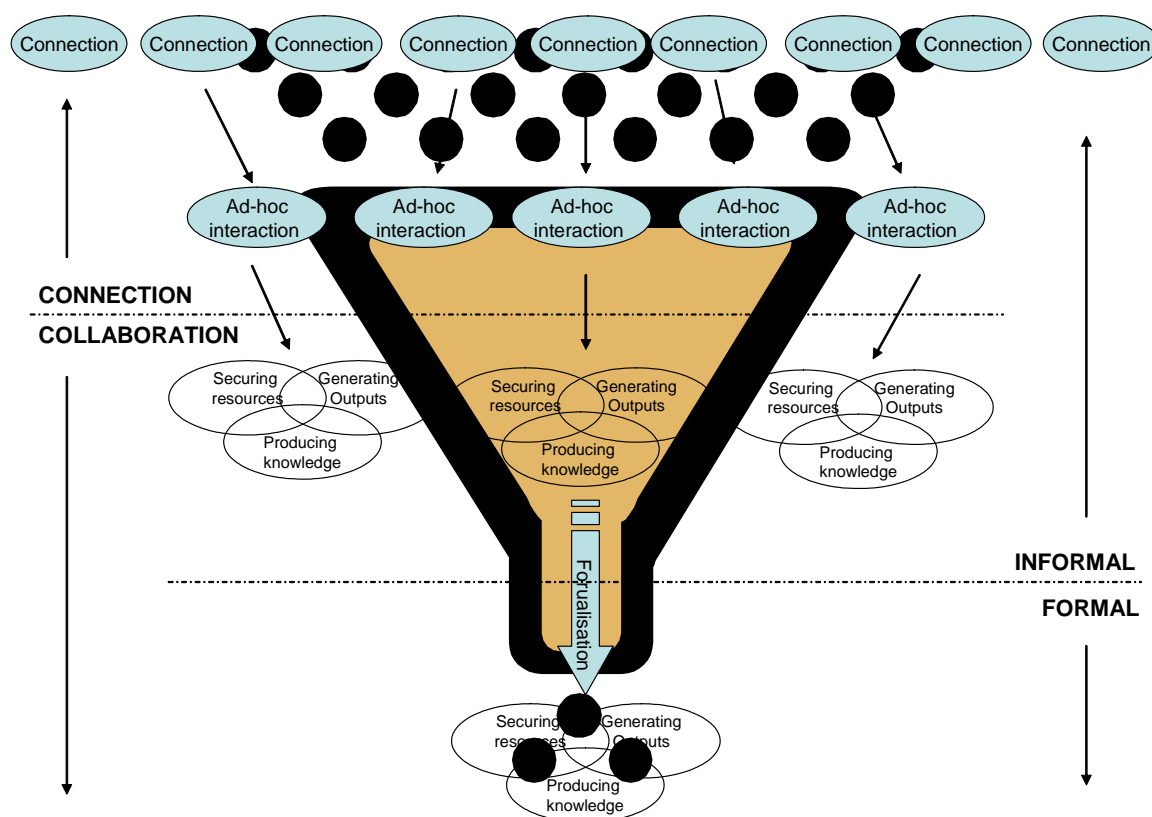
"It worries me that IP (as both patents and know-how) is used as a bargaining tool. Very frustrating if you just want an exploratory discussion, to be referred to a tech transfer office. Their reaction is you must sign a confidentiality agreement. Seems unnecessarily constraining in the first instance, and they are not really worth much. You get tied down, you sign but already you're defensive. It makes both parties less free with information which is not the point." (Industry scientist)

Informal collaborations effectively act as a filter, enabling a scientist (either consciously or sub-consciously) to reject or neglect a relationship that is not deemed likely to be productive. One scientist (a synthetic chemist) described how he approaches potential collaborators, and the balance between formal and informal relationships as follows

"I go out and I am very proactive and I go out and target people. I say look I think you should be interested in this [compound] and this is why I think you should be interested. Do you want a sample? 50% of the time, well some, very rarely have people said no. Generally speaking they have said yes let's try and do something. What often happens is that nothing happens. You send a sample and they just don't do anything, or you send a sample and the idea doesn't work. Or you send a sample and they want to do something but they haven't got a pair of hands that can be devoted to it and then it just falls between stools, between the cracks or whatever. So a huge number of collaborations have been informal, let's try, let's do it. Only more recently in the last three or four years have I now started to really try to use the collaborations, to try and make them formal. To try and use them as a way of leveraging money from research councils or companies or whatever." (University scientist)

This filtering process is important because of the social nature of science. Scientists forge numerous connections and have multiple ad-hoc interactions (at conferences, through peer review panels and editorial boards). Informal knowledge production is a means for identifying the few key people with whom a formal collaboration will be productive. This filtering process is depicted in Figure 5, which shows multiple potential collaborators being filtered out through an informal knowledge production process. A funnel has been drawn in the background of the figure to illustrate this filtering process.

Figure 5: The filtering process provided by informal collaboration



3.4. Differences between academics and industry scientists' approaches to formalisation

Academics' approaches. Academics⁵ commonly exchange knowledge on a purely informal basis, as part of a wider academic community of scientists that facilitates the forging of connections and informal knowledge production. Academics exchange knowledge with informal connections where

- a perceived scientific need exists
- and/or where some other intrinsic motivation exists (curiosity, a sense of obligation, commitment to a particular research group, region or institution)

Academics' motivation for migrating from informal to formal connections with one another (e.g. via a joint research application) is in order to generate additional capacity (time and resources) in their groups, and also for the kudos of obtaining research income.

Academics work informally with industry scientists in order to gain access to equipment and reagents that are otherwise unobtainable, access knowledge that resides in industry and/or work on interesting problems (all of these are different aspects of scientific 'need'). Beyond these motivations, academic scientists and clinicians migrate from informal to formal connections with industry scientists in order to

⁵ Clinicians are included within the term 'academics'

- increase capacity (keeping the lab funded; access to 'soft' money)
- cash in personally on the economic value of their knowledge (e.g. through consultancy)

Industry scientists' approaches. Industry scientists sometimes exchange knowledge on a purely informal basis, particularly where they engage with a wider academic community of scientists (e.g. at conferences). However, formalisation is more important for industry scientists than for academics because of greater concerns about commercial sensitivity. Industry scientists have other motivations for formalising relationships:

- to access knowledge that resides in universities and appropriate value from the academic's knowledge (these are different aspects of scientific 'need')
- to access potential recruits (through involvement with PhD students and post-docs)
- to set up a relationship that enables them to keep current with developments in an academic's lab

Industry scientists have more tightly defined areas of scientific enquiry (defined by their organisation) and less free capacity and time to invest in informal interactions than academics/clinicians. Industry scientists therefore have less opportunity than other academics to assess a collaborator's performance on an informal basis.

For these reasons, interactions between academics and industry are more commonly formal than informal, and more commonly proceed straight to being formal without a period of informal knowledge production. This understandable need for formalisation is however potentially undermining, since it increases the chances of collaborators not being 'right' (in terms of a mismatch of complementarity, or simply not able to perform as collaborators) and increases the exit costs associated with a failed collaboration.

At the same time, industry scientists often have difficulty convincing their managers of the benefits of investing in academic research. Where industry is expected to pay the full economic costs of research, grounds for justification of net benefit - perhaps by demonstrating evidence of preliminary results - is even more important.

It is therefore desirable that academic-industry collaborators are given the maximum opportunity to produce knowledge informally together before being required to formalise their relationship. This requirement may of course be very difficult to achieve, because of concerns about commercial sensitivity. Subsidised interactions that are relatively straightforward to set up (such as CASE and KTP projects) focused on pre-competitive research topics provide opportunities for knowledge production with low transaction costs on entry. These are referred to as quasi-informal opportunities here (see example 2).

Example 2: A CASE Studentship leads to a more significant collaboration

A virologist with expertise in baculovirus expression (a means of generating proteins) collaborated with a molecular bioscientist in a large pharmaceutical company to help the company appraise alternative approaches to high-throughput protein supply. The collaboration began with a CASE studentship, which was just coming to an end when I interviewed the industry scientist. The relationship appeared to have extended beyond the specific focus of the studentship in terms of the knowledge that had been exchanged. The academic, for example, had provided advice about whether the company should use a university-based company offering expression facilities. The pair now hope to move on to a bigger project involving BBSRC funding for one or more post-docs, and are working on a proposal together.

3.5. Is geographic proximity important for collaboration?

All interviewees were asked this question, and very few believed that geographic proximity is essential. Geographic proximity strongly increases the likelihood of personal connections being established, and weakly increases the likelihood of them being maintained over time (i.e. the likelihood of repeated interaction). Proximity reduces the time costs and/or the perceived difficulties of collaborating over distance.

However, complementarity and scientific need are more important than geographic proximity in increasing the likelihood of a connection becoming a collaboration. The reduction of time costs and the alleviation of difficulties associated with collaborating over distance are only of marginal importance compared with complementarity and scientific need. For example:

“If you collaborate with someone close by it’s easier to meet and discuss things. The reality is that people with similar interests are not all going to be within your institution, or even in your locality. Cambridge couldn’t have everyone! So proximity isn’t as important as people make out.” (Scientists, University of Cambridge)

However, if no scientific need is present, but complementarity and common scientific interest are present, proximity provides the possibility for ‘dalliance’ (low resource cost, low-risk exploration with minimal exit barriers; see example 3).

Example 3: Low-cost, low-risk collaboration afforded by proximity leads to a more significant collaboration

A synthetic chemist at the University of Sussex began collaborating with a pharmacist at the University of Brighton. Their informal interaction led to a collaboration where the pharmacist evaluated the biocompatibility of compounds synthesised by the chemist. They have subsequently both collaborated with, and generated patents and know-how on behalf of, a biomaterials companies. The chemist described the emergence of their collaboration as follows:

“I guess the [University of Brighton] collaboration ... that was probably the first collaboration which really became formal. We started working together because you know, we were geographically 4 miles apart. We didn’t need each other but we knew that we would each benefit if we worked together.”

Shared equipment (e.g. shared lab space in a business incubator, or businesses accessing university equipment) increases the likelihood of connections being created, being maintained over time and if scientific need, absorptive capacity and complementarity are in place increases the likelihood of informal knowledge production. The DiagnOx lab space in Oxfordshire run by Oxin is a great example of informal knowledge between entrepreneurial companies emerging around shared equipment (see Example 5 in section 4.2).

However complementarity and scientific need are more important factors than access to shared equipment, as illustrated by Example 4. Without these shared equipment does not promote collaboration.

Example 4: Proximity and shared equipment are not sufficient for collaboration

A life sciences company formalised an agreement with its local University for access to X-ray crystallography equipment. I interviewed a computational chemist from the company. The deal included funding for a PhD student for one of the faculty members involved in negotiating the deal. The university later recruited a structural biologist (also interviewed) as an academic member of staff to manage the equipment for commercial purposes. Company staff regularly visited the university to use the equipment, but very little informal knowledge production has taken place between the university structural biologist and the industry scientist. This is partly because their scientific interests differ, but perhaps also because they do not share a PhD student to oblige them to interact. The company has now taken the decision to invest in its own X-ray crystallography equipment. The industry scientist described the interaction as follows:

“As it turns out the crystallographers we’ve had have been very experienced and technically self-sufficient. So although our crystallographer has interacted with the people at [the University], in fact most of her preparation is done here, so she hasn’t really used the lab space element over there. Primarily I suppose she has used it as a kind of service provided. So it hasn’t been a collaboration in the sense of scientific collaboration.”

3.6. Scientific collaboration in clusters

Clusters are often said to be characterised by a relative density of firms with similar activities, and university(s) with science to exploit. Using the analytical framework set out here and the definition of clusters offered in Appendix 2, it could be argued that clusters are more likely to facilitate university-business interaction because

- Clusters reduce the time costs of interaction, and increase a sense of identity and shared goals (e.g. a goal of sustaining or developing one’s region). These factors might increase scientists’ motivation to invest in connections within the cluster in preference to those outside.
- Because they are defined by a concentration of complementary activity, clusters increase the likelihood of making ‘useful’ connections - i.e. meeting people working in similar fields (with similar absorptive capacity), who could meet one’s scientific need

However, the analytical framework proposed here indicates that complementary, absorptive capacity, scientific need and collaborator reputation are far more important than time costs and/or regional identity in decisions to invest time and resources in collaboration with a connection.

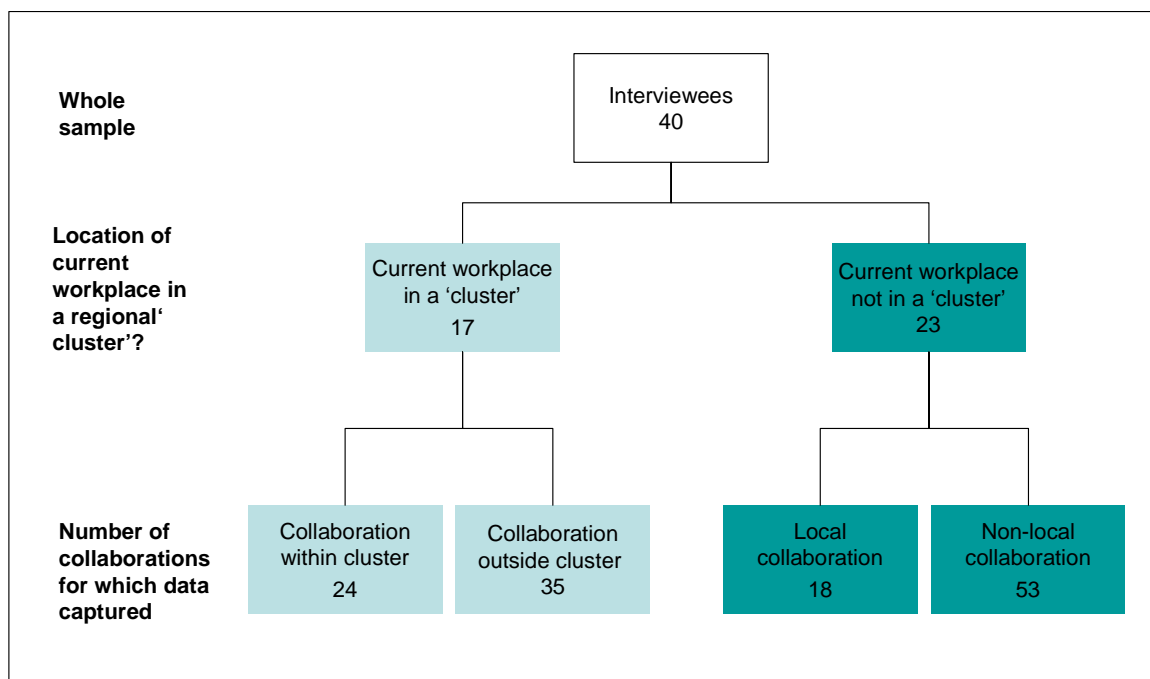
Analysis of the data on collaborations captured does imply a slight tendency for those located in a cluster to collaborate locally (see Figure 6). For the 17 interviewees located within a cluster 24 instances of collaborations taking place within the cluster were found. This is proportionately more than the number of local collaborations (18) identified for the 23 interviewees not in a cluster. However, this figure needs to be interpreted with some caution. Interviewees were not asked about all of their collaborations, but only those which they felt were most significant and/or those the researcher was interested in. The figure cannot therefore be considered to be representative of their collaboration preferences or past collaboration patterns.

It is conceivable that the greater proportion of local collaborations identified by interviewees located in clusters is the result of greater munificence increasing the probability of an appropriate collaborator being located nearby. However, beyond the

simple figures set out in Figure 6, the interview data do seem to suggest that these supposed benefits of being located in a cluster are of marginal importance to scientists. Indeed, the majority of interviewees based within the clusters studied were dismissive of the importance of localised relationships relative to national or international ones. The following quote from a scientist in a large life sciences company illustrates the lack of interest in local collaborations:

"I think the big fish like us, we would look to the specific experts that we want. We are not looking for leg up locally, or help locally ... You find them out in the literature and you go straight to them. We can afford to do that and we can afford the travel and the time and sending people out, to establish those relationships. So whenever there is a real need we will go anywhere, anywhere in the world in actual fact." (industry scientist)

Figure 6: Instances of local collaboration identified for interviewees located in clusters versus those not located in clusters



In summary, the data suggest that being located in a regional cluster may help to do the following (but it is important to bear in mind that complementarity and scientific need are more important factors):

- (through repeated interaction with local connections) increase appreciation of complementarity and potential gain from a collaboration
- (through identification with the cluster and/or the locality) increase motivation to collaborate for altruistic reasons (e.g. to support local university or science)

4. Policy implications

4.1. Do we need publicly funded initiatives to connect scientists?

Academic-academic connections. For academic scientists and clinicians, scientific reputation is established by their standing in the academic/clinical community (publications, research grants etc.). Conferences and academic societies provide a means for communicating one's knowledge, scientific need and potential complementarity. This is illustrated by the following quote:

"[A collaborator based in Brazil] wrote or emailed in 2001 and said he was keen to collaborate. No prior connection, just through the literature. I said that's fine but I'm retiring at the end of next year... He wrote back saying that is not a problem. I was going to a conference in Venezuela and while I was so 'close' he came to meet me. We met and talked and we actually have overlapping interests right across the board, it was quite extraordinary. He is a physical organic chemist and I am bio-organic but there is a big overlap." (University scientist)

Scientific reputation does not offer 'perfect' information to other scientists about their likely performance as collaborators. However, informal knowledge production provides a means to obtain this information (at a cost of time and resources, but otherwise minimal exit costs).

Scientific reputation does not offer 'perfect' information to other academics about their performance in a formal relationship. A potential collaborator needs information about the person (e.g. whether they deliver on time) and their institution (stance on IPR, contracts etc.). Such information is available to academics through institutional reputation (the 'grapevine') and also becomes available through informal knowledge production.

There is therefore no market failure in brokering collaboration between one academic and another, or one clinician and another; academic science as an institution does this perfectly well. Collaborations between clinicians and academics are similarly facilitated by clinicians engaging in the academic science community, although this may be undermined as it becomes less important to do research as part of a medical career.

Academic-industry connections: Scientists in large R&D intensive MNCs and research-intensive SMEs are usually involved with the academic community; they know from the literature who they want to connect with and they have some knowledge of the relevant sources of expertise in universities in the UK.

Scientific reputation does not offer 'perfect' information to industry scientists about academics' likely performance in a formal relationship. Similarly, scientific reputation offers sparse information to academic scientists about industry scientists' likely performance in a formal relationship. This is a particular issue for scientists in small companies, as illustrated by these quotes:

"Occasionally you get suggestions of projects from small business, and occasionally I have been in contact with a small business but their sights are not usually set at a level that is interesting to someone in a department like this. Research is an expensive business and a small company (unless started by people who have come recently out of a place like this and know what is what) will be looking for support rather than a two-way relationship." (Scientist, University of Cambridge)

"We found that collaborations with larger companies are better than ones with SMEs. They have to hit deadlines at regular intervals, they are very focused. It's better if there is a more open outlook from our perspective. Working with SMEs is harder. It's not necessarily their expectations about deliverables - we try to manage that. Very often they don't have a large amount of money. We may work for £10K but it takes £20K worth of time to do it. They are often relatively small

projects, but they tend to have to be bigger than small - bits you have to do around the outside. We still work with them because they should be companies we could exploit our technology through. They are more flexible, but it's a different way of working. We are still learning about that." (University scientist)

High demand for their knowledge from large companies and other academics (especially for highly prestigious scientists) increases the low desirability of interactions with small companies. This difficulty is compounded by the fact that small companies' research grants are often too small to fund a dedicated 'pair of hands'.

"They fund some of my time and some post-doc time. This may be a weakness in working with SMEs. There is not a dedicated person working on that grant. It's not that we are doing it in our spare time, but with the smaller grants for SMEs you are sort of fitting them in and the driver for them is not as strong as it might be." (University scientist referring to an arrangement with a small company)

Scientists in small companies also talked about the difficulties of working with universities. Although there were some examples of highly effective collaborations (such as a university spin-out company working with a clinician to conduct clinical trials of immunotherapy for cancer), these examples were balanced by stories of the difficulties small companies, and particular entrepreneurs, encountered with academics. One entrepreneur needed access to lab facilities to progress his idea, and had therefore shared lab space with academics, with the result that the academics filed a patent on which he should have been named. The organiser of a regional network commented on the time entrepreneurs in small businesses and academics spend trying to understand their respective worlds, and the time they spend trying to place interpersonal relationships onto a formal basis that is acceptable to both the company and the university.

These quotes illustrate that, because of constraints on time and resources, and/or uncertainty (due to lack of opportunity for informal knowledge production), academics may be reluctant to interact with industry scientists, particularly those in small companies - and that this reluctance may be shared by those in companies. The prior existence of a personal connection between an academic and a scientist in a small company (through a small informal network from a previous post-doc or employment position, mutual friends or repeated conference meetings) reduces uncertainty by increasing appreciation of complementarity.

For junior academics, who perceive a need to make contacts in industry but have not yet done so, there is some potential for engendering informal contact with industry scientists. Several senior scientists commented that their now mature links were formed when they were more junior. One scientist described this as follows:

"I suppose when you are starting off you don't know many people in these very big multinational companies. It is no good ringing them up. It just doesn't work. I suppose I found that it is personal contacts are the way it works. So at first there was not much of an opportunity, because, especially as a junior researcher, I just didn't know who was involved. For me, one of the major breakthroughs in setting up a network of industrial collaborators came from an initiative that was run by, at that time it was SERC, the forerunner of part of BBSRC, they had an initiative called the Protein Engineering Club. So this was something that they set up when protein engineering became possible. BBSRC put some money aside to fund projects that were interested in protein engineering and there was an element of the money that came from, there was an involvement of industry in that programme. ... You meet a lot of people, who are at the right level, so they are not the people at the top of the company they are the scientists. For me that was where I make a lot of my early connections." (University scientist)

In summary, with the possible exception of scientists at the beginning of their careers, there is limited scope for a third party to make connections between academics and

clinicians on the one hand, and industry scientists on the other. The problem is not making a connection but in overcoming the lack of informal knowledge production (a) being a barrier to assessing desirability of a collaboration in the first place and/or (b) reducing the likelihood of success after formalisation. Repeated interactions at conferences or meetings may (at the margins) help to increase appreciation of complementarity and potential gain from a collaboration.

4.2. Localised interventions to promote connections between scientists

In introducing this section, it is worth noting that very little evidence could be found of collaborations that had emerged from localised initiatives to connect scientists. Although 18 of the interviewees were involved in a regional intervention (see Figure 7 in Appendix 1), only 7 instances of 'exemplar process' collaborations arising as a result of an intervention could be identified (see Figure 8 in Appendix 1). Four of these arose from connections that were either made through the DiagnOx lab in North Oxfordshire or for which the lab has facilitated informal knowledge production. The DiagnOx lab - and the network it is associated with - is clearly a very good example of promoting connections between entrepreneurial scientists in small businesses (see example 5).

Example 5: Forging connections between entrepreneurial scientists in small business

The DiagnOx lab in North Oxfordshire has been set up to provide a range of services to researchers or companies with medical diagnostic technologies. The lab (which has been funded by DTI (BEP), SEEDA and Oxin) enables scientists to undertake proof-of-concept work cost-effectively and in a supportive environment, with access to **commercial, financial, regulatory and technical expertise and to training.**

The lab and the associated DiagnOx network thus perform a number of functions beyond the focus here on connecting scientists. It is clear that, for three entrepreneurs involved in the lab who were interviewed, access to subsidised wet lab facilities has been a critical factor in the growth of their businesses. (One entrepreneur told a number of 'war' stories about the difficulties he had had in building his own and in sharing lab facilities prior to the construction of DiagnOx; difficulties which were not just logistical but also profoundly challenging to his intellectual property.)

For the purposes of the analysis here, the DiagnOx lab provides an excellent example of scientists with common scientific need engaging in informal knowledge production around shared equipment. They were seeking to solve similar problems in the endocrinology and chemistry of producing reliable diagnostic tests in a low-cost, scalable format. DiagnOx also offers a good example of a network facilitator, Lisa Myneer, who previously worked in the diagnostics sector) very effectively making connections between members and potential members of DiagnOx.

"What does DiagnOx offer us? In its simplest it offers facilities ... DiagnOx needed tenants, and we were looking for facilities. We were the first tenant ... It also offers contacts. One contact Lisa found in an interesting new market; we took over developing that product and the guy is probably going to start working for us. Other projects come through in the same way. Another one, I knew the guy but he had finally come through Lisa. ... None of these were DiagnOx companies when we started working here." (Industry scientist)

In contrast to DiagnOx, localised networks that are largely targeted at running events, training and providing mentoring but do not provide common facilities (such as Oxfordshire Bioscience Network or Thames Valley Life Sciences Network) help to create connections between scientists at a local level. However, the analysis above suggests that connections

per se have no financial or scientific value in terms of exploitation of the science base. A connection will only become a collaboration where complementarity and common scientific interest exist.

Interventions which emphasise absorptive capacity and communicate participants' scientific areas have greater potential for collaboration. Thus, meetings which facilitate informal knowledge production (such as mentoring meetings, business plan competitions, panels for peer appraisal of proposals, scientific-industry liaison panels) have greater potential for engendering collaborations than meetings which simply connect people.

However, it is worth noting that, because interaction in local networks is not costly in terms of time or resources, scientists may be more willing to attend meetings that are not immediately relevant to their expertise or need (whilst they would not choose to travel far to such a meeting). Thus, local scientific meetings and/or networks may have greater potential than national networks for increasing awareness of diverse collaborators (those in fields the scientist might not have thought to explore).

Connecting universities with businesses. Of particular interest here is the question of whether localised networks help to address a market failure in connecting universities and business. The analytical framework proposed earlier in this report suggests that localised networks do not address a market failure connecting academics clinicians and scientists in large research-intensive companies. These scientists will find ways of identifying and making connections with the people they want to interact with.

The same applies to connecting universities with small business. One of the suggested benefits of localised networks is that they help small companies - and particularly those that are not currently engaged with universities - become aware of and connect with the public science base. However, within the science-intensive small companies studied here, scientists generally were closely engaged with the public science base, and knew where and how to access it. Their difficulty is in convincing academics to work with them, as illustrated by the quotes in section 4.1.

University scientists are particularly negative about the benefits of local initiatives to connect them with commercial businesses. With reference to such initiatives one scientist said:

"I don't consciously look out for meetings to go and meet people at. It may be a way of meeting people but you have to judge whether a collaboration is going to work and you decide that fairly quickly. I'm not sure that is the most time-effective way of finding collaborations. As you become better known, people approach you and that is probably slightly better." (University scientist)

The following quote was from a senior professor working in the field of tissue engineering, who referred to 'an increasing number of people trying to wring the same information out of a small number of scientists', commenting:

"If you ask me do I share the same confidence about the regional and the clusters right now, I'd have to say, no. I don't have the time to engage in this cluster stuff. As an academic I am not seeing this helping me, I'm seeing that they actually want me to help them. A bit frustrating, because I am someone who naturally wants to tell people what I am doing, but I've got to look at how I spend my time. In terms of managing my own research group and the teaching and the admin, it has not so far helped me do my job. I've not had any new opportunities brought to me by any of [these regional networks] so far. If I do the black box analysis I've given information to them, nothing has come back to me." (University scientist)

The analytical framework proposed here also suggests that initiatives to engender localised collaborations at the expense of national collaboration are undesirable to the extent that they reduce the sphere of possible collaborators, which in turn reduces the likelihood of

establishing complementarity. Judgements about complementarity are very fine-grained: a national collaborator with *exactly* the right expertise is far superior to a local collaborator with *almost* the right expertise (see example 6).

Example 6: The fine-grained nature of scientific need

One Cambridge-based academic, who had founded his own company, was searching for a particle coating technology that could add a waterproof coating to a hydrophilic particle inexpensively. (This is an unusual requirement as most coating technologies are for drugs where hydrophobic particles are coated with something biodegradable, and cost is less of an issue in drug design.) He described interactions with various local bioscience initiatives in the Cambridge area as follow:

"I sort of vaguely have interacted with some of these things ... It tended just not to be very useful really. At that point what we were looking for was sort of coating technologies and they were all just doing rather different things. So I suppose if it had happened that at that point some of them had been doing something very relevant then it probably would have been different. So there is an East Anglian investment forum and I think there is something like a bioscience network, but it is largely kind of genome projects. In the sense it is the problem of being in a kind of, well interdisciplinary but also rather odd area. ... It probably is true that someone in the world knows exactly how to solve our problem, but how do we find someone in the world?"

In the science-intensive fields studied here, it seems that policy initiatives to promote collaboration would be more effective if undertaken at a national not a regional level. RDA-led initiatives to promote regional science are also potentially problematic in that they generate duplication of effort and resources both within and between regions, as the following quote from a senior professor referring to the Bioscience Yorkshire initiative illustrates:

"I think they are doing what is needed, it is difficult to jump into that space and have it right first time out. Because it is a tricky game. Academics generally are not easy people to work with. They are in academia for many reasons and some of them are there maybe because they are, you know ... they don't like mixing and they are isolationist to some extent. So it isn't an easy sort of activity to get it right first time. I think these agencies are going to have to learn, see what goes down well, what doesn't go down well..."

"The nation needs them, I don't know if they need quite so many. There seem to be many, many of these agencies popping up. There is a danger that as they proliferate the level of quality is going to be diluted. Simply there aren't enough people to go around; there aren't the top end people. The worse thing that could happen would be that you get people coming that are not going to manage well the kind of difficult or challenging people that they have to deal with. Then it is worse than not having [a regional network] because it has tried and failed in a way, or not succeeded. So I think someone somewhere, sometime has to see what breadth of that we need and how many of these agencies we need. I get lots and lots and lots of stuff and you can't respond to them all because you are trying to do all this other stuff. It could be a bit of an overload scenario rolling along."
(University scientist, Yorkshire)

In summary, localised networks may help to do the following

- (through contact made from shared use of facilities) provide opportunities for informal knowledge production where complementarity and scientific/financial need exist (with the DiagnOx lab being an excellent example of this)
- (through repeated interaction at networking meetings or via presentations from speakers) increase appreciation of complementarity and potential gain from a collaboration
- (through repeated interaction) increase motivation to collaborate for altruistic reasons (e.g. to support local university or science)
- (by bringing together scientists in different fields and varying topics covered) increase scientists' exposure to fields of science outside their own, raising awareness of knowledge domains that might be useful to them

4.3. Funding interventions to promote inter-disciplinary research

The analytical framework proposed here, with its three-fold emphasis on resource generation, output generation and knowledge production, illustrates the significant proportion of time scientists devote to applying for funding. The time required to write a strong research proposal to a funding council can be as long as the time required to prepare a paper for publication, and for many scientists this is a difficult trade-off.

"The trouble with the research councils as well, is that they are rather slow so waiting six months or a year to collaborate with someone you met yesterday is not very useful. And they are very uncertain. And they are not very well adapted to doing slightly unusual, and you always find that what happens is that someone says that they haven't heard of you, or they haven't heard of the person you want to collaborate with. So I always feel that they would be much better off just giving you some money and letting you get on with it. I think the more you target these things in a way the worse they get, because they are always targeted slightly wrong and someone's always having to decide who to target them on and the person making the decisions inevitably is rather badly informed." (University scientist)

Targeted or 'managed' funding programmes such as those intended to expand scientific knowledge at the interfaces between scientific disciplines and/or introduce new partnerships were criticised by six of the academics interviewed. For example:

"The Research Councils spend money on initiatives intended to connect scientists (although admittedly not that much money). There are always setting up these 'sandpit' type initiatives to connect scientists; people go out of their way to find a way to fit their research into these initiatives, rather than the Research Councils funding research that is really worth doing. A lot of the early basic technology grants gave away £4-5m at a time in a way that was not good value for money. They do better now but even so it's a very hit and miss process. These big collaborations with £4m up front are not the best way of doing things. I think groups should get together spontaneously, like our medicinal chemistry group. We had a ready made set of people who were genuinely collaborating. That's quite different from people saying, look there is a call for such-and-such, I don't think that gives good value for money. I am not a believer in big initiatives." (University scientist)

Funding calls requiring particular types of partnership can engender rapid escalation to formalisation without prior informal collaboration and knowledge production. EU programmes were particularly criticised by interviewees in this respect. For example:

"A few years ago the MRC suddenly decided they wanted all these co-operative grants. It is a bit like the EU grants where they say you've got to have say six

partners from southern Europe, eastern Europe and all the rest of it. You end up contriving interactions with people for these funding agencies and it doesn't work. Because the people who you want to interact with, you are already interacting with. If you drum up an interaction it usually leads to nothing because you don't have any natural reason to be getting together." (University scientist)

Funding calls in new scientific areas or at the interface between disciplines are even more uncertain than known areas in terms of securing resources (as peer review processes are less of a known quantity) and output (due to doubt about whether journals in an academic's core field will accept publications arising from inter-disciplinary research). The analytical framework proposed in section 3 suggests that this uncertainty might act as deterrent to application, and the empirical data indicate that themed funding calls may engender ineffective collaborations.

Where research councils or the DTI are assessing inter-disciplinary proposals (such as applications under the Life Sciences Interface programme) they are right to look for evidence of prior formal and or informal knowledge production between collaborators. In the light of arguments made here, they might place a greater emphasis on this as a pre-requisite for funding.

4.4. Funding interventions to promote university-business interaction

The research councils, the RDAs, the DTI and others are investing considerably in mechanisms to promote university-business interaction (such as Industrial Partner Awards, LINK, CASE and KTP schemes). Similar arguments to those in the previous section apply to funding applications involving partnerships between academia and industry, especially where large sums of money are concerned. Where proposals involving academic and industry collaborators are assessed, funders should look for evidence of prior formal and or informal knowledge production between the collaborators.

Academics were mostly positive about CASE awards (especially those who viewed them as providing 'bread and butter' for research), and industry scientists viewed them as a means of keeping abreast with developments in academia. KTP schemes were also viewed positively. CASE and KTP should be effective mechanisms in facilitating collaboration, because the entry costs are relatively low and because the PhD process and the KTP governance mechanisms should oblige interaction between industrial and academic supervisors. (In practice, this varies; there were some great examples of collaborations through CASE, but also one or two comments about lack of interaction).

CASE and KTP projects are extremely valuable where they form part of the evolution of a successful academic-industry collaboration, as the following quote illustrates:

"A small company which is a spin-out of [a pharmaceutical company] came to me, they wanted some particle size testing done, and we did that very efficiently. They then came back and wanted some electron microscopy done, we did that. They then came back to us and said they wanted a longer project and then asked us if we had expertise in this field and we ended up with a KTP programme. They now fund a post doc. They are a company that we have built a relationship with, who are now working with on day to day business basis" (University scientist)

Both CASE studentships and Knowledge Transfer Partnerships are of course highly subsidised mechanisms for scientists to secure resources. For the scientists concerned the formalisation process is generally low in demands of time and resources (although there were one or two accounts of companies changing their minds or failing to make the final decision to fund a KTP). Compared with larger bids for funding, KTP and CASE are less vulnerable in terms of costs of failure, as the expectations of funders and industrial partners are generally lower (with the qualification that a failed CASE or KTP clearly has large exit penalties for the CASE student or KTP employee). They are therefore desirable mechanisms for formalising relationships and securing resources. Whilst unlikely in

themselves to generate the exemplar outcomes studied here, they provide a quasi-informal opportunity for knowledge production due to the low entry costs involved.

Mobility of people between organisations (such as in industry interchange programmes) is also an effective way to increase a scientists' number and diversity of connections, increase appreciation of complementarity and engender opportunities for informal knowledge production with those connections. The analytical framework proposed here suggests that, where mobility is appropriately targeted scientifically, interchange programmes should be an effective way of enabling the filtering process illustrated Figure 5 to identify appropriate longer-term partnerships.

4.5. How can we promote informal knowledge production?

This report has placed a strong emphasis on the benefits of informal knowledge production preceding the establishment of formal relationships, especially for collaborations involving academics and industry. This is inevitably a difficult ideal, since both parties are constrained for time, have numerous (often conflicting) short-term objectives, and want to avoid 'giving away the crown jewels' by disclosing important scientific insights without appropriate protection. A few tentative suggestions for how this could possibly be done are offered here:

- In networking initiatives that are intended to connect scientists (either on a local/regional basis or on a national basis), shifting the emphasis away from simply 'connecting' people towards providing opportunities for informal knowledge production. This could be done by inviting people to discuss a scientific or business problem (one recent example was an Institute of Directors event at which delegates were asked to comment on a charity's business plan). Networking meetings should help people identify potential complementarity with others in the room (e.g. delegate lists that indicate specialism or scientific need alongside one's name and institution) as this will maximise the chances of finding that one person who might be useful scientifically. Good network organisers have sufficient scientific knowledge to understand potential complementarity with the membership of their networks, and to suggest to members that they contact one another in such cases (see example 5 in section 4.2).
- Within universities, pooling financial resources between research groups and using them to create a formal structure that provides opportunities for academics and industry scientists to interact around a set of scientific problems (exemplified by the University of Dundee's Division Of Signal Transduction Therapy; see example 7). Clearly a certain critical mass in a common field is required for research groups to be able to combine resources in this manner, but the individualistic structure of individual labs generating and hoarding their own 'slush funds' might be counter-productive in more cases than is currently recognised.
- Within large commercial firms, providing opportunities for scientists to attend conferences, participate in scientific 'institutions' (such as research council committees), engage in exploratory research projects with academics (where possible, set up with minimum bureaucracy, low expectations of success and no penalty for failure) or to interact informally with academics through some other means. Interactions around the university curriculum are one possible means to achieve a preliminary engagement, with the additional benefits of enhancing student employability.
- Making technology transfer and business development officers aware of the need for informal knowledge production, develop their skills in facilitating this, and managing their expectations (and those of university managers) about the natural incubation period for a fruitful collaboration.

Example 7: Pooled resources creating a formal structure within which informal knowledge production can take place

The University of Dundee's Division of Signal Transduction Therapy (DSTT) has been widely heralded as an exemplary model of university-business interaction and knowledge transfer (and the 2005 Queen's Anniversary Prize was awarded in recognition of this). Two scientists involved in the DSTT (Sir Philip Cohen, Director of the MRC Protein Phosphorylation Unit in the School of Life Sciences at the University of Dundee, and one scientist from a large pharmaceutical firm) were included as respondents in this research, and additional case study material was collected from a variety of sources, including Prof Peter Downes, who with Sir Philip Cohen founded and directs the DSTT. The DSTT's achievements are outstanding in many different respects, not least its economic benefits for the University and its scientific contribution to drug discovery.

In the context of the analytical framework presented here, the DSTT is an excellent example of

- Exploiting complementarity by drawing on the complementary expertise of industry, a university and the Medical Research Council, as illustrated by the following quote from Peter Downes:

"It is clear that our research activities are very complementary; we have complementary skills and expertise. Companies bring screening expertise; we bring expertise with proteins and enzymes in relation to the signalling pathways we study. Put those two things together and things happen. Through the consortium large numbers of molecular targets have been generated in our hands in an active form suitable for screening capabilities that the companies have. Because we provided them with those molecules in sufficient quantities for high-throughput screening (and that's the unusual thing; they are unused to universities being able to generate materials of this kind on a scale that's required for high throughput screening), this has directly fuelled high throughput screens (with .5 to 1 million compounds at a time). So that's the starting point to drive a drug discovery programme on a particular target. That generates some useful reagents that can feed back into our own research ... a significant number of selected and interesting compounds that are unavailable to the wider community have been made available to us" (Prof Peter Downes)

- Formal structures enabling informal interaction between university and industry scientists. The formalisation process involved enormous commitment of time and resources both for the University and for the pharmaceutical companies involved, as Sir Philip Cohen noted:

"We got a potential interest if we could get a legal agreement together, and then the real problems started! To get the lawyers of five different companies to sign a single agreement was one of the most challenging things I've had to do."

Commitment of time and resources to formalisation will continue as negotiations begin around a further extension of the DSTT. However, once in place, the formal relationships create regular opportunities for scientists from the pharmaceutical companies to interact with academics, for faculty and post-doctoral fellows to showcase their research to industry and for informal conversations to take place around specific scientific problems.

Example 7 (cont): Pooled resources creating a formal structure within which informal knowledge production can take place

- Pooled large-scale resources reducing the resource generation and formalisation 'burden' for participating scientists. Informal interactions between university and industry scientists can naturally migrate within a pre-arranged contractual structure - in which intellectual property rights have already been agreed - into more formal collaborations. Also, the pooling of large-scale resources (both in financial and in scientific terms) available to the scientists in the DSTT and the University's MRC unit has huge productivity benefits:

" A major effect of this consortium has been to run our MRC unit in a unique way which doesn't exist anywhere else that I know of. 40% of the DSTT is a service facility with 5 major services: protein production, assay development, antibody production, DNA cloning and kinase profiling. Basically these provide the reagents for the companies' need, but all of their work is driven by the research of the 13 [university] labs. In other words this is a fantastic service for us; they do all our cloning, antibody and protein production which normally would have to be done by PhD students and post-docs before going on to interesting experiments. If you plan projects well you can have all the reagents you need ready the day the person arrives; already a year ahead of the game. Also, in cases where we suddenly see an idea where we want to tie up a whole area, we can put the whole power of the DSTT onto one problem and make a major stake before anyone has had the chance to get in there, which we did spectacularly recently with Dario Alessi tying up all the functions of LKB1 (a tumour promoter). I keep telling our other Divisions, why are you operating as individual labs each with its own slush funds? Pool all your money and resources; it's miles more effective." (Sir Philip Cohen)

5. Conclusion

This section presents some concluding remarks from the researcher. In reading these remarks, it is important to bear in mind that the study focused in scientists in research-intensive universities (only two post 1992 universities - Brighton and Oxford Brookes were represented) and science-intensive businesses (either global businesses or small, highly entrepreneurial enterprises). The comments made here do not necessarily apply outside this context.

This research project examined collaborative knowledge production in the life sciences, with a particular emphasis on localised collaboration and on university-business interactions. Difficulties in connecting the ivory tower with the 'real world' have long been debated, and to fuel the debate, the argument is wearily recycled that academics are only motivated by basic research and by the 'publish or perish' mantra, while R&D scientists in industry and scientific entrepreneurs thrive on finding commercial solutions to applied problems.

In contrast, this study suggests that differences in motivation between academics and industry scientists are overplayed. Both academics and industry scientists are deeply embedded in academic science as a social institution, and they produce knowledge in very comparable ways, using similar conceptual and practical techniques, albeit often on a different scale. Both value rigour, are enthralled by discovery, and derive satisfaction from the human elements of collaborative problem-solving and nurturing research capability in others. There are more similarities than differences in the means by which they secure resources (although some of the 'gatekeepers' to funding may be different, with academics focused particularly on research councils, entrepreneurs on public sources of funding such as Smart awards and industry scientists on senior managers, there are common elements of peer-review). Academics and industry scientists use some of the same mechanisms to communicate their discoveries to peers within their institution and externally, where appropriate.

The differences in behaviour, where observable, perhaps arise from differences in how time and resource constraints, uncertainty and the formalisation process are managed by scientists' employing organisations (or in the case of small companies and entrepreneurs, the scientists themselves). The priorities - and in larger companies and universities the incentives - set for knowledge production, resource generation and output generation determine how scientists allocate their time. Most commercial organisations have clear-cut priorities, and sometimes these cut across the collaborators and scientific enquiries that individual scientists might want to choose for themselves. Nonetheless, a large company that encourages its scientists to engage with the academic community in an open but focused way is likely to achieve a competitive advantage over rivals by participating in - rather than simply accessing at a later date - discoveries emerging from the public science base.

In contrast, many university scientists are beset by a clamour of conflicting messages about priorities from university managers - one day teaching is celebrated, the next day management asks for more research proposals and the following day third stream activities are actively promoted. Competing priorities within government departments (HEFCE, OST, the Treasury) are in part the cause of this problem. In a world where universities are increasingly competing with each other (for students, for research funding, for exploitation of intellectual property), a university that can help academic staff manage conflicting priorities in teaching, research or commercialisation in a manner consistent with corporate objectives will probably achieve a competitive advantage in one of these areas. The findings presented here might be taken as preliminary evidence that research and commercialisation activities are more closely aligned than is often suggested.

Within this world of competing priorities, it is to be expected that effective collaborations take time to emerge. Informal knowledge production is a critical success factor in many

collaborations (although not all; some examples were found of effective relationships that were formal from the outset). Attempts to 'hot house' university-business interaction by subsidising collaboration are most likely to be successful where evidence of a prior relationship exists. Arrangements with low entry costs, such as CASE studentships, can perform this 'hot housing' function - although over a long period - and have an important role to play in the evolution of a relationship to a more significant collaboration.

It was clear from the sample studied here that the transaction costs involved in placing collaborations onto a formal footing can represent a significant disincentive. Paradoxically, whilst HEIF and similar funding is intended to help universities cover these transaction costs, technology transfer staff and central enterprise services often increase the perceived transaction costs for academics. The formalisation process is an interpersonal as well as an organisational process, and especially in its early stages it may be invisible to university managers. The costs of failed attempts at securing funding and formalising collaboration (failed research applications or negotiations over contracts that reach stalemate or collapse) are nonetheless significant, and might be taken into account in calculating the full economic cost of doing research.

The findings presented here raise concerns about policy oriented toward promoting science-based clusters on a regional basis at the expense of national capability in science. Initiatives to connect scientists on a regional basis do not appear to add value unless they are also associated with informal knowledge production. The majority of interviewees represented here had little positive to say about regional interventions, and indeed were more likely to indicate that they represented a drain on their time and resources. One clear exception was the DiagnOx initiative, whose lab in Oxfordshire has had a very beneficial impact in terms of facilitating opportunities for informal knowledge production. In general, there does appear to be a grave danger of duplication of initiatives between regions. Given the 'thinness' of the regional market for scientific expertise (the fact that the optimal collaborator is unlikely to be in the region, and that there may not be even one person with the right expertise locally), initiatives to promote connections might be better done at a national level, differentiated by industry or technology (as per Knowledge Transfer Networks) rather than geography. Regional interventions are most likely to be effective where they facilitate informal knowledge production as well as simply making connections between scientists.

A final comment here relates to the evidence presented here of 'unseen' knowledge production. Public investment in R&D is often justified in terms of positive externalities or knowledge 'spillovers', but the returns are notoriously difficult to quantify. This research suggests why. Many of the collaborations investigated here were not funded by any transaction that would be apparent to economists trying to measure them; some were wholly informal and those on a formal footing often had 'dormant' periods where they were not funded. This includes relationships between academics and industry scientists, where several examples were found of industry scientists learning from academics (and vice versa) outside the context of a formal transaction. It seems that knowledge is being produced through these unseen, un-measurable collaborations between universities and industry, as well as within single HE institutions and commercial firms. Investment in public science pays for itself, in part, through informal knowledge production.

Appendix 1: Research Methodology and Analytical Strategy

The research project combined a theory-driven approach, drawing on psychology and economics literatures to illuminate the systematic reasons for occurrence or non-occurrence of localised knowledge production, with empirical insights derived from qualitative research. A set of initial propositions developed from the literature was reviewed and revised in a process of explanation building, following Yin's (2003) case study approach. Empirical findings were compared against the theory, revising the initial propositions where appropriate, in an iterative process that continued until the data collection and analysis was complete. The analytical framework in section 3 is an output of that process.

The data collection incorporated both interviews and case studies of research groups. Semi-structured interviews were conducted with forty scientists, based in industry, universities and hospitals in the UK. All worked in scientific areas relevant to the biotechnology, pharmaceutical, diagnostic and agrochemical industries and/or with clinical applications. All but six of the interviewees were male, and 34 were named inventors on patents. Interviews were typically conducted at the scientists' workplaces, and took place in Bradford, Brighton, Cambridge, Dundee, Guildford, Glasgow, London, Manchester, Nottingham, Oxford, Reading and Sheffield, and at other locations. Case study data was collected from public data sources and from a further set of 21 informants (see below for further details).

Both interviews and case studies focused on two distinct sets of 'revelatory' cases (Yin, 2003).

Group 1 was a set of scientists who demonstrated 'exemplar' outcomes in the form of a patent that had been granted, licensed, and/or resulted in the establishment of a commercial venture. All of the patent sampled had more than one scientist named as an inventor, indicated that the knowledge produced was generated collaboratively.

Group 2 was a set of scientists who have the opportunity to benefit from conducive situational factors in one of the following respects:

- Group 2a: located in a 'munificent' locality (i.e. one generating a high proportion of patents, with a research active university and with a high location quotient for bioscience). Appendix 2 shows how these localities - Oxford, Cambridge and Yorkshire - were chosen. In the body of the report these munificent localities are referred to as clusters
- Group 2b: involved in a regional intervention (Thames Valley Life Sciences Network, Oxford Innovation's DiagnOx network and lab) or a national intervention to connect scientists (e.g. Medical Devices Faraday)

From a policy-maker's perspective, Group 2 might be considered to exhibit 'exemplar process'.

(It is important to recognise that, whilst the various interviewees and their collaborations have been identified as exhibiting exemplar process or process (or neither), no attempt at statistical analysis has been made. Instead, the appraisal of rival explanations and the findings reported here have been derived inductively from the explanation building process that accompanied data collection and analysis.)

Table 1 (overleaf) gives more details on the selection and composition of the groups.

Table 1: Details of the two groups of 'reveatory' cases and other information on methodology

	Group 1: exemplar outcomes	Group 2: exemplar process
Unit of analysis	<ul style="list-style-type: none"> Scientists who have collaborated (either locally or over distance, and either intra- or extra-firm) to generate patents that have subsequently been granted, licensed and/or embodied in a commercial venture 	<ul style="list-style-type: none"> Scientists who are inventors (therefore with a demonstrated track record of making discoveries) and who are either (a) in a munificent locality or (b) involved in regional interventions
Examples of participants	<ul style="list-style-type: none"> Inventor named on granted patents and registered at different addresses within the same region of the UK 	<ul style="list-style-type: none"> Inventors located in Oxford, Cambridge or Yorkshire and/or members of regional science networks, Faraday partnerships, the DiagnOx lab etc.
Selection of participants	<ul style="list-style-type: none"> Selected from EPO patent office database of granted patents in relevant IPC categories. 	<ul style="list-style-type: none"> Group 2a were selected from EPO patent data and screened to include a range of 'reveatory' localised collaborations. Group 2b were identified from membership of regional interventions by discussion with relevant organisers or facilitators
Phase 1: Interviews	<ul style="list-style-type: none"> Semi-structured interviews with 9 scientists (each from a different team of inventors) Supporting evidence from publications, personal websites etc. 	<ul style="list-style-type: none"> Semi-structured interviews with 13 scientists (each from a different research team) Supporting evidence from publications, personal websites etc.
Collaborator interviews	<ul style="list-style-type: none"> Interviews with 7 collaborators of the 9 scientists interviewed in Phase 1 Supporting evidence from publications, personal websites etc. 	<ul style="list-style-type: none"> Interviews with 11 collaborators of the 13 scientists interviewed in Phase 1 Supporting evidence from publications, personal websites etc.
Phase 2: Case studies	<ul style="list-style-type: none"> Case studies of 5 collaborative teams Corroborating evidence from patent filing information, academic publications, websites press releases etc. 	<ul style="list-style-type: none"> Case studies of 7 collaborative teams Corroborating evidence from interviews with heads of department, facilitators of regional networks, press releases, websites, academic publications etc.

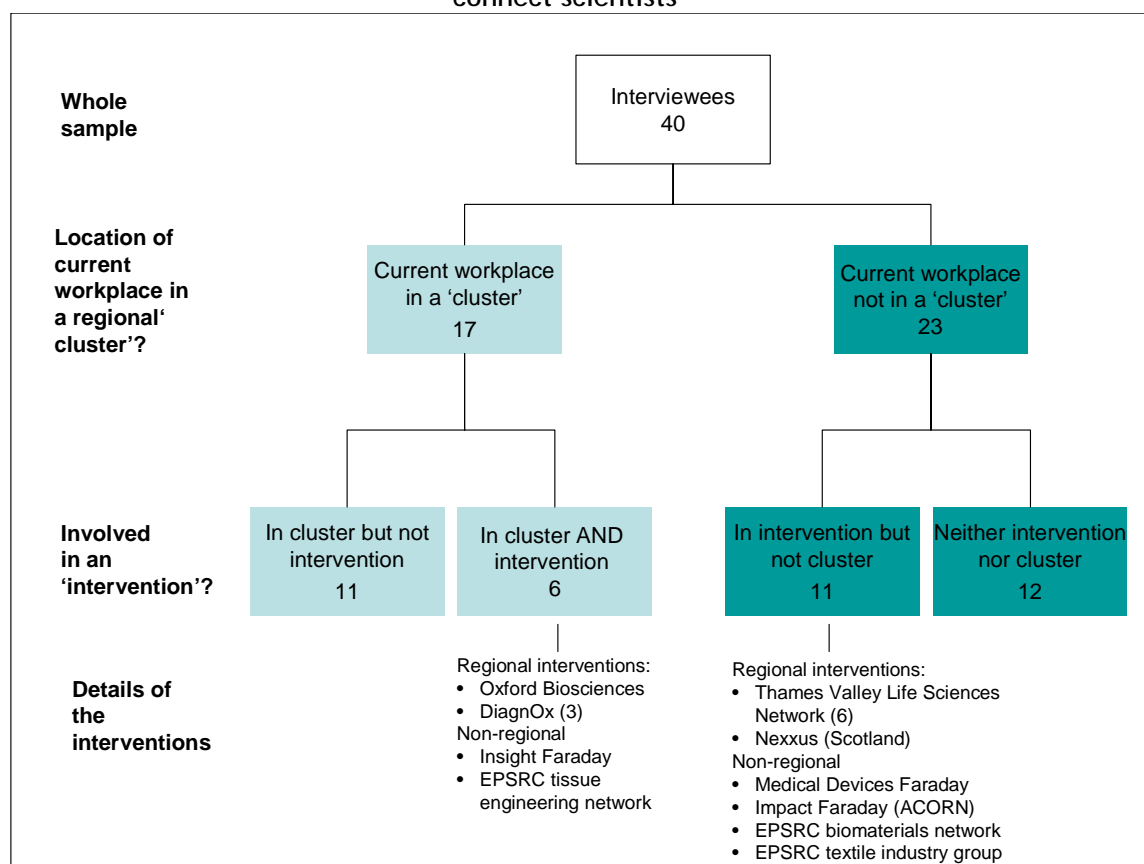
Table 2 shows the total number of scientists interviewed by type of organisation⁶.

Table 2: Number of interviewees by group and according to type of organisation

Type of organisation	Group 1	Group 2a	Group 2b	Total
NHS Trust	1	4	1	6
Large commercial firm	7	1		8
Small commercial firm		3	6	9
University	8	5	4	17
Total	16	13	11	40

Scientists were identified as falling in Groups 1, 2a or 2b prior to meeting them. Once interviewed, it became apparent that some interviewees could be categorised in more than one Group (e.g. a scientist selected for Group 1 had moved from Sussex to Yorkshire, thus potentially now falling within Group 2a). Some scientists in Group 1 were found to be involved in regional or sector interventions, thus potentially falling within Group 2b. This was one reason for conducting the analysis at the level of individual knowledge production events, as described below. However, the initial categorisations were maintained for Table 2 to illustrate the selection process. Figure 7 shows how the 40 scientists were distributed within clusters, and whether they were involved in any interventions to connect scientists.

Figure 7: Interviewees by workplace location and involvement in interventions to connect scientists



⁶ In selecting interviewees, the goal was to achieve a balance between scientists employed by universities, large and small commercial firms, and the NHS but this was not an explicit sampling strategy.

Interview questions focused on career history and orientation, and efficacy expectations for networking and entrepreneurial behaviour. Interviewees were asked about particular collaborators identified as being of interest by the researcher *a priori*, but also invited to identify and discuss their most important collaborations. Questions about collaborators addressed complementarity, process, output and outcomes. (Supporting evidence about the duration of and outputs from collaborations was gathered from publication and patent databases and personal websites.) Interviewees were asked how employers' HR and IPR practices affected decisions about collaboration, and for their views about the effectiveness of policy interventions in facilitating collaboration.

A second phase of interviews examined collaborative dyads in more detail through similar interviews with 18 collaborators of 22 interviewees from Phase 1. Some of these were collaborators of more than one scientist in the sample. Thus for 24 knowledge production events both collaborators' perspectives was captured. Finally, a series of case studies of 12 collaborative teams (in some cases widening the analysis to capture other collaborators) was conducted by collecting corroborating evidence from a further 21 interviewees (Yin, 2003). These included technology transfer officers, business development officer, university-industry liaison managers, line managers, network facilitators and a network 'business champion'. Corroborating evidence was also collected from contacts at the DTI, SEEDA and BBSRC.

Attributes of each event and each interviewee were entered in an Excel spreadsheet, and detailed notes from each interview were coded thematically in NVivo. This analysis process overlapped with data collection, and the iterative explanation-building process described above continued throughout the analysis phase.

As the analysis and explanation-building process unfolded, it became clear that the analysis needed to focus at two levels: the individual scientist as one level of analysis and discrete collaborative knowledge production 'events' as another. This was because the same scientist would describe varying motivations for investing time and resources with different collaborators. A knowledge production event was identified where an interviewee spoke of investing time and/or resources with a named collaborator.

From each interview transcript and corroborating evidence, a set of 130 knowledge production events, each representing a discrete collaborative dyad was identified. Each event was identified as depicting exemplar outcomes (generating a patent for example), exemplar process (involving two collaborators in the same postcode district, two collaborators in the same munificent locality, or two collaborators who had met through a regional or sector intervention) or neither. Not all collaborations had reached fruition; some were emergent whilst others had generated outcomes some time in the past. Typical outcomes of a knowledge production event were joint papers, research funding applications or patents. Table 3 shows the numbers of knowledge production events identified as exhibiting exemplar process, or outcomes, or both.

Table 3: Number of knowledge production events identified as exemplars

Number of knowledge production events	Exemplar outcomes	Other	Total
Exemplar process	10	41	51
Other	28	51	79
Total	38	92	130

Figure 8 (reproduced from earlier in the report) shows how the exemplar process collaborations were divided between the different exemplar types, whilst Figure 9 (also repeated from earlier) shows the collaborations exhibiting exemplar outcomes.

Figure 8 : Knowledge production events exhibiting exemplar process

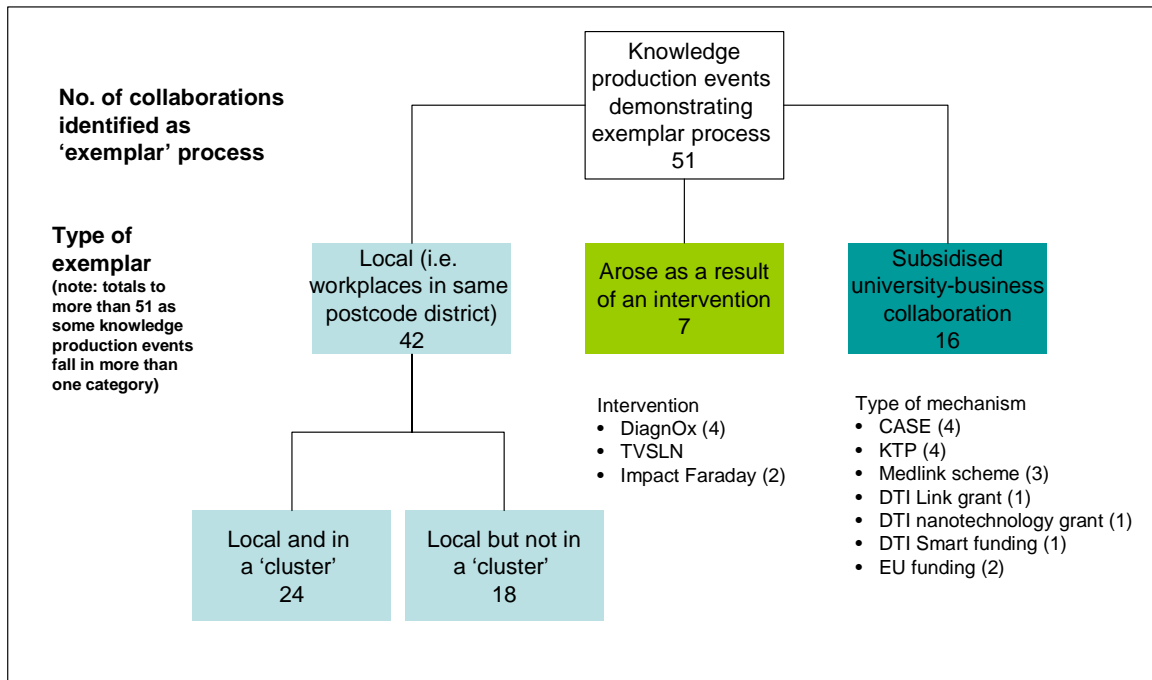
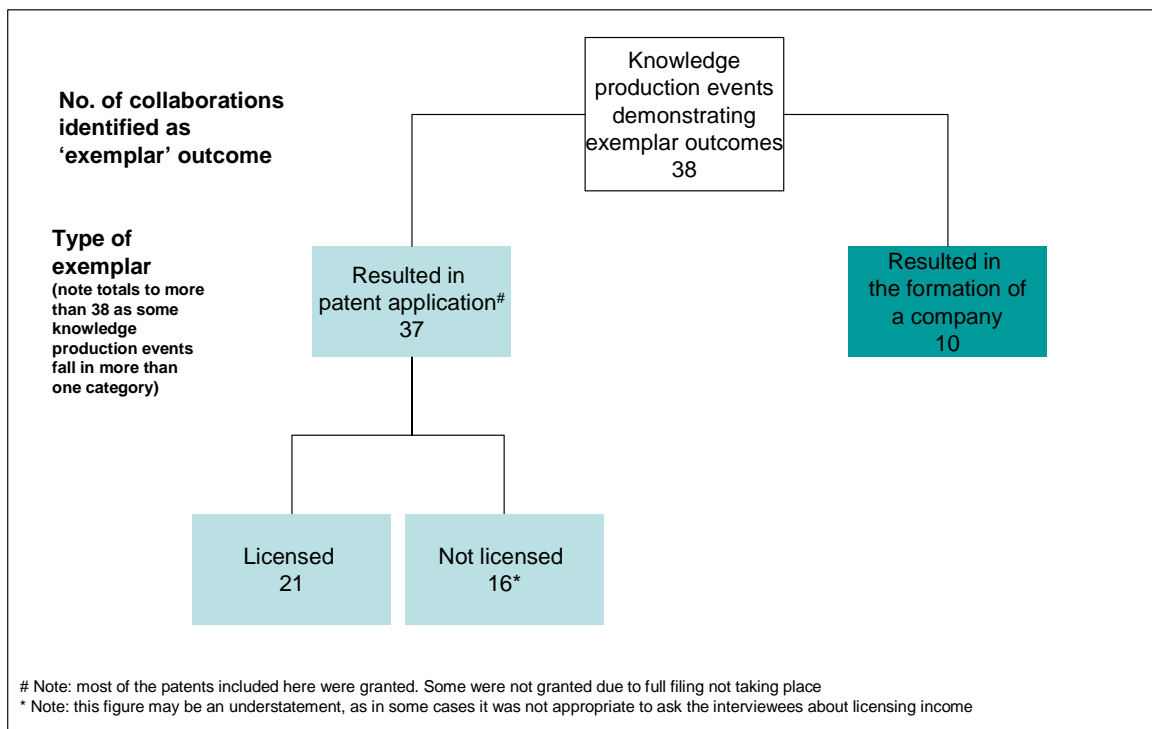


Figure 9: Knowledge production events exhibiting 'exemplar' outcome



Appendix 2: Identification of ‘munificent’ localities for bioscience research

This research project set out to examine the human behaviour underpinning ‘localised’ knowledge production, with a particular focus on collaborations that took place within a life sciences business ‘cluster’. This is a fraught area for research, as there are numerous definitions of a cluster, very limited agreement about what actually constitutes a cluster and no clear consensus about the precise characteristics or benefits of clusters (Martin & Sunley, 2003). A cluster can be defined very simply as ‘a spatial and sectoral concentration of firms’ (e.g. Bresnahan et al, 2001) or in very complex terms as containing shared tacit knowledge and a capacity for collective learning (e.g. Lawson & Lorenz, 1999).

A key distinction made in this analysis was between collaborations that were localised and (as a sub-set of these) collaborations that took place within a life sciences cluster.

- Collaborations were deemed to be localised where both scientists worked in the same postcode district (identified by the same first two letters of the postcode). This is a fairly stringent definition, as collaborations crossing neighbouring postcode districts were excluded
- Collaborations were deemed to take place within a cluster where both scientists worked in the same county of postcode district AND where that postcode district was deemed to part of a munificent locality

This appendix indicates how the clusters were chosen. To constitute a cluster for the purposes of this research, a locality needed to demonstrate not only spatial and sectoral concentration of firms (as identified for example in DTI, 2002) but also to be a ‘munificent’ locality in terms of available pools of knowledge workers and access to local university researchers and university research projects (DeCarolis & Deeds, 1999). A locality needed to demonstrate scientific and educational infrastructure generating science-technology spillovers and externalities (Cantwell & Piscitello, 2005) in order to be considered munificent.

From this and other academic literature, the following common factors can be identified as typifying a munificent locality in a particular scientific or technological area

- Research intensive university, with activities in scientific and/or technological areas relevant to nearby commercial businesses
- High (relative to national averages) proportion of patents generated in the relevant scientific and/or technological areas
- High (relative to national averages) density of employment in the relevant scientific and/or technological areas

This research was concerned with scientific areas relevant to the biotechnology, pharmaceutical, diagnostic and agrochemical industries. In a review of life sciences clusters, Cooke (2004) identified clusters in Oxford, Cambridge and Scotland (a triangle including Dundee, Edinburgh and Glasgow). Cooke (2004) also noted the rise of regional science policy, and the possibilities for other regions as candidates for development of life sciences clusters. These included Cardiff, Leicester, Leeds, Manchester, Wales and Yorkshire. This project included two established life sciences clusters (Oxford and Cambridge) and one of Cooke’s candidates for development (Yorkshire). Table 4, which builds on Cooke’s analysis, illustrates the process used to identify regions that were deemed to be munificent localities for the purposes of this research. (Note that Table 4 is meant to illustrate the selection process, but does not show all the regions that could have been identified as life sciences clusters according to the definition above.) These regions were used to sample (via patents) the interviewees selected for Group 2a.

Table 4: Illustration of methodology used for identification of 'munificent' localities for bioscience research

	Research active university (a)	High patenting region (b)	High location quotient (c)	Include in selection of Group 2a?
Cambridge	Cambridge	Yes	Eastern region has high LQ in pharmaceuticals and biotechnology as well as some medical devices and emerging bioinformatics	Yes
Oxford	Oxford	Yes	Oxfordshire has high LQ in biotechnology	Yes
Yorkshire	Sheffield, York Leeds (White Rose partnership)	Moderate	Yorkshire/Humberside has high LQ in medical devices/ surgical equipment	Yes
Cardiff	Cardiff (moderate patenting)	Moderate	Wales has 'embryonic' cluster in biotechnology	No
Thames Valley	Reading (research active, but low patenting in fields of interest) and Surrey (low patenting)	TW, UB and SL are high patent areas due to pharma cos. Also GU due to MOD	Pharmaceutical wholesaling concentrated in West Berkshire	No

(a) Source: Cooke (2004) and EPO patent database to identify high patenting universities

(b) Source: Researcher's analysis of EPO patent database from all patents filed between 1999 and 2004 in IPD categories encompassing biotechnology, medical devices and pharmaceuticals. Advice on the selection of IPC categories was provided by the UK Patent Office. High patenting regions were identified by first two letters of post-code

(c) DTI 2002

In summary, a collaboration was deemed to take place within a cluster where

- Both scientists worked in the same postcode district
- That postcode district was within a region or sub-region of the UK identified as having a high location quotient (i.e. proportionately high employment) in some aspect of life science-related industries
- That postcode district exhibited high (relative to the national average) patenting activity in the IPC classes incorporating biotechnology, pharmaceuticals and medical devices
- That postcode district also included a research-intensive university with research strength in life sciences AND high patenting activity in the IPC classes incorporating biotechnology, pharmaceuticals and medical devices

Note that in this definition of a cluster, no significance is attached to the existence of a supporting infrastructure such as business support, professional services, venture capital or networking mechanisms.

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