KNOWLEDGE WORKERS AND COLLABORATION: THE HR AGENDA

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Abstract

We present a theory of the discretionary selection of collaborators by knowledge workers. The theory is grounded in an empirical study of collaboration in the life sciences. Our theory identifies three dimensions upon which relationships can deliver value – operational, relational and intellectual. Relationships are associated with benefits, investments (costs) and risks on each of the dimensions. We identify how supplementary and complementary characteristics affect value on each of these dimensions People make judgements weighing up costs and risks against benefits both within each dimension (intellectual, relational and operational) and between them. Knowledge workers build up constellations of relationships that provide balance across the three dimensions. A constellation of relationships provides a set of 'real options', stabilizing the anticipated return from investments in collaboration.

Key words: COLLABORATION; CONSTELLATIONS; HRM; KNOWLEDGE WORK; VALUE

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As the foundation of industrialized economies has shifted from natural resources to intellectual assets, executives and managers have been compelled to examine the knowledge underlying their businesses and how that knowledge is used (Hansen, Nohria, & Tierney, 1999). Recognizing that much of the knowledge in an organization resides in individual employees, scholars have recently advocated the need to examine the foundations of knowledge creation at the level of individual motivation and behavior (Felin & Hesterly, 2007). It is also widely accepted that the creation, acquisition and sharing of knowledge requires social interaction (Grant, 1996), so the formation of productive relationships by individual employees is important for collective (organizational) knowledge creation and learning (Crossan, Lane, & White, 1999; Kogut & Zander, 1992).

In endeavoring to foster and encourage organizational learning, however, managers face a conundrum. Since knowledge sharing involves costs as well as benefits, knowledge workers' decisions about whom to collaborate with matter both for short-term productivity and for renewal of knowledge over the longer term. At the same time, the autonomous and discretionary nature of knowledge-based work makes it costly for managers to monitor or control (Drucker, 2002). As a result, the discretionary selection of collaborators is an important micro-foundation of organizational knowledge creation and renewal, but one that managers can only indirectly observe and influence.

Much of the existing work on knowledge sharing takes the opportunity for knowledge sharing (the existence of a relationship) as given, and explores workers' discretion about how much and what type of knowledge to share (Schrader, 1991; von Hippel, 1987). There has been little work on how relationships are selected in the first place. On the other hand, work on careers and literature on social networks (e.g. Burt, 2005; Ibarra, 1993; King, 2004) makes it clear that social relationships are selected on a discretionary basis – whether for entrepreneurial purposes, career advancement or for psychosocial support – but tends not to focus specifically on selection of collaborators for the purposes of innovation and knowledge renewal.

This paper examines how knowledge workers select collaborators. We present a theory of the discretionary selection of collaborators that emerged from an exploratory study of collaboration between scientists working in the life sciences. These are knowledge workers in the classic sense of working both autonomously and collaboratively, and relying on their ability to leverage their social capital in order to deliver new ideas and innovations (Drucker, 2002). We started out with questions about how collaborators are chosen for the purposes of knowledge creation and exchange. It became clear during the course of the research that opportunities for leveraging and renewing knowledge are not the only basis upon which relationships are valuable for knowledge workers. Our theory identifies three dimensions upon which social relationships can deliver value – operational, relational and intellectual – and points to factors affecting value on each of these dimensions. We argue that knowledge workers build and maintain a constellation of relationships that, taken together, provide knowledge renewal alongside other career outcomes.

Our work has direct implications for the management of knowledge-based work. Some knowledge workers – such as those in technology companies – don't view their jobs as being about human relationships (Rosenkopf & Correcloira, 2008). Managers can benefit from raising employees' awareness of when social relationships provide operational, relational and intellectual value – and when they don't – in order to help them develop and maintain constellations of relationships that support both immediate job performance and longer-term career development.

Literature review

It is widely accepted that, because much knowledge is socially embedded, knowledge creation is a social activity (Nahapiet & Ghoshal, 1998). Scholars from many perspectives have argued that interaction and cooperation are necessary if tacit knowledge from specialist domains is to be integrated and combined so as to generate new insights and innovations (e.g. Crossan et al. 1999; Grant & Baden-Fuller, 2004; Hansen, 1999; Kogut and Zander, 1992; March, 1991; Wenger, 2000). Many of these perspectives assume that knowledge-creating interactions occur as and when it is productive to do so, and that their effectiveness is contingent on the ease with which transfer and integration can occur within a relationship (Haas & Hansen, 2007; Hansen, 1999; Szulanski, 1996). In other words, the existence of relationships is taken for granted. The primary focus of our paper is to examine what brings such relationships into being in the first place.

Many knowledge workers operate in contexts of high discretion, with considerable or absolute autonomy over their tasks (Drucker, 2002), This autonomy extends, we suggest, to the selection of partners for collaboration. The literature on collaboration amongst academics is clear on this point. For example scholars have examined academics' choices of partner through studies of co-authorship (McFadyen & Cannella, 2004; McFadyen & Cannella, 2005; Zucker, Darby, & Armstrong, 1998), studies of engagement with non-academic partners (Bozeman & Gaughan, 2007; Link, Siegel, & Bozeman, 2007), and accounts of scientific careers (Bozeman & Corley, 2004). Similarly, scholars have noted that for scientists in commercial organizations, external connection to the wider scientific community is related to productivity and performance, and have examined the incentive structures appropriate to fostering such discretionary relationships (Cockburn & Henderson, 1998; Cockburn, Henderson, & Stern, 2000; Stern, 2004).

The literature linking motivation with knowledge sharing suggests that knowledge sharing is predominantly motivated by intrinsic rather than extrinsic factors (Bock, Zmud, Kim, & Lee, 2005; Osterloh & Frey, 2000). People are internally motivated to collaborate and share knowledge in anticipation of intrinsic benefits, such as states of enjoyment and ‘flow’ that arise from heightened challenge and intellectual engagement (Csikszentmihayli, 1990; Deci, 1975). However, work on the discretionary formal of social relationships in the workplace (not directly concerned with knowledge sharing) implies there could be other internally motivated reasons for forming ties, such as the desire for a sense of affirmation and belonging, or to seek out sources of psychosocial support (Higgins & Kram, 2001; Ibarra, 1993). More instrumental considerations are also identified as reasons for forming ties, such as the desire for visibility or the need for buy-in (Podolny & Baron, 1997). The literature on collaboration in science points to further instrumental benefits that can arise from forming relationships that are more operational in nature, such as access to equipment, resources and funding (Beaver, 2001; Katz & Martin, 1997; Melin, 2000).

Thus, collaborative relationships may be ‘multiplex’, providing a variety of instrumental and expressive benefits. The idea that a single relationship serves multiple purposes is well-established in the literature (Kilduff & Tsai, 2003). However, it is also plausible to argue that a multiplicity of benefits might be derived from multiple ties, rather than a single relationship, and that a portfolio of collaborators serving different purposes could be built up. Most of the analysis of reasons for collaboration and factors affecting choice of collaborators has been done at the aggregate (individual) level, meaning that these heterogeneous motives at the inter-personal level are not observed. Few studies in management predict who will be selected as a tie at the dyad (i.e. person-person) level, although modeling in social network theory, economics and mathematics has examined this (e.g. Hummon, 2000). To our knowledge no studies of tie selection have accommodated a multiplicity of reasons for choosing particular partners. Such an approach raises some interesting questions. For example, is a multiplex tie (one providing multiple benefits) more efficient than a tie providing only one type of benefit? Would someone with fewer multiplex relationships be more effective someone who maintained more singular relationships. How are tradeoffs made between different types of benefit in the selection of partners?

Whilst the costs of forming and maintaining relationships are recognized (Adler & Kwon, 2002), they are rarely made explicit in the management literature as they are in (say) economics (Hummon, 2000). The knowledge sharing literature does however, make clear that knowledge is sticky; transferring and creating knowledge is not a costless activity (Haas and Hansen, 2007; Szulanski, 1996). Costs and risks arise in relational as well as intellectual terms; some relationships are arduous and de-energizing (Cross, Baker, & Parker, 2003), and some people are more trustworthy than others (Levin & Cross, 2004). In choosing relationships, how do people balance anticipated benefits against costs and risks? At issue here is value in relationships. How do people manage the various ties that they form and maintain so that, in aggregate, they are not too draining and vulnerable, but nonetheless provide necessary and sufficient benefits? How are risks in sharing one's knowledge managed, given the uncertainties inherent in knowledge creation (will this idea lead anywhere? will the partner abuse or exploit the relationship?).

The stickiness of knowledge is a particular issue when thinking about integrating a variety of specialist knowledge from different sources or perspectives. Whilst it may be beneficial to collaborate with someone with different knowledge, it can also be more costly than collaborating where extensive prior knowledge is shared, and also more risky since outcomes are less certain. Again, interesting question arise here. How do people strike a balance between a relatively familiar 'easy' source of knowledge (where benefits from novelty may be low), and a distant ‘arduous’ source of knowledge (where benefits from novelty may be greater, but costs are also higher)?

Other questions arise when one acknowledges that social relationships naturally have a time dimension, forming, evolving and dissolving over time. Studies of both work-related and personal ties over time (Burt, 2000; Cummings & Higgins, 2006; Wellman, Wong, Tindall, & Nazer, 1997) indicate a high turnover in people’s social networks. Given that the ‘novelty’ value of a partner’s knowledge relative to one’s own depreciates over time (McFadyen and Cannella, 2004), how and when do people switch from one collaborator to another? Little work has been done on how collaborative relationships decay over time. When does it become appropriate to replace one relationship with another? Obligations to existing ties may be such that the opportunity costs are too great to let them decline, particularly when one takes into account friendship and emotional attachment, and tendencies to transact with people who also transact with one’s partners (a tendency referred to as embeddedness; Ibarra, Kilduff, & Tsai, 2005).

In this paper, we aim to illuminate the question of ‘why some ties and not others?’. We draw on a dataset on R&D collaboration to develop a theory of the discretionary selection of collaborators. In the following section we outline our methods, sample and analytical approach.

Methods adopted

In the literature on knowledge sharing and collaboration there is an inclination towards quantitative studies using surveys and social network analysis (e.g. Hansen, 1999; Reagans & McEvily, 2003). Such approaches are well suited for predicting the existence of a relationship in terms of wider network structures, and for addressing the extent and nature of knowledge transfer in pre-established or prescribed relationships (e.g. Szulanski, 1996). However, qualitative studies have been suggested to be preferable when addressing the process, content and dynamics of relationships, and when one is interested in the meanings and intentions that lie behind actions (Cross & Sproull, 2004; Jack, 2005). Since our interest lay in reasons for forming and maintaining relationships – and for not forming or maintaining them – we felt that a qualitative approach was appropriate because it would enable us to get inside people's minds, offering insights into the logics people apply in the selection of collaborators.

Moreover, because of the open questions with which we initiated our study and the absence of theoretical insight to explain why one relationship is favored over another, we favored an approach that could enable the construction of theory. Our chosen approach was grounded theory building (Glaser & Strauss, 1967). We began without *a priori* theories for why relationships are chosen, and undertook a process of theory building using insights derived from contact with the social world (Locke, 2001). Empirical data were collected to support and direct the theory-building process, rather than to test theory explicitly.

Sample and Analytical Approach

In grounded theory, the rationale behind sampling is to direct data gathering efforts towards information that will best support the development of the theoretical framework (Locke, 2001; Shah & Corley, 2006). Because we were interested in situations where selection of collaborators is highly discretionary, we chose to focus on scientists, and in particular the formation of collaborative relationships that spanned organizational boundaries on the basis that these were unlikely to be pre-assigned. By examining what makes collaborators valuable in scientists' minds, and their reasons for choosing or not choosing partners, we intended to tease out insights for theory-building about selection of collaborators.

The research design incorporated interviews and case studies conducted by the first author, with the unit of analysis being a pair of collaborators (a dyad) or a potential pairing. In a study of whether and why relationships are valuable, it was important to consider pairings that did not arise as well as those that did. To achieve this, we 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 patents that had been granted and licensed to multiple inventors. This group was expected to reveal how valuable relationships are initiated, how they unfold and how they result in knowledge renewal for the individuals concerned. Group 2 was a set of scientists who were named as inventors on a patent (as evidence of their potential for knowledge creation) and who had the opportunity to form collaborative relationships because either (a) they were located in a ‘munificent’ locality[1] or (b) they were involved in some kind of network that was intended to connect scientists. This group was expected to reveal how relationships that “could have been” with others in the locality or network did not form or evolve. For further details on the selection and composition of the groups, see Table 1.

Insert Table 1 around here

Table 1 shows how the interviewees were distributed by type of employing organization. All worked in scientific and/or clinical areas relevant to biotechnology, pharmaceuticals or medical diagnostics. Questions were structured and open-ended. Interviews began by capturing data on interviewees’ career history and orientation, and their scientific specialism (supplemented by data from CVs and personal websites). Questions about collaborators addressed the nature of particular relationships, their evolution over time, and the extent to which scientific specialisms were shared. Interviewees in Group 2 were also asked about the

[1] A ‘munificent locality’ was defined as one generating a high proportion of patents, with a research active university and with a high location quotient for bioscience

anticipated value of working with potential collaborators within their local area and/or other members of the network that they participated in.

Detailed notes on each interview (typically 6-7 single spaced sheets) were sent to interviewees for verification. Most interviewees returned annotated and edited versions of the notes. For all but three interviewees (who declined recording), full interview transcripts were also prepared. In the later stages of interviewing, collaborators of the earlier interviewees were deliberately included, in order to gain the partner's perspective. By the time theoretical saturation was reached (Glaser and Strauss, 1967), forty interviews had been conducted, from which a total of 130 collaborative pairings had been analyzed. For 26 of these pairings, both parties were interviewed. Additional material was collected from discussions with line managers of some of the interviewees, and organizers of networks intended to foster collaboration.

At the start of the interviews, a coding process was used to categorize and compare reasons for choosing collaborators. As the study progressed, these reasons were integrated into various categories: we came to refer to these as dimensional categories (intellectual, operational and relational), value-related categories (costs, benefits and risks) and attribute-related categories (similarity and difference, closeness and distance). These categories enabled us to characterize our 130 pairings, to examine how their character varied over time, and – in the later stages of theory building – to examine the effect of one category on another. (For example, what was the effect of becoming closer or more similar in relational terms on the costs or risks of a relationship?) Constant comparisons were made between the emerging categories, ideas about their effect on each other, and interpretation of the original data in an iterative process that continued until data collection was complete.

Dimensions of value in collaborative relationships

Because of the emphasis on theory building, we present our data together with the emergent theory, supported with reference to relevant literature. We use tables to encapsulate the theory, and examples, quotes and figures to illustrate aspects of it. Our theory is founded on three dimensions of value in collaborative relationships that emerged from the theory-building process. In talking about who they chose to collaborate with, interviewees referred to intellectual, relational and operational aspects, with each having an effect on the anticipated value of the relationship. Implicitly or explicitly, anticipated *benefits* of the collaboration are weighed against perceived *costs* or investments, and *risks* associated with those investments. These benefits, costs and risks are affected by several facets of similarity and difference that enter the judgment of scientists when they are selecting potential partners. Table 2 summarizes the judgments made on each dimension. We review each dimension in turn, beginning with the intellectual dimension.

Insert Table 2 around here

Intellectual value in knowledge workers' collaborative relationships

The most obvious benefit of a collaborative relationship is its potential for creation or exchange of knowledge. Knowledge workers form relationships with others who have knowledge that complements or supplements their own to deliver some kind of intellectual benefit. At one extreme, the benefit was highly practical and specific (such as the need to know a specific technique in protein expression, the desire for insight into the structure of an enzyme or the need for help with characterizing an emulsion), and could be achieved by a relatively transactional transfer of knowledge from the partner. At the other extreme were highly open-ended and speculative benefits that might one day be realized through co-production leading to new fields of research (such as building a super-computer grid for computational biology, or thinking about how to use photonics to solve problems in pharmacology).

It became helpful to think about intellectual benefits using the terms *component* and *architectural* knowledge (Henderson & Clark, 1990; Matusik & Hill, 1998). Component knowledge refers to discrete parcels of expertise that can be applied to a project without the need to fully appreciate of the scope and direction of that project. Examples from our interviewees included expertise in statistics, protein crystallization, or assay techniques. Architectural knowledge refers to understanding the trajectory of an entire project or program, including the ideas or questions on which it is based, and the 'prior art' and component knowledge that it builds upon. In a therapeutic program for drug discovery, someone with architectural knowledge would appreciate the scientific and clinical issues being addressed, the prior knowledge upon which the program builds, and the combination of people, processes and component knowledge assembled to address these issues.

Some relationships were beneficial because the partner's component knowledge strengthened that of the interviewee, such as where two polymer chemists compared notes on a particular development in ligand chemistry. Other relationships entail the incorporation of the partner's component knowledge into the interviewee's architectural knowledge. For example, a polymer chemist approached an academic with knowledge of both pharmacology and chemistry to help him understand the biocompatibility of a drug-eluting bead that was being developed by his company. Finally, some relationships involve the collective development of new architectural knowledge, bringing together component knowledge of each partner in novel combinations (Kogut and Zander, 1992). For example, a pharmacologist and a chemist collaborated to build a tissue engineering scaffold for growing skin. Their architectural knowledge began with a conversation over coffee in which they talked about their areas of expertise (their component knowledge), and germinated into a spin-out company that develops treatments for regenerative wound healing.

As Table 2 indicates, judgments are also made about anticipated costs and risks. As a collaborator, one needs to be willing to contribute one's own ideas and insights to the relationship; indeed such investments – discussing, thinking, writing, analyzing, and musing – provide the basis upon which knowledge is created. We refer to these investments of one's own knowledge as 'costs', and found that they are not necessarily balanced between partners. In a fairly transactional relationship where one partner is asked to solve a problem for the other, that person would expect to make a considerable intellectual investment, while the other invested only enough to explain the problem and absorb the solution. One other hand, an intense and prolonged collaboration on a new research area would involve considerable investments on both sides.

Interviewees also considered intellectual risks in collaboration, especially where commercially sensitive or intellectually promising ideas were at stake.[2] They made judgments about the risks that knowledge offered or co-produced would be appropriated for the other's gain, without due acknowledgement or compensation. In some cases, risks were low because partners would not be expected to absorb much sensitive knowledge (especially as their absorptive capacity would be limited where component knowledge was not shared). For example, structural biologists are often asked to help crystallize proteins in order to understand their structure, without knowing why the protein is being studied, or what inhibitor compound (drug) is being searched for. On the other hand, more intense

[2] Non-disclosure agreements are a means to mitigate this risk, and are often put in place where relationships cross organisational boundaries. Such agreements only contain risks, or provide a means to recoup losses; they not negate the need to think about risk in collaboration.

relationships, where partners are addressing shared problems or questions, involve higher levels of risk. In relationships that develop architectural knowledge, it might be necessary to reveal nascent ideas, emerging plans or new inventions. One interviewee told how he had collaborated with a partner to develop a diagnostic assay device, only to find that the partner filed a patent without naming him as an inventor. In initiating subsequent relationships, he became more cautious.

Factors affecting costs, benefits and risks on the intellectual dimension. Since some relationships are more beneficial and/or more costly than others, it became important to think about how value varies with characteristics of the collaborator. We noted above knowledge workers form relationships with others who have knowledge that complements or supplements their own to deliver some kind of intellectual benefit. We now examine what we mean by ‘complementary’ and ‘supplementary’ in more detail.

Value on the intellectual dimension is affected by the ease with which knowledge exchange, recombination and co-production can be achieved. Our analysis identified three characteristics of relationships that impact on value: the extent to which partners have similar formal education, the extent to which they share component knowledge, and the extent to which their respective architectural knowledge is underpinned by similar component knowledge. Partners’ knowledge is ‘supplementary’ to the extent that they are similar in these respects, and has the potential to be ‘complementary’ (though with important caveats that we outline below) where they are different in these respects.

Supplementary knowledge makes communication easier (reducing the costs) since less effort has to be put into finding a common basis for sharing knowledge. With formal education or component knowledge in common, heuristics for how to tackle problems already exist, and shared vocabulary and common approaches to collecting and integrating data can be drawn upon. Supplementary knowledge can also reduce the risks of collaborating, because it should be easier to agree what the joint endeavor is intended to achieve, and to anticipate where its outcomes might lie. On the other hand, the benefits may be limited too. By focusing on common ground, supplementary knowledge is likely to be associated with exploitation of existing ideas and concepts, rather than radical new approaches or ideas (March, 1991) One interviewee commented about the limited benefits of supplementary relationships:

> Then when I came here … I hadn't done any genetics and so the collaboration with Jim and Adam, really was a complementarity. Actually that's the most important thing; I think unless you [are] both bringing something to the table, things don't work. … If two groups are bringing the same technology then essentially they can do it without each other. I… think those sorts of collaborations eventually fall down. I think if you need each other then it can work. There has got to be something in it for both parties.

Too much similarity, then, and the partner's knowledge becomes redundant; whilst is may be very feasible to work together, it may not be functional to do so because the partner does not 'bring anything to the table'.

The quote above also illustrates that different knowledge creates possibilities for learning. Where the partners' knowledge lies in separate domains that can be productively combined, the potential for recombination that enhances architectural knowledge, or extends it into new domains, increases, but so do the costs as communication becomes more difficult. A vivid example of the costs and benefits of complementary relationships was provided by a professor with expertise in physiology and endocrinology, who had become interested in tissue engineering. As a physiologist she had component knowledge of skin and wound tissue that would help her grow artificial skin tissue. However, she needed an organic chemist to make polymers that mimic the epidermis. Whilst she greatly values the complementary collaboration that emerged with an organic chemist, she gave a graphic illustration of the costs of communicating with her colleague

> We wrote the first grant with colleagues, got it funded, set off on it and discovered that we didn't understand each other's language. Okay we knew that. What was amazing was that even 18 months later we were still having to translate each other's language because the different terms in different disciplines mean different things. Things you think you understand you don't really understand and time after time we'd be sat at meetings, we usually used to meet up on this project about once a month. Why didn't that work? I don't know. Or was it beyond the glass transition temperature. Remind me what that is again! Even when you have a term translated it doesn't mean much to you. So we had the most crazy examples of things. What you have to do is you have to have a lot of patience and willingness not to just to go round the house, but several times!

Complementary knowledge, then, is knowledge that is different to one's own (either due to different component knowledge or different architectural knowledge) but is worth combining despite the costs of doing so.[3] We found that interviewees chose collaborators with complementary knowledge either in anticipation of building or extending their architectural knowledge of a problem, or in anticipation of opening new areas of architectural knowledge. As example of the former, a computational chemist asked a structural biologist to help him understand the structure of a particular enzyme, so that he could understand the effect of a proprietary compound on that enzyme. The compound was in development by the company as an antibiotic. As an example of the latter, a physicist described how after attending an inaugural lecture by a new physiologist professor, he started to collaborate with her to develop a whole new area which he calls biophotonics:

> She has got things she wants to do to examine things biologically. Yes there're bits of equipment that are around that do it a bit. But on the other hand I am aware that I've got this toolbox of things. In one case it comes from astronomy, I am aware of this technology that's in astronomy. Can we take that, modify having understood what her real problem is from a physics point of view, from an optics point of view, can I take this technology, modify it, or even invent something new if it has to be, to solve the challenge that she has sent?

[3] Where difference in architectural knowledge is concerned, the relationship with costs is a little trickier. Where one partner combines another's component knowledge into her own architectural knowledge (for example by seeking help on a specific and discrete aspect of her project), the costs should be no more than those arising from different component knowledge, so long as the insights can be easily slotted in. For example, a synthetic chemist seeking help with characterising a particle-stabilised emulsion from a physical chemist can relatively easily interpret the results of characterisation and deduce the implications for what to do next with the compound. Where partners share architectural knowledge of a joint project, however, the costs will increase with different component knowledge because they have to work harder to keep their architectural knowledge in step as new insights emerge.

Partners have complementary knowledge to the extent that they have different component or architectural knowledge which they believe it is functional – and feasible – to combine. The costs and risks increase with complementary knowledge; more effort and attention is required to establish a common basis for investigation and keep in step, and communication difficulties and failures are more likely. With too much distance, the costs of finding common bases for coordination ('going round the house several times') become so high that differences start to detract from, rather than complement each other.

On the intellectual dimension, then, anticipated benefits of collaboration increase with difference in component knowledge and formal training, but so do the costs. People make judgments about intellectual value in their choice of collaborators, weighing up costs and benefits against risks. It became apparent that intellectual value was only one element of choice, however, and that interviewees were prepared to undertake collaborations where intellectual value was negative – i.e. where the costs were deemed to outweigh the benefits on the intellectual dimension. We now turn to relational considerations in choice of collaborator.

Costs and benefits in collaboration: the relational dimension

Literature on mentoring and personal networks (Higgins and Kram, 2001; Ibarra, 1993; Kram, 1986) has shown how social relationships at work deliver both instrumental and expressive benefits. Instrumental benefits include access to jobs, enhancements to reputation, political influence and visibility, and can arise as a result of having contact with relevant gatekeepers (King, 2004), or by association. If one is associated with a powerful, widely respected or high status individual, reputation benefits may ensue. Expressive benefits of social ties are those that deliver support, friendships, feelings of well-being, competence or affiliation and those that confer role expectations (Ibarra, 1993; Katz & Kahn, 1978; Podolny and Baron, 1997). Our data supported these arguments by confirming the ‘multiplex’ nature of social ties, whereby links between two people serve a multiplicity of interests. Following the literature, we suggest that collaborative relationships provide relational benefits of two kinds: instrumental and expressive, as shown in Table 2.

For a combinatorial chemist working for a large pharmaceutical company, and charged with developing the company’s use of flow chemistry in organic synthesis, a link with one of the leading academics in flow synthesis was instrumental in providing credibility within his organization. Instrumental benefits are also derived by being able to access a wider social network; for example, a encapsulation specialist in a pharmaceutical firm funded some research with a university chemist in order to keep in touch with someone he perceived to be a ‘hot guy’ of the future. He hoped that via the ‘hot guy’ he would be able to connect with the wider group of polymer chemists at the same university. Similarly, Lam (2007) has shown how high-technology firms fund collaborative projects to gain access to the open knowledge networks of university researchers, and Murray (2004) has argued that university scientists contribute social capital to the entrepreneurial firms they collaborate with. For the academics concerned, these links can be highly instrumental, providing a means to develop ‘social capital’ throughout their career (Bozeman, Dietz, & Gaughan, 2001).

Collaboration also provides expressive benefits, as noted above. A professor of physical pharmaceutics described two colleagues who had given him valuable support and advice over the years, including advising on whether to set up a company at an important juncture in his career. He said that both were too close to his field to write papers with, but he enjoyed having philosophical forward-looking conversations with them. There was plenty of evidence for multiplex ties. For example, a virologist described how his former boss in a public research organization had been a mentor and guide (expressive benefits), and had also persisted in persuading senior managers to help him file his first patent (instrumental benefits). Many examples were given of how collaborators had become friends, and friends had become collaborators.

From interviewees' descriptions of investments they made on behalf of collaborators, as well as the benefits they received, we identified various sources of relational costs and risks (see Table 2). Providing expressive and instrumental benefits to others can entail considerable investments of personal energy and attention, and almost all relationships have some level of relational cost. Continued requests for attention or support can be frustrating or irritating, even when they are well-intentioned. 'Amplified reciprocity' (being asked to do things that go beyond the core basis for the relationship) can make life difficult (Cross and Sproull, 2004). Negative emotional reactions can arise from having one's ideas challenged or criticized, or from a need to monitor or pester a partner for results or progress.

Connecting partners to others within one's network also has attendant risks and costs. One interviewee described how a former mentor had invested considerable personal time on his behalf in persuading senior managers to support his first patent application. There are risks that backing someone who subsequently proves to be untrustworthy or incompetent could have a negative impact on one's own reputation. Burt's (1992; 2005) work on structural holes suggests that connecting people who were previously disconnected may be disadvantageous in reducing later opportunities for controlling flows of information or resources between them. Above we described how an industry scientist funded research with a 'hot guy' of the future, in order to link to others in his department. If the 'hot guy' helps his industrial contact connect with others in his department, he could find they bypassed him in setting up their own links with the company.

Factors affecting benefits, costs and risks on the relational dimension As for the intellectual dimension, it became clear that some partnerships are more beneficial and/or more costly than others, and that it was important to think about how relational value varies with characteristics of the collaborator. Value on the relational dimension is affected by the ease with interaction can be achieved, and the diversity of third parties that can be accessed. Again, we draw on idea of supplementary and complementary relationships, this time using the terms to refer to the attributes of the partners.

Partners' attributes are supplementary to the extent that they are similar. Many studies have found that people who are similar in age, gender, class, organizational role, status or values tend to associate, a tendency known as homophily (McPherson, Smith-Lovin, & Cook, 2001). Provision of support and advice is easier where others are similar (Ibarra, 1993). Shared identity can also increase expressive benefits, by reinforcing a sense of belonging and increasing normative rewards from working together. For these reasons, supplementary attributes can increase the expressive benefits, and reduce the costs, of working together.

On the other hand, complementary attributes can provide benefits, especially of a more instrumental nature. If the partner is higher in status, there may be reputation benefits from being associated with him or her. Being visible to his or her connections may yield benefits. Links via the partner to relevant third parties (such as gatekeepers who control access to opportunities or brokers who can provide useful information) may be advantageous. Thus instrumental benefits are increased with differences in status, where the partner is senior. If the partner has lower status, expressive benefits (feeling good about helping someone) can arise from acting as a mentor. Instrumental benefits are perhaps less likely, although mentoring others has been linked to objective career success (Allen, Lentz, & Day, 2006).

Connections to third parties via the partner can also be beneficial irrespective of status differences. Third party connections are useful for finding out what areas people are working in, and who would be good to work with. If the partner has contacts that are complementary to one's own, possibilities for advantageous network configurations that facilitate the control of information or resources increase (Burt, 2005). A Cambridge professor nearing retirement offered an example of the benefits offered by being able to access his partner's connections.

> This guy from Brazil wrote to me or emailed me in 2001 and said he was keen to collaborate. No connection at all, just through the literature. I said that's fine but at the end of next year I am going to retire. Someone in that situation is really interested in having his students come over, a connection to Cambridge so that he can send his best students here, this is well understood

As it turned out the pair had very compatible research interests, and their collaboration turned out to be one of the best the professor had had, enabling him to carry on conducting research after retirement through students in the Brazilian's lab. The Brazilian had previously been the Vice-Chancellor of his university, so in turn the Cambridge professor was able to benefit from his connections

> What he can give me is the chance to do original research as I was doing before retiring. What he gets, he was just coming back from being the Vice Chancellor of his university, going back into research. To give the idea he was collecting a big [research] group and so he wanted to give them impetus. So it was to our mutual benefit.

Cohesion is a term used in the social networks literature to describe the proportion of ties that two actors share relative to their total number of ties (Reagans and McEvily, 2003). As cohesion increases – i.e. as partners become more embedded within a shared network – their networks become more similar. In supplementary networks, there are likely to be fewer instrumental benefits from connection to new third parties, but the risks of collaborating diminish, as norms for collaborative behavior are more likely to be shared, and the threat of sanctions from the shared network reduces the attractiveness of opportunistic behavior (Granovetter, 1985). Where they have few shared ties, both partners stand to benefit from the connection (for example by providing a bridge across a structural hole; c.f. Burt, 2005), but the costs and risks of reciprocating by providing access to their own contacts increase.

Costs and benefits in collaboration: the operational dimension

It became clear that knowledge workers have operational reasons for forming relationships that can be independent of intellectual or relational benefits. The operational benefits listed in Table 2 include money, resources (in the form of equipment and materials), artifacts that are products of the partner's work and capacity (in the form of additional labor). For example, a biologist researching lysosomal storage diseases emailed a scientist who had published a paper on Tay-Sachs disease, asking for the mouse models (artifacts) he had previously developed. After he sent the models, they co-authored papers, although five years passed before they actually met. Literature on collaboration in science provides many examples of operational reasons for forming relationships, including economic incentives (Bozeman and Gaughan, 2007; Heffner, 1981; Poti, 2001), the need to pool resources (Katz and Martin, 1997) and access to equipment (Beaver, 2001; Melin, 2000).

Capacity benefits can be achieved through economies of scale or by being able to outsource some aspect of knowledge production (such as testing a compound for biocompatibility) to the other party. Not all relationships are funded, but where knowledge workers in commercial firms want to learn from academics, they often need funding to secure academics' engagement (Cockburn and Henderson, 1998). Funded relationships have subsidiary benefits in that they are usually formally contracted, and arrangements for the protection of intellectual property are usually in place, reducing the risks of opportunism.

The costs in operational terms are shown in Table 2. Relationships involve investments of one's own time, and can also require contributions of materials and resources, provision of access to equipment and in some cases use of staff to help with joint projects. Risks and opportunity costs are important here. There is the risk that the other party will misuse materials or equipment or will appropriate resources for purposes other than those that were intended (For example, a polymer chemist who received industrial funding for a post-doctoral researcher commented that he was able to deploy the researcher for other projects.) And whilst time, staff and equipment are dedicated to the partner, there is also the risk of falling behind on other projects that might be more important for one's career. In public science, success is denoted by being the first to establish priority (Dasgupta & David, 1994), so diverting resources away from core research areas may have opportunity costs.

Characteristics affecting benefits, costs and risks on the operational dimension Value on the operational dimension is affected by the ease with collaborative working can be achieved. Our analysis identified three characteristics of partners that impact on value: similarity in processes and protocols, similarity in objectives and physical proximity. It became apparent that there are two modes of working together (with most relationships having episodes of each type). One is synchronous working, where partners have real-time discussions face-to-face or electronically, pore over data or documents, or work at a bench or desk together. Asynchronous working occurs where the parties do not interact in real time (working on documents or experiments in parallel or in series, and exchanging them). Where the partners are similar in protocols and processes (i.e. they have supplementary characteristics), asynchronous working is much easier, because the results from one partner's effort can fit relatively easily into the other's workflow. In either mode, supplementary characteristics increase productivity, because less time and attention is required for specifying what needs to be done, and how it is to be done.

Where targets and objectives are similar, the likelihood of realizing benefits that are useful should increase, due to common expectations about what outputs are desirable, and the form they should take. Shared views about relevant timescales also matter, and were a common concern for some industry scientists who said that academics tend to be poor at short-term delivery. Difference in targets and objectives requires time to be spent monitoring and managing the partner. These additional costs are illustrated in the following quote from a scientist working on cancer immunology in a start-up company:

> Disadvantage is that if you work with academics you are dealing with personalities. These people don't see your objective, they see their objective is to publish papers and do something they want to do. You can have a very good relationship with academics and you get great data but on the whole I think they are very difficult to manage. The only control you have is finances, and so if funding isn't their main thing, they are pretty well funded anyway, then they won't be very responsive to a request.

Physical proximity makes it easier to work synchronously where this is necessary, and tends to be important in the early states of identifying a basis for working together. Thereafter most interviewees reported alternative mechanisms for synchronous communication, such as teleconferences, and were relatively dismissive about the need for geographic proximity once a good working relationship had been established. Physical proximity is important for sharing equipment, and access to complementary assets (such as expensive tools and machines) becomes increasingly relevant in capital-intensive areas of science and technology.

Shared objectives increase the likelihood of finding a basis for working together and can be an essential starting point upon which collaboration is founded. Conversely, if objectives are not shared, there can be no justification for committing operational resources (time, money, equipment) to working together, and no basis for a match (objectives are detracting on the operational dimension). Money can provide a complementary asset to overcome this difference of interest. As we have seen, scientists in commercial firms acquire knowledge by working with academics and can provide operational value to the academic partner through funding. A relationship that is net negative in terms of intellectual value – or even relational value – might nonetheless be undertaken because it offers operational value. In the next section, we examine how the dimensions can compensate for one another.

Collaboration choices in knowledge work

In the previous sections we have set out a conceptual framework for thinking about collaborative relationships in terms of value. We now examine the relationships between costs and benefits on each dimension, and the relationships between the dimensions. We then consider how people build portfolios of relationships to achieve balance, and how these develop over time.

Compensation: benefits on one dimension offset costs on another

Almost any relationship has costs and benefits on each dimension. (You invest in explaining and communicating your knowledge – a cost – in order to benefit intellectually; you put effort into a relationship with someone as well as deriving benefits from that relationship; and often, it is necessary to invest operational resources, such as equipment and materials or money, in order to benefit operationally.) It became clear from the interviews that knowledge workers make implicit judgments about the value of potential and current partnerships in terms of their costs, benefits and risks on each of the dimensions. We refer to a relationship having a net benefit where the benefits exceed the costs, and net cost where benefits are less than costs. We are not suggesting that costs and benefits are always calculated, nor that the costs and benefits are directly commutable, but simply that people understand intuitively whether relationships are likely to be net positive or net negative on any dimension. Risks inflate costs (by making it necessary to invest time in managing or monitoring the partner's behavior or performance) and cause benefits to be discounted. (For example, if an outcome is very uncertain, the return may be not worth pursuing.)

In assessing the value of a single relationship, positive value on one dimension can compensate for negative value on another. A relationship that is difficult in relational terms might be worthwhile because of the partner's ability to challenge accepted wisdom and apply her knowledge in novel ways. A relationship that brings little value intellectually (has a net intellectual cost) might have compensations in operational terms. People compromise by accepting a net cost on one dimension in anticipation of benefits on the others. Note that this is a compensatory rather than a multiple hurdle model – a partnership does not have to be net positive on all dimensions to be valuable in overall terms.

Many studies of knowledge sharing examine how relational dynamics are important in information seeking (Andrews & Delahaye, 2000; Borgatti & Cross, 2003; Bouty, 2000), supporting the idea of both relational and intellectual dimensions being taken into account in the selection of relationships. Similarly, literature on collaboration in science brings out operational considerations in the formation of relationships (Katz and Martin, 1997; Traore & Landry, 1997), and highlights the fact that people make tradeoffs between different types of characteristics. For example, Mansfield (1995) examined how industry firms tradeoff the quality of faculty they collaborated with against the ease of accessing them (in terms of geographic proximity).

Illustrating compensation between dimensions: the Cambridge professor. We use an example from a Cambridge University professor to illustrate how dimensions compensate for one another. He was approached by a scientist in a local small business for help solving a problem. The scientist offered a financial contribution to the professor's research group, providing operational benefit. This quote illustrates the professor's thought process about the attractiveness of such a proposition:

> I've sometimes, occasionally been in contact with a small business. But their sights are not set at a level that is interesting to someone in a department like this, as a rule. Research is an expensive business and small companies just, unless they are small or start up companies which are started up by people who have come out of a place like this, and of course they know what's what, and they know what the contacts are. They would be looking for support rather than a two way relationship

From an intellectual point of view, the relationship was expected to require "support rather than a two way relationship" – i.e. considerable intellectual cost in investing and solving the company's problems, with minimal intellectual benefit for the professor. The comment about "people who have come out of a place like this" who "know what the contacts are" reveals that some propositions of this nature are more attractive from a relational perspective than others. Someone who had come from Cambridge University, implying a degree of shared identity, understanding and mutual contacts, would be a more attractive proposition (lower costs and greater benefits on the relational dimension) than a cold call from a local business unconnected with the University.

We illustrate the anticipated costs and benefits from this collaboration in Figure 1. The right hand side of the radar diagram shows the anticipated benefits from the relationship. Operational benefits are relatively high, since the company will fund the collaboration, but intellectual and relational benefits are low. The left hand side depicts the anticipated costs. Operational costs are low, because the professor can undertake the research by scaling up activities or using equipment and staff that are already in place. The intellectual cost is high, because he would need to invest time and thought in understanding to the company's problem, applying his own knowledge to that problem and preparing a recommendation to the company. Relational costs are moderately high; the company will expect to draw upon contacts and expertise within the university and to be given a considerable amount of support to resolve their problem. In this case the compensation in operational terms was insufficient; the professor declined the company's offer.

Insert Figure 1 around here

Constellations: building a portfolio of relationships for overall value

From the previous discussion we know the following. First, relationships are associated with different facets of value, and are 'multiplex' in that they deliver more than one type of benefit. Second, since relationships are associated with costs as well as benefits, some may carry a net cost on one or more of the dimensions. The challenge for knowledge workers then becomes how to configure their entire set of relationships to provide a balance across the dimensions. How do they achieve knowledge renewal alongside instrumental and expressive benefits, whilst also maintaining operational viability?

Higgins and Kram developed the notion of 'constellations' of mentoring relationships, arguing that it is the composition and quality of an individual's entire constellation of developmental relationships that account for long-run protégé career outcomes such as organizational retention and promotion (Higgins and Kram, 2001; Higgins & Thomas, 2001; Kram, 1985). We apply the same term here, arguing that it is the composition of knowledge workers' entire constellation of relationships that accounts for knowledge renewal alongside other career outcomes. A relationship that is costly in intellectual terms may nonetheless provide extra operational capacity which, in turn, supports a partnership that is intellectual valuable but draining in operational terms.

Evidence from the careers and the knowledge sharing literatures support the notion of constellations of relationships maintained at any point in time. A study of lawyers showed that those who rely on a broad set of individuals for career and psychosocial support, rather than a single mentor, were more likely to achieve promotion to partner within the organization (Higgins and Thomas, 2001). Research on MBA graduates, taking a social capital approach, found that relationships providing information, resources and career sponsorship enhanced career success (Seibert, Kraimer, & Liden, 2001), and that the configuration of those relationships determined the extent and quality of benefits accessed. These studies suggest that career success depends not only on the number of people who provide developmental help, but on creating a balanced constellation of people who can provide different types of help and support. The knowledge sharing literature provides evidence for constellations of relationship providing a variety of intellectual benefits. Cross and Sproull (2004) found that people cultivate different kinds of information relationships that are the source of five components of actionable knowledge: solutions, referrals, problem reformulation, validation, and legitimation. In a similar study examining these components of knowledge, Cross et al. (2001) argued that individuals create balanced portfolios of complementary contacts that provide different benefits.

Illustrating constellations: the case of Dominic. We illustrate constellations using the example of Dominic, who had recently set up an entrepreneurial venture when he was interviewed. Dominic had a background in optics and in metrology (the science of measurement). With a colleague Gordon from business school (also with an optics background), his goal was to develop a non-invasive device that could measure the glucose levels of diabetics from their eyes. Dominic was responsible for sourcing the external knowledge they needed. As Dominic put it,

> I knew about optics and measurement, but I needed to know about diabetes and optometry, among other things.

Here we describe three relationships in the constellation Dominic built up in the early stages of establishing his company. These are illustrated in Figure 2. Gordon and Dominic were tight-knit collaborators, jointly developing architectural knowledge of the company's commercial and technological strategy. Gordon's value to Dominic was in making it possible; without him, the business would not exist. Together they had pooled their component knowledge of optics to come up with an idea for the business, written a business plan, invested their own capital and raised funding, and supported each other through the ups and downs of starting a business.

Insert Figure 2 around here

Other collaborators in Dominic's constellation cannot see the whole picture in the way that Gordon can, but from their work Dominic has been able to develop component knowledge in new areas. For example, Dominic's company funded work (an operational cost) in John's research group. John's group worked asynchronously to develop a model eye (an artifact, providing an operational benefit) that Dominic could use for test measurements using his prototype measurement device. John's assistant Brad an optical modeler who had previously worked at the Lions Eye Institute in Perth, Australia. This link was unknown to Dominic initially, but resulted in Brad building an optical software model of the eye which showed that that their prototype wasn't working in the way they thought. Subsequently, other complementary aspects – John's knowledge of ophthalmology and experience of developing optical diagnostics for teeth – became apparent. This knowledge has underpinned and extended Dominic's architectural knowledge of what the company is trying to achieve in scientific terms, and where it should head next.

Other relationships, such as that with Mark (an ex-colleague from Dominic's former employer, who had left to set up his own business), have been less valuable intellectually, but yielded other benefits. Describing his business plans to Mark helped Dominic understand some of the challenges associated with running a business, and how to manage the presentation of technical information to investors. Dominic described this as free advice (minimal operational costs); he simply made a couple of visits to the Mark's house to talk things through. The connection with Mark at that point in his career provided support and affirmation for Dominic's ideas (expressive benefits) and helped to confirm his identity as an entrepreneur.

Real options: managing constellations over time

Relationships and careers are, of course, are embedded within a time dimension. A relationship that is beneficial at one point in time may decline in value over time. As partners learn from each other and their knowledge converges, returns from complementarity decrease (McFadyen and Cannella, 2004). Operational value is usually time-limited: a project is done, a paper or report written, funds are spent. Interests and objectives may diverge, such that the partners are no longer a good match for each other. Relational value may be sustained, or it too can decline with time as partners grow apart.

Likewise, relationships take time to develop on all three dimensions, with each dimension developing around the others. Friends such as Dominic and Gordon identify a common area of interest, start playing with ideas and a collaboration is born. Colleagues learn about each other's expertise, seek out funding for a joint project and then get to know each other better, as in the tissue engineering example described above. We found that many long-term relationships begin with an exploratory period, where not too much is invested, in order to see whether there is a basis for a deeper collaboration.

Over time, constellations are reconfigured as new relationships are added and existing relationships fade away or are terminated. In a descriptive study of developmental relationships for MBA graduates in early career, Cummings and Higgins (2006) showed that only 45% of ties were reported at three points in time spanning five years, and that these ‘inner core’ ties tended to be those that provided high psychosocial support and low career support. ‘Outer core’ ties provided a mixture of psychosocial and career support and were more susceptible to decay over time. The authors suggest these findings support Morgan et al’s (1997) idea of a core-periphery structure in personal networks, where core members remain in the network while peripheral members come and go.

Our findings illuminate the decay as well as the formation of relationships. In this succinct quote, an interviewee describes how collaborations often come to an end: the partner stops phoning because he or she chooses other things to do:

> Collaborations end naturally. The work ends, the telephone stops ringing. Not usually bitter ends.

Scholars have applied utility maximization arguments to social networks to highlight that the time and resources available for relationships are constrained (Doreian, 2006; Hummon, 2000; Jackson & Wolinsky, 1996; King, 2008). Since people can only maintain a certain number of ties, they make implicit judgments about the marginal benefits of a relationship relative to alternative uses of time, energy, resources and attention. In the quote above, the collaborator stopped phoning because other uses of time became preferable. In another example, a scientist described how he would no longer work with a partner who had violated his expectations of reciprocity:

> I wrote up a short paper very quickly and he wrote up a longer paper which took a few more months to come out. But, I went to [him] with the short paper and said okay this is what I am proposing to write, what are your comments? …Then a few months later I emailed him and said how is your paper going? “Oh I’ve submitted it. Sorry!” He sends me a copy and there are some really, there are two or three really bad mistakes in it … I was pretty peeved that I’d done him the courtesy of allowing him to comment on ours and make the modifications and he hadn’t. … I didn’t say anything to him, [but] it was clear I wasn’t going to work with him again.

After this experience, the relational costs of that relationship were too high to merit continuing, despite the potential for intellectual value.

At any stage collaborative relationships carry risks and uncertainties. Will the partner deliver on what she promised? Will our project or experiment yield any usable results? Is the commercially sensitive material I've shared with her secure? How will she react when I give her this feedback on her performance? The fundamental uncertainty is this: will we still have a basis for working together in the future? Once a relationship is underway, experience is available with which to make judgments about costs, benefits and risks, permitting tradeoffs between one dimension and another to be made. At the outset when a collaborative relationship is just emerging and where the partners do not know each other well, however, there may be limited experience to draw upon. At this stage, evaluations of cost, benefit and risk have to rely on cognitive rather than experiential learning (Gavetti & Levinthal, 2000). Limited investments are made, without committing too much, in order to test the water for continuing and perhaps deepening any given relationship. As a relationship begins to yield intellectual, operational and/or relational value, further investments can be made.

We argued above that constellations of relationships provide balance in terms of relational, operational and intellectual benefits. Here we suggest that constellations serve another, related purpose. A constellation of collaborative relationships provides a knowledge worker with set of 'real options', upon which he or she has the option, but not the obligation, to continue in the future. Real options reasoning is an approach to the evaluation of investments in situations of uncertainty, that originated within finance but has been applied to the strategic management of firms and human resources (Barnett, 2008; Bhattacharya & Wright, 2005; McGrath, 1999). Real options are created on real, tangible assets to reduce risks of loss of value and increase future opportunities for returns. They provide time-deferred and flexible investments that can be increased, adjusted or abandoned in the future, providing a means to stabilize returns from real assets (Bhattacharya and Wright, 2005). Since in collaboration, any investment in a relationship carries with it uncertainty regarding the future return (benefits) from that investment, and the risk that the pay-off will not be as expected.

Illustrating real options: Jim's need for baculovirus expression knowledge. We illustrate real options reasoning using the Jim's need to develop capability for baculovirus expression (a means of producing proteins using insects). Jim worked in a protein production unit in a pharmaceutical firm. He describes his need for external expertise follows:

> To start it [insect expression in house] up would have been a year's go, you would have to have sequestered some resource, dedicated people to it. All sorts of political discussions would have to take place. At the time my project demands were much more immediate than that, so initially the easiest way was just to contract it straight out. Supply the projects from stuff that Ivan could do for us at a price.

To meet these immediate needs, he approached Ivan, a virologist in a nearby university. They knew other having met at conferences, and because Ivan worked with Jim's wife. Ivan had the facilities to create the cultures Jim needed in his lab, and spare capacity to do so. Ivan did the work for a 'bench fee' only. Ivan described this operational benefit as 'handle-turning': an easy way to generate cash for his research group. After this initial interaction went well, they agreed to a deeper investment in the relationship by jointly supervising a PhD student, who is based in Ivan's group and who receives a stipend from Jim's company. For Jim, intellectual benefits arise from having regular interactions with Ivan, who he described as a world-leader in the field of insect expression.

> Then there came a need, I wanted to do some insect work and it was bloody obvious where was the easiest place to go rather than trying to set something up here at a huge cost initially. So I just went and saw [Ivan] and asked him and he agreed to do some stuff at a contract price that we agreed and he did some work for us. That's been great. Then after a year of that, I think I said to him, well why don't we get a CASE award going. You know you provide the student and I can provide some cash and we can come up with some project goals and we can move it forward. It has had its ups and downs but it has worked pretty well.

The PhD studentship (referred to in this quote as a CASE award) deepened the relationship and for Jim it was a way of 'giving something back' to Ivan. However, Jim has a further motive; he anticipates that his company will at some stage establish insect expression in-house; having a foot in the door with Ivan could – in that case – be extremely valuable. Jim's investment in Ivan at this and earlier stages can be seen as an investment in the option of having a deeper relationship with him in the future

> … initially the easiest way was just to contract it straight out. Supply the projects from stuff that Ivan could do for us at a price. That was fine. Then I am thinking well that worked quite well, let's give, *there's an option,* giving something back by giving Ivan a CASE award. But we also gained lots from that because that means we will increase our interface with them, *if I want to start up an insect group here, which we are starting now, then we've got a much bigger interface. We have got a foot in the door much more*. Our relationship is much deeper because we've had a year's CASE award, and you know, we can get help from them and they are helping us. (Italics added.)

Ivan is not the only person Jim turns to for baculovirus expression expertise, however; he also has a more commercial collaboration with scientists in another company, again holding the option for deepening the relationship:

> So we do use this company called Chesapeake Pearl. … We do collaborations where they do feasibility studies for us and things … The model that I had in my head was that Ivan couldn't really scale up because they don't have the facilities [to do more than produce] milligrams of protein. Sometimes we need to make grams of protein which is three orders of magnitude more. So my idea was to get Ivan to make the viruses, do the feasibility work in cells and then get the company to use their caterpillars and infect half a million caterpillars. It hasn't quite worked out as well and as smoothly as I would like, that end of it. Hence this is why we are starting up our own expression system for insect stuff here. … Because, we can afford and bring in and buy the equipment to do hundreds of liters of culture, whereas Ivan just hasn't got that sort of budget to do that. So we can still use Ivan and his group and his expertise in the initial stage and then hopefully we will put in place the scale up processes for that. Then we don't have to use the caterpillar stuff at all. The jury is still out there a bit, we've still got that thing going on with Chesapeake Pearl but I'm just trying to back [a number of options]

Jim's example illustrates how a set of relationships is intended to stabilize the return on the intellectual dimension. To date the relationship with Ivan has been operationally efficient for Jim: although it has been costly, the costs have been less than those he would have incurred by doing the same things in house, and he has been able to realize operational benefits much more quickly. At some point the relationship with Ivan might cease to offer operational value, since Ivan cannot scale up his operations, but it might still provide intellectual value. The relationship with Chesapeake Pearl scientists has been difficult in relational terms, but the investment might nonetheless pay off for operational reasons. In the meantime, Jim enjoys working with Ivan and wants to ‘give him something back’.

Discussion

In this paper we have developed a theory to explain the discretionary selection of collaborators by knowledge workers. We described three dimensions upon which collaborative relationships can deliver value – operational, intellectual and relational – identifying factors affecting the costs, benefits and risks of collaborating on each. Costs and risks can outweigh benefits on one dimension, but compensation between dimensions means that a partnership might nonetheless be valuable. People develop constellations of partnerships that, taken together, provide value across all three of the dimensions. A constellation makes it possible to sustain a relationship that is negative on all three dimensions, so long as other relationships compensate for its draining effect. Over time, constellations are reconfigured as individual ties evolve, strengthen, endure or die. A knowledge worker’s constellation can be seen as a set of real options at varying stages of maturity. Some may be low-cost, exploratory and short-lived, while others that are tried and tested attract greater investment and deliver a higher level of benefit.

Another important aspect of our theory is that it reveals how supplementary and complementary aspects of relationship affect their costs and benefits. The idea of complementarity is widely accepted in studies of alliances and partnerships (e.g. Dyer & Singh, 1998), but supplementary characteristics are less often considered. Supplementary knowledge, attributes and working patterns may be ideal for exploitation of existing capabilities, whilst complementary knowledge promotes exploration (March, 1991). March argued that both are essential for learning especially in situations of rapid technological change, but they complete for resources. A constellation of collaborators offering supplementary and complementary characteristics provides a means to balance exploration with exploitation.

Our theory bears some resemblance to the much-cited intellectual capital framework developed by Nahapiet and Ghoshal (1998) from a synthesis of the literature. Our intellectual and relational dimensions are similar to their cognitive and relational embeddedness dimensions respectively. Like them, we are also concerned with how similarities, differences, proximity and distance on each of the dimensions affect conditions for combination and exchange of knowledge. However, there are some crucial differences. Nahapiet and Ghoshal's primary objective was to explore ways in which social capital influences the development of intellectual capital at a collective level. In contrast, our approach draws attention to alternative purposes that social relationships serve. In our theory, the creation and exchange of knowledge is only one objective that in some cases could be subordinate to others, perhaps even to the point where intellectual capital is depleted rather than developed. Also, Nahapiet and Ghoshal's structural dimension refers to the overall pattern of connections between actors in a social network, connections that may or may not be formally prescribed through organizational roles. Our operational dimension captures something different, providing the opportunity to examine the value of relationships in terms of their potential for exchange of physical and financial resources alongside relational and intellectual resources.

Moreover, our theory extends beyond a three-dimensional approach to understanding social relationships. By combining the notion of compensation between dimensions with the idea that constellations that are reconfigured over time, it provides a means to build a complete picture of a person's current and evolving set of collaborative relationships. It offers a framework that could be used for empirical studies of motivations for knowledge sharing. People might not share knowledge in order to learn or to generate new understandings; they might do so to access financial or physical resources or because the partnership enhances their career. Studies of motivations for knowledge sharing could usefully take multiple motives into account. Such studies could also exploit the potential offered by examining motives for knowledge sharing using dyad- rather than ego-centered levels of analysis.

The theory also opens up approaches to understanding individual differences in partner selection, and, by extension, heterogeneity in emergent social networks. It is likely that individuals differ in preferences for overall balance between the three dimensions. Some might prioritize knowledge renewal above all else, and deploy their operational and relational resources to optimize that. Others might attach great importance to working with people they like and enjoy, even if this means compromising on knowledge renewal. Others might experience such negative arousal from 'selling' their ideas to potential funders of research, or monitoring progress with contractual relationships that they tend to avoid projects with high operational value, again at the possible expense of knowledge renewal. We do not have space here to examine factors affecting these differences in detail, but it is likely that career orientations (Allen & Katz, 1995), and aspects of personality such as self-monitoring (Kilduff & Day, 1994) are important. Self-monitors might make more accurate predictions of the likely trajectory of a relationship, anticipating whether benefits on any dimensions are likely to increase or decrease with time, and thereby building constellations that are more likely to deliver career benefits (c.f. Higgins and Thomas, 2001).

The time dimension is another important aspect of our theory. Collaboration is often undertaken in contexts of uncertainty, with outcomes only apparent at distant points in time. A constellation provides a means to increase the likelihood of a return on the time invested in collaboration by having a stake in a variety of ventures. Initial investments can be made at low cost and low risk, and ramped up or dissolved as the likely outcomes become more certain. Ventures requiring greater investment may be worth pursuing so long as the anticipated benefits are expected to increase and to outweigh the costs of continuing. The point at which the anticipated benefits are in decline, and/or the costs start to outweigh the benefits might be the time to reconsider.

We illustrate this kind of reasoning for value on the intellectual dimension in Figure 3. In Figure 3 the size of the circle denotes the amount of intellectual benefit (high and low) derived from a relationship. Red circles denote relationships that are net negative in intellectual value (i.e. costs outweigh benefits) and blue shows positive relationships. The small arrows show relationships that are either increasing or decreasing in terms of net benefit. Each circle has been labeled with comments about the likely trajectory of the relationship (on the intellectual dimension only) over time. There may, of course, be relational or operational reasons for sustaining relationships that in intellectual terms are ‘exit now’ or ‘high risk’

Insert Figure 3 around here

Reasoning of this nature has potential applications for HRM in knowledge-based work. Mapping constellations using a tool such as that in Figure 2, and applying the reasoning illustrated in Figure 3 to each dimension, could help knowledge workers think about the overall value of their constellations of collaborators, and the implications for their short-term productivity and long-term career development. Are they compromising on one dimension in order to maximize others and if so could there be some benefits to rebalancing? If costs on the intellectual dimension outweigh the benefits in overall terms, is their stock of knowledge in need of renewal? If their collaborators are predominantly those with supplementary knowledge, could there be some marginal benefits from seeking out complementary partners? Are they being overcome by relational demands, providing support and advice to many partners, and perhaps becoming a bottleneck or unduly stressed in the process? Do they have too many gestating (low investment, exploratory) relationships and not enough high benefit relationships, or vice versa? Could they benefit from concentrating relationships amongst fewer partners offering multiplex benefits, or conversely, diversifying more?

The theory also has the potential to guide managers in situations where they wish to ‘prescribe’ collaborative relationships, such as where employees are expected to be involved in R&D alliances or joint ventures. Where managers wish to encourage employees to add such prescribed collaborations to their constellations, they need to consider a number of factors. First, there may be the opportunity costs for employees where they are expected to add prescribed relationships to their constellation. Since time is constrained, what other relationships will be displaced, and with what implications for intellectual, operational or relational value? Second, how can they make the benefits of prescribed relationships attractive? Since knowledge sharing is often internally rather than externally motivated, it is conceivable that extrinsic rewards might be counter-productive, crowding out intrinsic motivations for knowledge sharing (Osterloh and Frey, 2000). Are there ways of designing project teams and jobs and organizing work such that employees can derive relational or operational value from the prescribed relationships? Could managers provide a way for employees to ‘test the water’ with low-investment, low-risk relationships to start with? Third, in cases where partners have different knowledge, to what extent are they complementary or detracting? Can bridge mechanisms be used to help make it feasible to overcome such differences? Using insights such as these offers managers a way to help knowledge workers configure their constellations in ways that could benefit them and the wider organization.

Reference List

Adler, P. S. and Kwon, S.-W. 2002. Social capital: Prospects for a new concept. ***Academy of Management Review,*** 27: 17-40.

Allen, T. D., Lentz, E., and Day, R. 2006. Career success outcomes associated with mentoring others - A comparison of mentors and nonmentors. ***Journal of Career Development,*** 32(3): 272-285.

Allen, T. J. and Katz, R. 1995. The Project-Oriented Engineer - A Dilemma for Human-Resource Management. ***R & D Management,*** 25(2): 129-140.

Andrews, K. M. and Delahaye, B. L. 2000. Influences on knowledge processes in organizational learning: The psychosocial filter. ***Journal of Management Studies,*** 37(6): 797-810.

Barnett, M. L. 2008. An attention-based view of real options reasoning. ***Academy of Management Review,*** 33(3): 606-628.

Beaver, D. D. 2001. Reflections on scientific collaboration, (and its study): past, present, and future. ***Scientometrics,*** 52(3): 365-377.

Bhattacharya, M. and Wright, P. M. 2005. Managing human assets in an uncertain world: applying real options theory to HRM. ***International Journal of Human Resource Management,*** 16(6): 929-948.

Bock, G. W., Zmud, R. W., Kim, Y. G., and Lee, J. N. 2005. Behavioral intention formation in knowledge sharing: Examining the roles of extrinsic motivators, social-psychological forces, and organizational climate. ***MIS Quarterly,*** 29(1): 87-111.

Borgatti, S. P. and Cross, R. 2003. A relational view of information seeking and learning in social networks. ***Management Science,*** 49(4): 432-445.

Bouty, I. 2000. Interpersonal and interaction influences on informal resource exchanges between R&D researchers across organizational boundaries. ***Academy of Management Journal,*** 43: 50-65.

Bozeman, B. and Corley, E. 2004. Scientists' collaboration strategies: implications for scientific and technical human capital. ***Research Policy,*** 33(4): 599-616.

Bozeman, B., Dietz, J. S., and Gaughan, M. 2001. Scientific and technical human capital: an alternative model for research evaluation. ***International Journal of Technology Management,*** 22(7-8): 716-740.

Bozeman, B. and Gaughan, M. 2007. Impacts of grants and contracts on academic researchers' interactions with industry. ***Research Policy,*** 36(5): 694-707.

Burt, R. S. 1992. ***Structural Holes: The Social Structure of Competition***. Cambridge MA: Harvard University Press.

Burt, R. S. 2000. Decay functions. ***Social Networks,*** 22(1): 1-28.

Burt, R. S. 2005. ***Brokerage and Closure: An Introduction to Social Capital***. Oxford: Oxford University Press.

Cockburn, I. M. and Henderson, R. M. 1998. Absorptive capacity, coauthoring behavior, and the organization of research in drug discovery. ***Journal of Industrial Economics,*** 46(2): 157-182.

Cockburn, I. M., Henderson, R. M., and Stern, S. 2000. Untangling the origins of competitive advantage. ***Strategic Management Journal,*** 21(10-11): 1123-1145.

Cross, R., Baker, W., and Parker, A. 2003. What creates energy in organizations? ***MIT Sloan Management Review,*** 44(4): 51-+.

Cross, R., Borgatti, S. P., and Parker, A. 2001. Beyond answers: dimensions of the advice network. ***Social Networks,*** 23(3): 215-235.

Cross, R. and Sproull, L. 2004. More than an answer: Information relationships for actionable knowledge. ***Organization Science,*** 15(4): 446-462.

Crossan, M. M., Lane, H. W., and White, R. E. 1999. An organizational learning framework: From intuition to institution. ***Academy of Management Review,*** 24(3): 522-537.

Csikszentmihayli, M. 1990. ***Flow: The Psychology of Optimal Experience***. New York: Harper and Row.

Cummings, J. N. and Higgins, M. C. 2006. Relational instability at the network core: Support dynamics in developmental networks. ***Social Networks,*** 28(1): 38-55.

Dasgupta, P. and David, P. A. 1994. Toward a new economics of science. ***Research Policy,*** 23(5): 487-521.

Deci, E. L. 1975. ***Intrinsic motivation***. New York: Plenum.

Doreian, P. 2006. Actor network utilities and network evolution. ***Social Networks,*** 28(2): 137-164.

Drucker, P. 2002. Knowledge Worker Productivity: The Biggest Challenge. ***California Management Review,*** 41(2): 79-95.

Dyer, J. H. and Singh, H. 1998. The relational view: cooperative strategy and sources of interorganizational competitive advantage. ***Academy of Management Review,*** 23: 660-679.

Felin, T. and Hesterly, W. S. 2007. The knowledge-based view, nested heterogeneity, and new value creation: Philosophical considerations on the locus of knowledge. ***Academy of Management Review,*** 32(1): 195-218.

Gavetti, G. and Levinthal, D. 2000. Looking forward and looking backward: Cognitive and experiential search. ***Administrative Science Quarterly,*** 45(1): 113-137.

Glaser, E. M. and Strauss, A. 1967. ***The discovery of grounded theory***. Chicago: Aldine.

Granovetter, M. 1985. Economic Action and Social Structure: The Problem of Embeddedness. ***American Journal of Sociology,*** 91(3): 481-450.

Grant, R. M. 1996. Prospering in Dynamically Competitive Environments: Organizational Capability as Knowledge Integration. ***Organization Science,*** 7(4): 375-387.

Grant, R. M. and Baden-Fuller, C. 2004. A knowledge accessing theory of strategic alliances. ***Journal of Management Studies,*** 41(1): 61-84.

Haas, M. R. and Hansen, M. T. 2007. Different knowledge, different benefits: toward a productivity perspective on knowledge sharing in organizations. ***Strategic Management Journal,*** 28(11): 1133-1153.

Hansen, M. T. 1999. The search-transfer problem: The role of weak ties in sharing knowledge across organization subunits. ***Administrative Science Quarterly,*** 44: 82-111.

Hansen, M. T., Nohria, N., and Tierney, T. 1999. What's your strategy for managing knowledge? ***Harvard Business Review,*** 77(2): 106-116.

Heffner, A. G. 1981. Funded Research, Multiple Authorship, and Sub-Authorship Collaboration in 4 Disciplines. ***Scientometrics,*** 3(1): 5-12.

Henderson, R. M. and Clark, K. B. 1990. Architectural innovation: the reconfiguration of existing product technologies and the failure of established firms. ***Administrative Science Quarterly,*** 35: 9-30.

Higgins, M. C. and Kram, K. E. 2001. Reconceptualizing mentoring at work: a development network perspective. ***Academy of Management Review,*** 26: 264-288.

Higgins, M. C. and Thomas, D. A. 2001. Constellations and careers: Toward understanding the effects of multiple developmental relationships. ***Journal of Organizational Behavior,*** 22(3): 223-247.

Hummon, N. P. 2000. Utility and dynamic social networks. ***Social Networks,*** 22(3): 221-249.

Ibarra, H. 1993. Personal networks of women and minorities in management: A conceptual framework. ***Academy of Management Review,*** 18: 56-87.

Ibarra, H., Kilduff, M., and Tsai, W. 2005. Zooming in and out: Connecting individuals and collectivities at the frontiers of organizational network research. ***Organization Science,*** 16(4): 359-371.

Jack, S. L. 2005. The role, use and activation of strong and weak network ties: A qualitative analysis. ***Journal of Management Studies,*** 42(6): 1233-1259.

Jackson, M. O. and Wolinsky, A. 1996. A strategic model of social and economic networks. ***Journal of Economic Theory,*** 71(1): 44-74.

Katz, D. and Kahn, M. R. L. 1978. ***The Social Psychology of Organizations 2nd ed***. New York: Wiley.

Katz, J. S. and Martin, B. R. 1997. What is research collaboration? ***Research Policy,*** 26(1): 1-18.

Kilduff, M. and Tsai, W. 2003. ***Social Networks and Organizations***. London: Sage.

Kilduff, M. D. and Day, D. V. 1994. Do chameleons get ahead? The effects of self-monitoring on managerial careers. ***Academy of Management Journal,*** 37: 1047-1060.

King, Z. 2004. Career Self-Management: Its Nature, Causes and Consequences. ***Journal of Vocational Behavior,*** 65(1): 112-133.

King, Z. 2008. ***Ties that blind? Career self-management, network structure and the choice of partners for collaboration***. Unpublished paper.

Kogut, B. and Zander, U. 1992. Knowledge of the firm, combinative capabilities and the replication of technology. ***Organization Science,*** 3: 383-397.

Kram, K. 1986. Mentoring in the workplace. In D. T. Hall, (Ed.), ***Career Development in Organizations:*** San Francisco: Jossey Bass.

Kram, K. E. 1985. ***Mentoring at Work***. Glenview IL: Scott Foresman.

Lam, A. 2007. Knowledge networks and careers: Academic scientists in industry-university links. ***Journal of Management Studies,*** 44(6): 993-1016.

Levin, D. Z. and Cross, R. 2004. The strength of weak ties you can trust: The mediating role of trust in effective knowledge transfer. ***Management Science,*** 50(11): 1477-1490.

Link, A. N., Siegel, D. S., and Bozeman, B. 2007. An empirical analysis of the propensity of academics to engage in informal university technology transfer. ***Industrial and Corporate Change,*** 16(4): 641-655.

Locke, K. 2001. ***Grounded Theory in Management Research***. Thousand Oaks, CA: Sage.

Mansfield, E. 1995. Academic Research underlying industrial innovation: sources, characteristics, and financing. ***The Review of Economics and Statistics,*** 77(1): 55-65.

March, J. G. 1991. Exploration and Exploitation in Organizational Learning. ***Organization Science,*** 2(1): 71-87.

Matusik, S. F. and Hill, C. W. L. 1998. The utilization of contingent work, knowledge creation, and competitive advantage. ***Academy of Management Review,*** 23(4): 680-697.

McFadyen, M. A. and Cannella, A. A. J. 2004. Social Capital and Knowledge Creation: Diminishing Returns of the Number and Strength of Exchange Relationships. ***Academy of Management Journal,*** 47(5): 735-746.

McFadyen, M. A. and Cannella, A. A. J. 2005. Knowledge creation and the location of university research scientists' interpersonal exchange relations: within and beyond the university. ***Strategic Organization,*** 3(2): 131-155.

McGrath, R. G. 1999. Falling forward: Real options reasoning and entrepreneurial failure. ***Academy of Management Review,*** 24(1): 13-30.

McPherson, M., Smith-Lovin, L., and Cook, J. M. 2001. Birds of a feather: Homophily in social networks. ***Annual Review of Sociology,*** 27: 415-444.

Melin, G. 2000. Pragmatism and self-organization - Research collaboration on the individual level. ***Research Policy,*** 29(1): 31-40.

Morgan, D. L., Neal, M. B., and Carder, P. 1997. The stability of core and peripheral networks over time. ***Social Networks,*** 19(1): 9-25.

Murray, F. 2004. The role of academic inventors in entrepreneurial firms: sharing the laboratory life. ***Research Policy,*** 33(4): 643-659.

Nahapiet, J. and Ghoshal, S. 1998. Social capital, intellectual capital, and the organizational advantage. ***Academy of Management Review,*** 23(2): 242-266.

Osterloh, M. and Frey, B. S. 2000. Motivation, knowledge transfer, and organizational forms. ***Organization Science,*** 11(5): 538-550.

Podolny, J. M. and Baron, J. N. 1997. Relationships and resources: Social networks and mobility in the workplace. ***American Sociological Review,*** 62: 673-693.

Poti, B. 2001. Appropriation, tacit knowledge and hybrid social regimes in biotechnology in Europe. ***International Journal of Technology Management,*** 22(7-8): 741-761.

Reagans, R. and McEvily, B. 2003. Network structure and knowledge transfer: The effects of cohesion and range. ***Administrative Science Quarterly,*** 48(2): 240-267.

Rosenkopf, L. and Correcloira, R. A. 2008. What you can gain when you lose good people. ***Harvard Business Review,*** 86(4): 24-+.

Schrader, S. 1991. Informal Technology Transfer between Firms: Co-operation through information trading. ***Research Policy,*** 20: 153-170.

Seibert, S. E., Kraimer, M. L., and Liden, R. C. 2001. A Social Capital Theory of Career Success. ***Academy of Management Journal,*** 44(2): 219-237.

Shah, S. K. and Corley, K. G. 2006. Building better theory by bridging the quantitative-qualitative divide. ***Journal of Management Studies,*** 43(8): 1821-1835.

Stern, S. 2004. Do scientists pay to be scientists? ***Management Science,*** 50(6): 835-853.

Szulanski, G. 1996. Exploring internal stickiness: Impediments to the transfer of best practice within the firm. ***Strategic Management Journal,*** 17: 27-43.

Traore, N. and Landry, R. 1997. On the determinants of scientists' collaboration. ***Science Communication,*** 19(2): 124-140.

von Hippel, E. 1987. Cooperation between rivals: Informal know-how trading. ***Research Policy,*** 16: 291-302.

Wellman, B., Wong, R. Y. L., Tindall, D., and Nazer, N. 1997. A decade of network change: Turnover, persistence and stability in personal communities. ***Social Networks,*** 19(1): 27-50.

Wenger, E. 2000. Communities of practice and social learning systems. ***Organization,*** 7(2): 225-246.

Yin, R. K. 2003. ***Case Study Research: Design and Methods (3rd edition)***. Thousand Oaks, CA: Sage Publications.

Zucker, L. G., Darby, M. R., and Armstrong, J. 1998. Geographically localized knowledge: Spillovers or markets. ***Economic Inquiry,*** 26: 65-86.

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

	Group 1: exemplar outcomes	**Group 2: exemplar process**
Unit of analysis	• 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	• Scientists who are inventors (therefore with a demonstrated track record of making discoveries) and who are either in a munificent locality (Group 2a) or involved in networks intended to connect scientists (Group 2b)
Examples of participants	• Inventor named on granted patents and registered at different addresses within the same region of the UK	• Inventors located in Oxford or Cambridge and/or members of regional science networks, Faraday partnerships, the DiagnOx lab etc.
Selection of participants	• Selected from EPO patent office database of granted patents in relevant IPC categories.	• Group 2a were selected from EPO patent data and screened to include a range of 'revelatory' localized collaborations. Group 2b were identified from membership of regional interventions by discussion with relevant organizers or facilitators
Phase 1 interviews	• Semi-structured interviews with 9 scientists (each from a different team of inventors) • Supporting evidence from publications, personal websites etc.	• Semi-structured interviews with 13 scientists (each from a different research team) • Supporting evidence from publications, personal websites etc.
Phase 2 interviews	• Interviews with 7 collaborators of the 9 scientists interviewed in Phase 1 • Supporting evidence from publications, personal websites etc.	• Interviews with 11 collaborators of the 13 scientists interviewed in Phase 1 • Supporting evidence from publications, personal websites etc.

Table 2: Judgments of value in knowledge workers' social relationships

	Benefits	**Investments (costs)**	**Risks of investment**
Intellectual dimension – cognitive aspects of collaborating	• Enhancement of one's component knowledge within existing domains • Gaining new component knowledge to extend existing architectural knowledge • Development of new architectural knowledge through process of co-production and recombination of component knowledge,	• Explaining one's own component or architectural knowledge • Investing in understanding the partner's knowledge • Using one's knowledge to extend component or architectural knowledge of partner	• Risk that knowledge offered and/or co-produced will be appropriated for the other's gain, without due acknowledgement or compensation
Relational dimension – social aspects of collaborating	Expressive benefits • Affective benefits arising receiving advice, support or guidance from the partner • Affective benefits arising from helping the partner Instrumental benefits • Reputation benefits arising from being associated with the partner • Benefits arising from being able to access the partner's contacts– e.g. gatekeepers	• Investing personal energy and emotion in a relationship • Affective costs (negative emotions) arising from the relationship • Investing in the partner's social ties - providing introductions, making connections between partner and others in one's own social network	• Risk that personal contributions will not be reciprocated or appreciated • Risk of misuse by partner of contacts made • Risks to reputation/standing amongst own and/or partner's social ties
Operational dimension – practical aspects of collaborating	• Money – receiving money from the partner to carry out work • Resources – gaining access to equipment, materials • Artifacts – gaining access to products of the partner's prior work (e.g. models, reagents, datasets) • Capacity – gaining access to additional labor – a 'pair of hands'	• Money – financing work done by the partner • Resources – offering access to equipment, materials • Artifacts – providing reagents, models, prototypes • Capacity – one's own time	• Risk that resources, money or artifacts will be misused or appropriated for gains unrelated to the partnership • Opportunity costs?

Figure 1: Depiction of the costs and benefits derived from a collaborative relationship

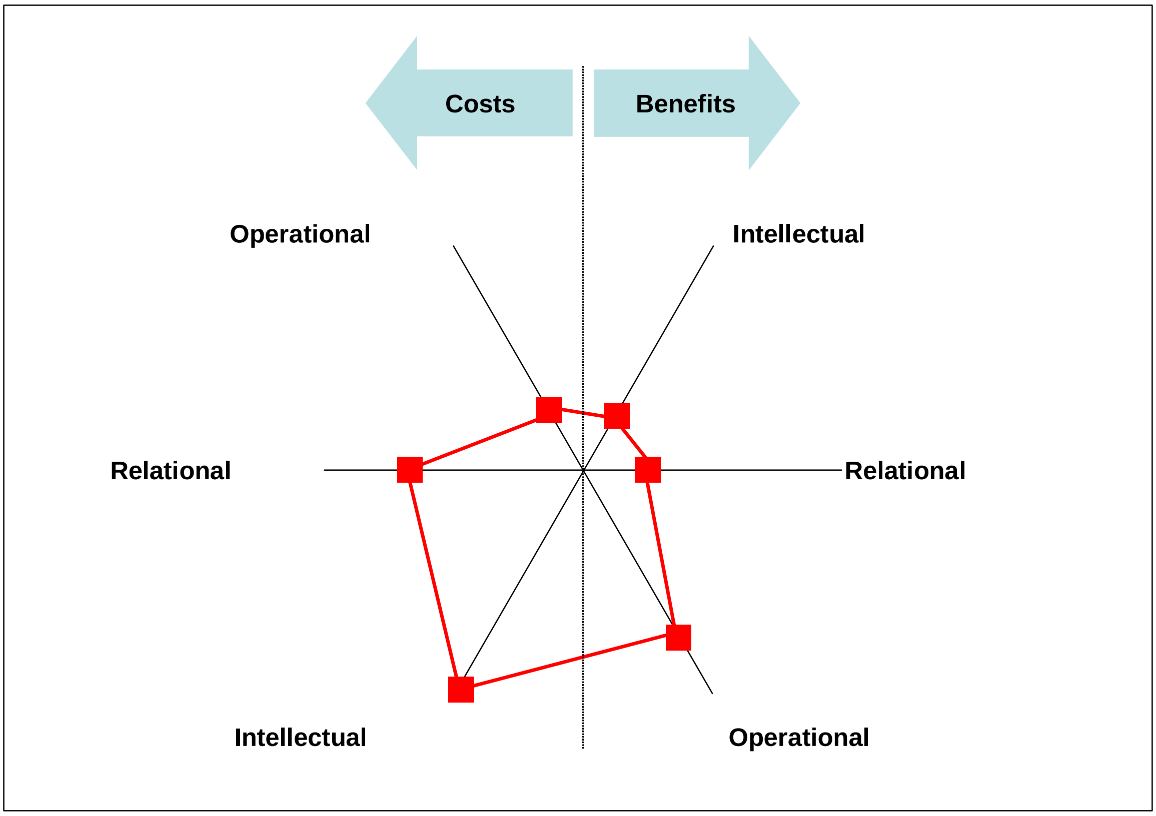

Figure 2: Depiction of the costs and benefits from a constellation of relationships: the case of Dominic

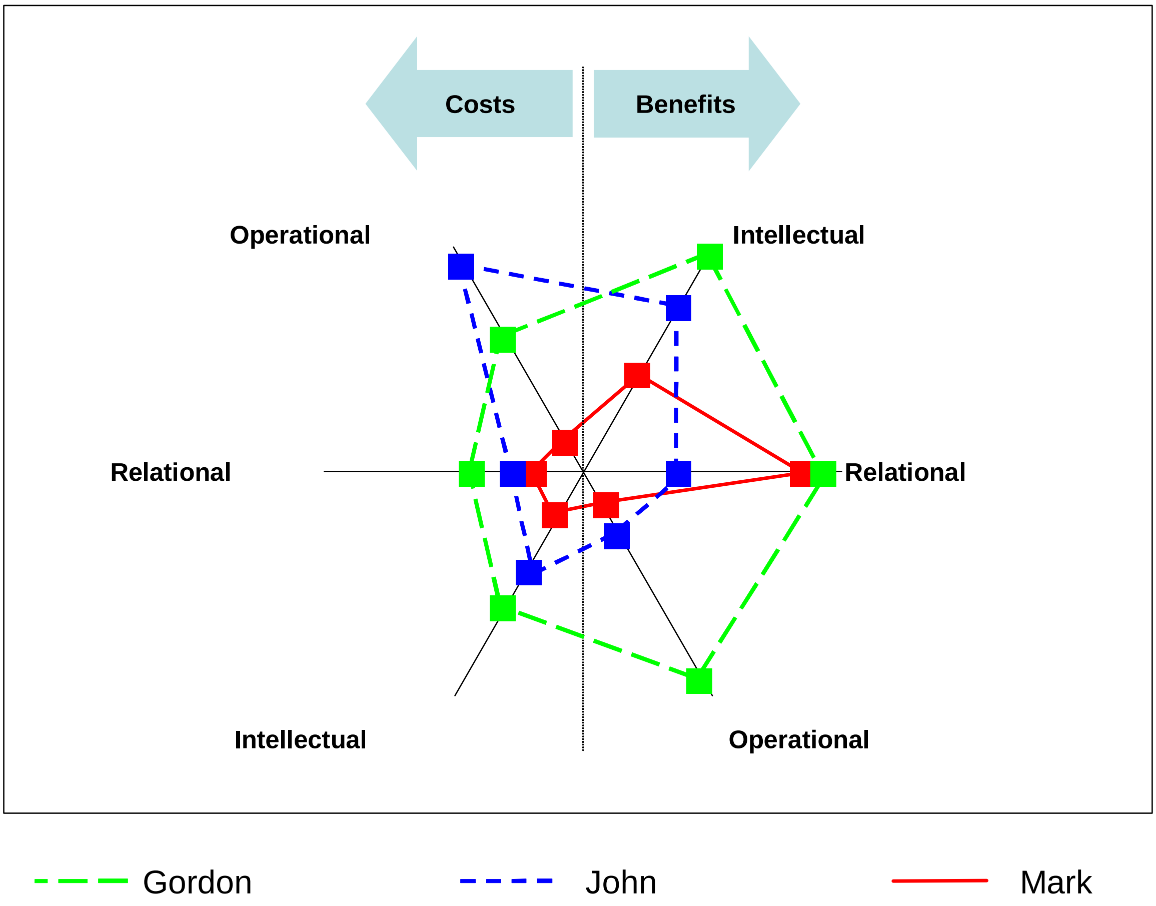

Figure 3: Example of real options thinking on the intellectual dimension