THE INFORMATION VALUE OF (UN)EMBEDDED R&D ALLIANCES

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Abstract

This paper assumes that a firm sets up information generating alliances or R&D network ties that create alliance groups to reduce technological uncertainty. Our model indicates it is only worthwhile for a firm to establish an alliance with a new, unembedded partner outside its existing alliance group when the value of technological information, obtained through this alliance, outweighs the cost advantage of finding a partner embedded within its alliance group. If the information obtained from an embedded alliance is largely redundant or very similar, a firm may prefer an unembedded alliance even if the information obtained from this tie is less precise. At some point, a firm is willing to exchange precise but redundant information for inaccurate but novel information. The higher the level of technological uncertainty in the environment, the more a firm should consider entering into an alliance with an unembedded partner instead of forming an embedded alliance. The higher the degree to which embedded ties are redundant, the more a firm is inclined to enter into a new alliance with an unembedded partner. We also show that the degree of information redundancy among the existing partners of a firm and the level of technological uncertainty faced by the firm interact, mutually reinforcing the effect these variables have on the desirability to form an unembedded tie. Finally, we find that information redundancy tends to be desirable (undesirable) if the degree of accuracy of information obtained from previous ties and either embedded or unembedded ties is dissimilar (similar).

(249 words)

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INTRODUCTION

We define alliances as inter-organizational entities that imply the sharing of resources and assets by two firms. In the context of this paper, we understand alliances to be of a technological nature which implies that the purpose of firms engaging in alliances (network ties) is to reduce the technological uncertainty in their environment and to gain access to useful technological information. More in particular, these alliances are set up for sharing, developing, and scanning new technologies with partners (Anand & Khanna, 2000; Contractor and Lorange, 2000; Dussauge & Garrette, 1999; Gulati, 1995; Hagedoorn, 1993).

Alliances that are part of a cohesive and dense network or an alliance group, where a number of firms collaborate with each other over an extended period of time and possibly through multiple alliances, are considered embedded or local ties from the perspective of an individual group member. The embeddedness of ties provides a number of advantages to a firm that engages in alliances. Due to trust between firms participating in embedded ties, these firms are for instance able to negotiate lenient and less formal governance mechanisms without equity sharing (Robinson and Stuart, 2007). Embedded, local ties may also reduce the costs of searching for new partners. Current partners of a firm may suggest other useful future partners that have a track record of desirable behavior in cooperative relationships. In addition, embedded, local ties enable the transfer of fine grained knowledge and joint problem solving arrangements (Duysters, Hagedoorn, Lemmens, 2003; Uzzi, 1997). However, at some point repeated interaction with members of the same alliance group may lead to over-embeddedness when the inflow of new and novel information is hampered. In that case, the lack of alliances with new, outside partners may reduce the exposure of firms to new innovative ideas (Uzzi, 1997).

In recent studies by Baum, Rowley, Shipilov and Chuang (2005) and Sorenson and Stuart (2008), two types of partners are considered to be embedded. First, prior ties are an obvious candidate as previous alliances between firms yield relevant information about these alliance partners through repeated interaction. Secondly, ties that are connected to the focal firm through a common partner are indirect ties, yet through this common partner they are considered to be embedded, local ties as well. Firms that are neither prior nor local ties are considered to be unembedded, because very little information is likely to travel through chains with a path length longer than two, i.e. the distance or steps between two firms connected through a common partner (Baum et al., 2005; Sorenson and Stuart, 2008). Allying with these non-local, unembedded new partners is not without consequences and related costs. Forming alliances outside a firm's current group of local ties may compromise previously formed alliances, if the existing arrangements are based on the expectation that a firm will not turn to other, non-allied firms to limit the risk that valuable information leaks to competitors. Maintaining the already existing alliances while at the same time engaging in these new alliances may require costly additional managerial efforts from the focal firm to maintain or rebuild trust (Mesquita, 2007). Furthermore, new unembedded ties are likely to involve more costly governance arrangements (Robinson and Stuart, 2007) and higher contracting costs since trust may not have been developed yet (Uzzi, 1997). There are, however, also benefits of tying to unembedded partners and these benefits are found in the potential access to novel information which may reduce uncertainty concerning relevant technological developments. This information about new technological developments is important for the survival of firms, in particular in a dynamic high-tech environment (Contractor and Lorange, 2000; Dussauge & Garrette, 1999; Gulati, 1995; Hagedoorn, 1993; Beckman, Haunschild & Phillips, 2004).

Research on the formation of unembedded ties or non-local ties is still in its infancy. Sorenson and Stuart (2008, p. 266) note that: " …. (t)he most salient shortcoming in the literature pertains to theory that can explain the emergence of ties of spatially, relationally and socio-economic distant actors." So far, very few studies have focussed on this topic. Beckman et al. (2004) find that firm-specific uncertainty induces firms to form alliances with unembedded ties whereas market uncertainty, which is common to all industry participants, makes firms prefer repeated ties with existing partners (see also Podolny, 1994). Baum et al. (2005) find that, if performance levels of existing ties are below historical or social aspiration levels, firms are more likely to take the risk of forming new, non-local ties.

Our contribution provides a formal understanding of the strategic implications for a firm whether it engages in ties within an already well-established alliance group of embedded ties or whether it opts for a more venturous strategy with new alliances (i.e. non-local, unembedded ties) outside its existing alliance group. Using a parsimonious Bayesian learning model, we consider the choice between to either increase collaboration with partners through embedded ties or to set up new, non-local, alliances. An advantage of this model is that it facilitates an explicit analysis of which parameters determine a firm's potential to learn from its alliances. Our theoretical approach allows for an investigation of how constructs like technological uncertainty, redundancy and information accuracy jointly affect the formation of non-local, unembedded ties. As such this contribution, advances the work of others, e.g. Beckman et al. (2004) who investigate how only one of these aspects, i.e. uncertainty faced by a firm, affects the non-local search for partners.

Our model reveals that a firm has an incentive to establish an alliance with a partner 'outside' its set of local ties when the value of the information regarding technological development, obtained through this non-local alliance, outweighs the cost advantage of finding an additional partner within the group of its already existing, embedded alliances. If the information obtained from embedded ties is largely redundant or very similar, a focal firm may turn to alliances with non-local partners even if the information obtained from these unembedded ties is less precise. The level of technological uncertainty increases the incentive to enter an alliance with an unembedded tie, which supports empirical findings of Beckman et al. (2004). The degree to which existing partners are redundant, has a positive effect on the decision of a firm to enter into a new alliance with a non-local partner. To the best of our knowledge no empirical research explicitly investigates this outcome of our model.

Another new result we obtain from our theoretical work is that the degree of technological uncertainty a firm faces and the degree of redundancy within its alliance group of local ties interact. This implies that the incentive to form an unembedded tie increases substantially with uncertainty only if the degree of information redundancy among existing partners is high enough. A firm is likely to still form local ties even if uncertainty is high, if non-redundant information is readily available within its alliance group. Likewise, a firm's inclination to form a non-local, unembedded tie increases significantly with the degree of redundancy within its existing alliance group only if it faces a substantial degree of technological uncertainty. This interesting result implies that a focal firm will only tolerate a moderate level of redundancy within its current group of alliance partners when uncertainty is high and it will quickly become interested in tying up with unembedded, non-redundant partners when uncertainty increases.

The final issue we address in our paper concerns the question of how accuracy of information affects the desirability of information redundancy or overlap of information obtained from various types of alliance ties. We show in this paper that the disadvantages of information redundancy apply when the accuracy of information made available by prior ties and information provided by embedded partners have the same degree of accuracy. Under these conditions, firms are inclined to avoid redundancy. However, if the accuracy of the embedded ties and the precision of the knowledge already available to the firm by prior ties differ substantially, then some overlap is beneficial. In that case, the Bayesian learning model we adopt in this paper provides a surprising result. According to the model we advance, the precision of one source of information (prior ties, embedded ties or unembedded ties) may benefit the accuracy of the combination of an imprecise and a precise piece of information obtained from alliance partners if there is a certain degree of redundancy. Likewise, we find that information overlap between information obtained from previous partners and unembedded partners is beneficial if the accuracy of information from these ties is dissimilar.

A recent contribution by Letterie, Hagedoorn, van Kranenburg & Palm (2008) focuses on alliance formation of a firm within a set of embedded, local ties. They determine the optimal number of partners of these embedded ties and study the choice of the type of partner if the optimal size of the group of alliance partners has not been reached yet, while various types of partners are still willing to join the alliance group. They also discuss the disadvantages of redundant information. The model in the current paper is more general as our extended model allows for a comparison of the quality (i.e. precision) of information obtained from either embedded, local partners or non-local, unembedded partners. It also explicitly accounts for the history of a focal firm’s alliances before turning to others. In addition, the present paper addresses the interaction between uncertainty and redundancy on the dynamics of unembedded tie formation.

INFORMATION FROM EMBEDDED TIES

When a firm uses multiple alliances to jointly explore technologies with more than one partner, it engages in an alliance group with a multitude of partners. Social network terminology refers to this group of partners of a firm as an extended, n-step ego-network. The more this firm and its partners, but also these partners amongst themselves, are connected to each other, the more this generates a densely connected alliance group of firms. This dense group of alliance partners is also characterized by repeated interaction amongst group members during a more extended period of time (Gulati, 1998; Nohria & Garcia-Pont, 1991). Based on experience through previous contacts within a particular group of partners, a firm is expected to select partners for new alliances within this existing group of partners (Gulati, 1998; Gulati & Gargiulo, 1999). This repeated tie effect creates cohesive ties through frequent interaction in a group of cooperating firms (Gomes-Casseres, 1996; Harrigan, 1985; Nohria & Garcia-Pont, 1991).

When a firm invests a substantial amount of time, assets, technology, and human resources to establish these alliances, changing partners in the short run is not very likely due to switching costs and the reputation effect that this might have on other existing relationships with its partners (Chung, Singh & Lee, 2000; Uzzi, 1997). In that context a firm may even experience implicit or explicit social pressure from its partners to replicate its ties to prevent knowledge leakage to firms outside of its existing alliance group (Duysters, Hagedoorn & Lemmens, 2003). Such an expectation of loyalty to current partners can prevent a firm from setting up alliances outside its alliance group as this can create a conflict of interest with its existing partners (Gulati, Nohria & Zaheer, 2000; Nohria & Garcia-Pont, 1991). Competing alliance groups can thus block alternative partnering opportunities for a firm with non-group members (Gomes-Casseres, 1996). As a consequence, such potential partners are excluded from partner selection.

An advantage of building alliances with well connected and trusted partners is the reliance on less costly governance mechanisms in inter-firm transactions. Embeddedness and proximity of partners reduce the size and propensity of equity participation as a control mechanism (Robinson and Stuart, 2007). Therefore, a firm is expected to prefer local search, i.e. it rather replicates its existing ties than search for new partners outside its existing group of partners (Anand & Khanna, 2000; Dyer

& Singh, 1998; Gulati, 1998; Kale & Singh, 1999; Walker et al., 1997). In the context of (joint) technological development and the sharing of technological information, a firm can also use local search to start common R&D projects based on technological characteristics that it shares with its partners (Stuart & Podolny, 1996). An explanation for the relevance of this overlap or similarity in R&D activities for the local search for partners is found in the need to assimilate and understand the technology that a firm develops and shares with its partners (Lane & Lubatkin, 1998; Mowery, Oxley & Silverman, 1996; Rosenkopf & Nerkar, 2001). This similarity encourages further interaction between firms as similarity, interaction and mutual attraction reinforce each other (Brass, Butterfield & Skaggs, 1998). In this context of local search and similarity, firms maintain and replicate ties with each other, which lead to the formation of densely connected alliance groups (Gomes-Casseres, 1996). As these group members focus on similar technologies, local search for partners within this group contributes to the technological competence and information sharing of cooperating group members (Rosenkopf & Nerkar, 2001).

Technological development and uncertainty

We understand technological development to be intrinsically uncertain. This uncertainty is caused by the wide range of technological sources available to firms, the different patterns of diffusion and adoption of particular technological options, and the unstable preferences of consumers and companies (Nelson & Winter, 1982; Rosenberg, 1996). A firm confronted with this technological uncertainty has some notion of the expected direction of technology and the degree of uncertainty surrounding technological development. In that context, one has to think of a firm operating in a technological space, a set of industry-specific technological opportunities which are defined by a technological paradigm (Dosi, 1982). Somewhat similar to Kuhn’s understanding of scientific paradigms (Kuhn, 1977), this technological paradigm generates a broad search model for selected technological problems with which firms are confronted and that provides prescriptions for which directions of technological development to pursue and which to neglect (Dosi, 1982).

Technological paradigms will steer the search process of firms towards an optimal future technology along technological trajectories (Dosi, 1982; Geels, 2002; Nelson & Winter, 1982). These technological trajectories drive technology into particular directions (Breschi, Malerba & Orsenigo, 2000; Rosenberg, 1976). The cumulative nature of these technological trajectories and the set of search procedures are common to a technological community or a set of firms that operate within the same technological paradigm. As a consequence an individual firm has some understanding of the direction of technological development and the heuristics and search procedures for new technologies.

In line with the above, in our model the firm's optimal future technology is reflected by a parameter *T*. Using information that is already available, the firm determines prior expectations about the variable *T*. The precise value of this parameter is unknown, uncertain and not controlled by the firm. The uncertainty surrounding the technology *T* or the lack of knowledge of the technology *T* is reflected by the prior distribution of *T*, which is normal with mean μ and variance σ_T^2: $T \sim N(\mu, \sigma_T^2)$. Hence, μ denotes the expected value of *T* and σ_T^2 reflects the degree of uncertainty a focal firm faces prior to engaging in alliances. The value of μ and σ_T^2 are known to the focal firm and are firm specific. These parameters are affected for instance by a firm's earlier experiences in R&D and they reflect a firm's knowledge base concerning products and technologies. Since these may differ across firms μ and σ_T^2 may be different as well for various companies.

As already well established in the alliance literature (Contractor & Lorange, 2002; Dussauge & Garette, 1999; Gomes-Casseres, 1996; Hagedoorn, 1993; Stuart & Podolny, 1996; Walker, Kogut & Shan, 1997), a firm can set up alliances geared towards joint technology development with its partners to reduce technological uncertainty. The firm's optimization problem is to choose the group of alliances yielding the lowest value for the expected total cost *TC*

$$(1) \qquad TC = b \cdot \sigma_n + c_n ,$$

where $b>0$ and c_n denotes the cost of building its alliance group of size *n*. This equation shows that the expected cost that the firm incurs measured by *TC* depends on the degree of uncertainty which remains after observations are obtained from its partners as given by σ_n. The cost of uncertainty about the technology *T* is an increasing function of σ_n. As a consequence, the firm is inclined to reduce the uncertainty it faces. The idea behind the optimization problem of the firm is that a focal firm selects a certain technology *d* and it is costly if it deviates from the optimal technology *T*. The expected error the firm is likely to make when choosing d is large if the degree of technological uncertainty σ_n the firm faces is high. As a result, the firm has an incentive to learn about the value of T and to reduce the amount of uncertainty surrounding it prior to selecting its choice of d in order to avoid making big mistakes. In appendix A we provide a formal derivation for the objective function presented in equation (1).

Each time the firm forms an alliance with a firm from the group it is embedded in, it obtains an observation x_i. The expected value of x_i equals T. Hence, if the firm obtains an observation x_i this yields some information about the desired future direction of the technology. An observation x_i is normally distributed and its variance is given by σ_x^2. The parameter σ_x^2 reflects the precision of the information contained in observation x_i. If the information is very noisy then σ_x^2 is high. Alternatively, the focal firm may have a limited absorptive capacity due to which it finds it hard to correctly understand the observation. Finally, the information provided by partners may largely be tacit due to which transmission can be very cumbersome, inducing substantial noise.

Two observations x_i and x_j (where $i \neq j$) are positively correlated which is represented by a correlation coefficient $\rho \geq 0$. This means that knowledge obtained from these partners partly overlaps. Hence, to a certain extent observations from these partners are similar. This information overlap may stem from prior interaction between firms through alliances due to which their knowledge bases start to show some similarity (see also Mowery, Oxley & Silverman, 1996).

In the remainder of the paper we assume that the parameters σ_T^2, σ_x^2 and ρ are known to the focal firm. They may be perceived as an assessment of the firm about the uncertainty it faces in its environment, the precision of the information it acquires, and the information overlap of its observations. In reality it may be hard for a firm to pinpoint an estimate for these parameters. However, we conjecture that managers of partnering firms at least have an intuitive understanding of the size of these parameters due to which our stylized optimization problem allows us to describe relevant features of a firm's decision problem when it searches for information through alliances.

Alliance groups and networks

In figure 1 we present a hypothetical symmetrical network of an alliance group, with the focal firm labeled as ‘a’. In this network all firms are equally linked to each other. Here, it is likely that all alliance partners of the focal firm ‘a’ (here b, c, and d) are equally informative, which implies that, in line with the assumptions of our stylized model, the information overlap and accuracy of an observation will be about the same for all of the observations obtained from the firms populating the alliance group.

*** Insert figure 1 about here ***

In reality inter-firm networks are more likely to look like the one depicted in figure 2, which represents an n-step ego-network for each firm plus one node (h) that is not connected to this alliance group. Suppose the focal firm is node ‘a’ again. In this situation the cost of forming a new alliance with some of these alliance group members will differ substantially. For instance, the cost of setting up an alliance with a firm that is close in the network is likely to be relatively low. In particular, alliances with prior ties (partners b, c, and d) are likely to be the least costly ones for the focal firm especially if such firms have built up substantial alliance experience with other firms. Our model can easily accommodate this feature of the network shown in figure 2, by assuming different costs for all possible alliance candidates.

In this network observations are also likely to possess different degrees of information overlap. For instance, firm ‘a’ is well connected to firm ‘b’, but it has no prior ties to firm ‘e’ to which it is indirectly connected. Hence, the degree of information overlap associated with information stemming from ‘b’ is likely to be higher compared to information received from firm ‘e’. Information overlap with firm ‘i’ is even lower. Information overlap with ‘h’ is expected to be zero since firm ‘h’ stands alone. To take account for this, our model can be extended by allowing for different degrees of correlation $corr(x_i, x_j) = \rho_{ij}$. The parameter ρ_{ij} may be assumed to be approximately the same

($\rho_{ij} \approx \rho$) for observations stemming from firms considered to be close to the focal firm and that constitute a group of embedded ties.

*** Insert figure 2 about here ***

We follow Baum et al. (2005) and Sorenson and Stuart (2008) who define embedded or local ties as both prior ties and those indirect ties that are connected to the focal firm by a common party. Unembedded ties are those that do not satisfy these two criteria. A focal firm is not likely to receive useful information through unembedded ties as this information needs to travel a long way through the network from the non-local tie to the focal firm. In figure 2, the focal firm ('a') has six connections to firms that, according to the definition given in the above, are embedded (i.e. b, c, d, e, f and g). In the remainder of this paper, we refer to these cases as type *A* firms. Potential partners that are type B firms, i.e. unembedded and hence non-local partners, are firm 'h' and 'i'. For firm 'a', the network can be characterized by *6A*. As soon as it connects to firm 'h' or 'i', the network can be described as *6A+1B*. Note that the network description is dependent on the focal firm: e.g. if firm 'f' is the focal firm, its network is indicated by *3A*.

At this stage of our analysis we assume that for embedded ties (like b, c, d, e, f and g) the informational features given by ρ and σ_x^2 are the same, though one can imagine that these parameters may differ for prior and indirect ties. We will investigate a more general model in the section on information accuracy, which allows for an assessment of different values for ρ and σ_x^2 for different types of partners.

Alliance groups and information overlap

Based on our understanding of the role of embedded and unembedded ties, we continue with the conjecture that if the firm establishes m alliances within an existing network of partners, that we refer to as alliance group *A*, this yields m observations $x_1, x_2, \ldots, x_m$. The posterior variance of T incorporates all information $x_1, x_2, \ldots, x_m$ obtained from alliance group *A* is given by

(2) $$\sigma_{mA}^2 = \left(\frac{m}{\sigma_x^2(1-\rho) + m\rho\sigma_x^2} + \frac{1}{\sigma_T^2} \right)^{-1}.$$

The derivation of this expression is provided in appendix B. This expression reveals that the uncertainty faced by the focal firm contains a substantial idiosyncratic component. In fact, the first element of the between brackets part of the equation reflects how uncertainty is affected by the partnering efforts of the firm. This implies that if the alliance activities differ substantially across firms, the ex post assessment of technological uncertainty tends to become more heterogeneous. From equation (2) we can see that if the number of ties in alliance group *A* becomes very large, uncertainty reduction becomes very difficult as $\rho>0$. In particular,

(3) $$\lim_{m\to\infty} \sigma_{mA}^2 = \left(\frac{1}{\rho\sigma_x^2} + \frac{1}{\sigma_T^2} \right)^{-1}.$$

This indicates that if no information overlap exists (i.e. $\rho=0$), then uncertainty about *T* could be countered entirely by engaging in a large number of alliances. In fact, equation (3) shows that the variance σ_{mA}^2 becomes zero if the number of alliances *m* is very large in case $\rho=0$. However, if a certain degree of information overlap exists (i.e. $\rho>0$), then it is impossible to obtain certainty concerning the parameter *T*.

Equations (2) and (3) suggest that the participation of a firm in a particular group of alliance partners creates the highest returns in terms of technology observations at the early stages of that network formation. The emerging network environment and the growing abundance of ties increases the probability that the firm will discover and exploit new technological opportunities. The positive effect of an alliance group membership, as described in the above, is based on the replication of preferential relations within a group of partners. However, this positive effect can turn into a paralyzing effect when a firm becomes locked-in and overembedded. The literature also refers to this as relational inertia which occurs when group members are constrained in their partner choice which prohibits them from linking up with outside partners (Gomes-Casseres, 1996; Uzzi, 1997). Our model shows that embeddedness becomes a liability if uncertainty reduction is important. Increased embeddedness in combination with redundancy reduces the ability of the current alliance group to provide a flow of useful novel ideas allowing for further uncertainty reduction which at some point necessitates the search for partners outside the established alliance group.

AN ADDITIONAL EMBEDDED TIE VERSUS AN UNEMBEDDED TIE

In this section we address the question under which conditions it is either optimal for a firm to stay exclusively within a certain group of embedded ties or to also link up with firms outside its existing alliance group. If the firm builds an alliance with an unembedded, non-local tie (i.e. nodes ‘h’ or ‘i’ in figure 2), the information obtained from this new alliance does not show overlap with observations derived from its existing alliance group. An additional distant tie, such as node ‘i’, is to be considered as an equally non-embedded tie as an alliance with ‘h’ because this new alliance is not built on the existing ties within the firm’s existing alliance group. In statistical terms this means that this observation for ‘i’ or ‘h’ is uncorrelated with the observations obtained from previous alliances. This notion reflects the idea that non-local partners, i.e. distant or unconnected partners, may yield new and innovative information.

In empirical network studies, distant partners are identified by measuring the geodesic path length between network members. The geodesic path length is the shortest path connecting any two nodes in the network. Firms with high distance according to the geodesic path length may be considered non-local firms in terms of our model as well. What is important is that firms with a high distance or firms that are unconnected have a low information overlap with firms to which a focal firm is closely connected and hence they are non redundant ties. For instance, firms ‘h’ and ‘i’ in figure 2 may satisfy this condition. Therefore, in principle embeddedness does not have to be a dichotomous variable in the sense that an unembedded firm has to be completely unconnected to the focal firm through other firms, as is the case for firm ‘h’. Firm ‘i’, which is at considerable distance from focal firm ‘a’, could also qualify as an unembedded tie.

An alliance with such a non-local firm yields an observation y, which is normally distributed with mean T and variance σ_y^2.[1] If the firm establishes alliances with m firms from its existing alliance group, i.e. alliance group A, and one alliance with a non-local tie, its new alliance group is indicated by $mA + 1B$.[2] It follows straightforwardly that the variance of the parameter T after establishing $mA + 1B$ is equal to

$$(4) \qquad \sigma^2_{mA+1B} = \left(\frac{m}{\sigma_x^2 (1 + (m-1)\rho)} + \frac{1}{\sigma_T^2} + \frac{1}{\sigma_y^2} \right)^{-1} .$$

Suppose now that an alliance group consists of m firms of type A. The expected net change of the loss due to adding one alliance of type A equals $L_{A|mA} = b \cdot \sigma_{(m+1)A} - b \cdot \sigma_{mA} + c_{A|mA}$ where $c_{A|mA}$ denotes the marginal cost to be made when expanding the alliance group of size m by one alliance with a type A firm. In principle the cost of adding a tie from alliance group A may vary with the number of prior ties and hence does not have to be same for each additional tie. In line with equation (2): $\sigma^2_{(m+1)A} = \left(\frac{m+1}{\sigma_x^2 (1 + m\rho)} + \frac{1}{\sigma_T^2} \right)^{-1}$. Marginal costs have to be distinguished from total costs c_{mA+1B} for setting up a group consisting of m alliances of type A firms and one alliance with a type B firm, characterized as a non-local tie. This expansion of the alliance group is sensible if $L_{A|mA}<0$. If $L_{A|mA}=0$, then the alliance group has reached the optimal number of type A firms. The expected net change of the loss function as a result of adding a type B firm rather than a type A firm equals $L_{B|mA} = b \cdot \sigma_{mA+1B} - b \cdot \sigma_{mA} + c_{B|mA}$ where $c_{B|mA}$ denotes the marginal cost of adding a type B firm to the alliance group of m type A firms. The cost of adding a type B firm may depend on the number of prior ties. The expected benefit from the expansion of the alliance group is determined by the reduction of uncertainty, measured by the change in the posterior variance. When $L_{A|mA}<0$ and $L_{B|mA}<0$, the decision to add a type A firm and the decision to expand the alliance group with a type B firm (or equivalently to set up a new group with one type B firm) are both sensible. Adding a type B firm to the alliance group rather than a type A firm may be desirable even when $L_{A|mA}<0$, if $L_{B|mA} <0$ and $L_{B|mA} <L_{A|mA}$. The latter condition holds if $b \cdot \sigma_{mA+1B} + c_{B|mA} < b \cdot \sigma_{(m+1)A} + c_{A|mA}$. Hence, to assess whether m observations from alliance group A and one observation based on an unembedded tie with a type B firm are more desirable than m+1 observations from embedded ties in alliance group A, the firm should calculate

(5) $$L = b \cdot \left(\sigma_{mA+1B} - \sigma_{(m+1)A}\right) + c_{B|mA} - c_{A|mA},$$

where L compares, on the one hand, the features of information obtained from the two different decisions, as given by $\sigma_{(m+1)A}$ and σ_{mA+1B}, whereas, on the other hand, the focal firm evaluates the costs associated with these different options. These costs are given by $c_{B|mA}$ and $c_{A|mA}$. It is optimal to switch to a non-local, unembedded partner if $L < 0$. In that case the net value of information obtained from a distant or unconnected partner is higher than the value associated with information obtained from embedded, local alliance partners.[3]

In line with the literature on alliance formation, our model incorporates the idea that for a focal firm the cost of setting up a distant or unconnected, i.e. unembedded, non-local, alliance is higher than the costs of an additional alliance with a firm from its present, closely connected alliance group (i.e. $c_{B|mA} > c_{A|mA}$) for three main reasons. First, as explained in the previous section, it is likely that building up an additional alliance with a firm that is already well connected within the focal firm's existing alliance group involves relatively low search costs. Also, through referral, other partners may hint at valuable alliance contacts within the existing alliance group. Second, by turning to a new distant partner through an unembedded tie, the focal firm may compromise its alliances with firms from its existing alliance group. Such alliances may have been set up under the assumption that a firm will not turn to other firms to avoid valuable information leaks to firms that may harm the competitive position of firms in the present alliance group. Given the already substantial costs of alliances (Gulati, 1995; Kale & Singh, 1999), maintaining the existing alliances, while also engaging in an alternative alliance, will ask additional managerial effort from the focal firm to maintain or rebuild trust (Mesquita, 2007). Hence, these efforts will create additional costs for the firm in order to continue its relationships with its 'older' partners (Gomes-Casseres, 1996; Parkhe, 1993).[4] Third, alliances with embedded, local ties are likely to involve less costly governance mechanisms. Trust between well connected partners reduces the need for extensive control mechanisms based on equity (Robinson and Stuart, 2007). Furthermore, contracting costs between embedded ties are likely to be small because trust between these ties ensures that payoffs will be distributed equally between partners (Uzzi, 1997).

PREFERENCE FOR AN UNEMBEDDED TIE

In the previous section we observed that it is likely that the costs of establishing an alliance with a distant or unconnected, non-local firm are higher than the costs of forming an additional tie with a firm from the current alliance group of a focal firm: $c_{B|mA} > c_{A|mA}$. Due to this, from an informational point of view, allying with an unembedded, non-local tie becomes a viable option only if the information yields a more precise estimate of the desired future technology than an observation from a new, indirectly connected, partner in a firm's existing alliance group. However, at some point the firm's alliance group may become over-embedded. Our model indicates that this happens if changing to an alliance with an unembedded firm (a type *B* firm) yields a net benefit and the higher cost of an alliance with this firm is compensated with the more precise estimate of the parameter *T*: $\sigma_{mA+1B} < \sigma_{(m+1)A}$. This is the case if

$$(6) \qquad \sigma_y^2 < \sigma_x^2 \frac{(1+m\rho)(1+(m-1)\rho)}{1-\rho}.$$

An interesting feature of the condition presented in the above equation is that it may even be satisfied if information obtained from the unembedded tie contains more noise than information received from a firm belonging to the present alliance group (i.e. $\sigma_y^2 > \sigma_x^2$) because

$\sigma_x^2 < \sigma_x^2 \frac{(1+m\rho)(1+(m-1)\rho)}{1-\rho}$. This possibility becomes more likely the higher the degree of redundancy in the current alliance group as measured by ρ, since the right hand side of equation (6) increases with ρ. A firm may be willing to form an unembedded tie even if information obtained from that firm is less accurate ($\sigma_y^2 > \sigma_x^2$). This result reflects that an alliance with a distant or unconnected firm (a type *B* firm) yields information that does not overlap with information obtained previously from firms in alliance group *A* and hence provides the focal firm with valuable new innovative information.

One issue that is likely to affect the choice for staying in a certain group of partners or to engage in alternative alliances outside this alliance group refers to the degree of technological information overlap between current members (Mowery, Oxley & Silverman, 1998). To address this topic we determine how the firm's decision rule given by equation (5) is affected by the parameter ρ in our model. It reflects the information similarity of the observations obtained from the alliances due to overlap of for instance knowledge and technology amongst the firms in an alliance group. We find after some straightforward derivations that[5]

$$(7) \qquad \frac{\partial L}{\partial \rho} = \frac{bm}{2\sigma_x^2}\left(\frac{\sigma_{mA+1B}^3(m-1)}{\left(1+(m-1)\rho\right)^2} - \frac{\sigma_{(m+1)A}^3(m+1)}{(1+m\rho)^2}\right) < 0.$$

This expression indicates that if ties are partly redundant (the observations obtained from the current alliance group are correlated) it is more likely the focal firm will choose an unembedded tie. Empirical findings by Mowery et al. (1998) indicate that firms prefer repeated ties with previous partners with which they share a technological information overlap which then leads to an increased post-alliance overlap. However, as also found in that research, if the technological information overlap of partners increases further, it has a curvilinear, inverted U-shaped, effect on future alliance formation between these firms.

We also find that with higher uncertainty it is probably desirable to select an unembedded, non-local partner since

$$(8) \qquad \frac{\partial L}{\partial \sigma_T^2} = \frac{b}{2\sigma_T^4}\left(\sigma_{mA+1B}^3 - \sigma_{(m+1)A}^3\right) < 0.$$

With lower levels of technological uncertainty, when a firm has a clear perspective on the relevant technological trajectory, based on the observations made from within its alliance group, there is little need to engage in new alliances with firms outside its alliance group (Rowley, Behrens & Krackhardt, 2000). However, with increasing levels of technological uncertainty, when a firm is confronted with an increasing number of alternative technological trajectories (Bower & Christensen, 1995; Burgelman & Grove, 1996; Tushman & O'Reilly, 1996), new partners outside a firm's existing alliance group might create better opportunities than those provided by repeated ties with an extant group of partners (Beckman et al., 2004). As such this may have a negative effect on the attractiveness of alliances in an existing group, which can lead towards a more outward orientation in partner selection as a firm embedded in an alliance group may look for new opportunities outside this existing group. This argument is reflected in Rowley et al. (2000), where it is argued that a high network density of ties with a small set of long-term partners is not positive for a firm operating in a technologically uncertain environment when it is interested in widening its technological options. This point also echoes the ‘structural holes’ argument made by Burt (1992) which we interpret in terms of the benefits for a firm that forms bridges among previously unconnected parts of the overall alliance network as it gains access to new and non-redundant information about new technological trajectories. Also, Park & Ungson (1997) found that firms operating in dense networks (or alliance groups in our terminology) within the US electronics industry were more inclined to enter into alliances with new partners, outside their existing alliance group, which would offer new opportunities for their collaborative efforts.

According to our model there is an interaction effect between the degree of redundancy ρ and the degree of uncertainty σ_T^2 faced by the firm. We find that:[6]

$$\frac{\partial^2 L}{\partial\rho\partial\sigma_T^2}=\frac{3bm}{2\sigma_T^4\sigma_x^2}\left(\frac{\sigma_{mA+1B}^5(m-1)}{(1+(m-1)\rho)^2}-\frac{\sigma_{(m+1)A}^5(m+1)}{(1+m\rho)^2}\right)<0. \tag{9}$$

This result implies that, if redundancy increases, the effect of uncertainty on the desirability of tying with a distant or unconnected, unembedded partner (a type *B* firm) becomes stronger. For instance, if the degree of redundancy is very minor among the participants in the alliance group of a focal firm, then a higher degree of uncertainty will hardly affect the desirability of forming an alliance with an unembedded firm. Obviously, this reflects the idea that the need to establish an unembedded tie is low when local ties can provide non-redundant information. Then, even with high uncertainty the firm is likely to establish an alliance with a relatively close tie or local partner, because it is less costly. Similarly, the higher the degree of uncertainty, the stronger the effect of redundancy on the information benefits of a distant or unconnected partner. So with a very high degree of uncertainty a firm is inclined to form unembedded ties even if the degree of redundancy is moderate. This indicates that a firm is more likely to avoid redundancy in its alliance group if the uncertainty it faces is high. These results indicate that the effects of uncertainty and information redundancy on unembedded tie formation are contingent. We find that there are first order effects according to the findings depicted in equation (7) and (8). However, second order effects as found in equation (9) may explain why the effects of uncertainty and or redundancy may vary across firms even within an industry if the characteristics of an alliance group of a firm vary with respect to information redundancy or if technological uncertainty faced by a firm contains an idiosyncratic component. Theoretically, these results provide an explanation why some firms within an industry are more inclined to form bridging ties outside their alliance group than others.

INFORMATION ACCURACY

We now investigate to what extent our previous results depend on the accuracy of information provided by the different types of partners. As before, we consider a focal firm that has prior information concerning a technology T. The precise value of this parameter is uncertain and normally distributed with mean μ and variance σ_T^2: $T \sim N(\mu, \sigma_T^2)$. This prior distribution reflects the knowledge of the firm before it engages in alliances. Next, we assume that the firm has already established one alliance and that the information resulting from this alliance is given by a univariate variable z, which is normally distributed with mean T and variance σ_z^2. This variable z can also be thought of as the average of the observations obtained from embedded, previous alliances of the focal firm. We adopt a univariate setting in this section to facilitate tractability of the derivations.

The focal firm faces two options. First, it can enter an alliance through a direct or indirect embedded tie. This yields an observation x which is normally distributed with mean T and variance σ_x^2. However, the variables x and z are correlated with correlation coefficient ρ. Hence, the parameter ρ reflects a certain degree of redundancy due to the formation of an embedded alliance. Secondly, it can form an alliance through an unembedded tie and this yields an observation y which is normally distributed with mean T and variance σ_y^2. The variables y and z are uncorrelated.[7] One advantage of the model presented in this section is that it can be used to investigate the benefits of a range of different partners. Hence, we can deal here with different potential partners that might have different values for σ_x^2, σ_y^2, ρ (and ρ^*, which we define later as the correlation between y and z).

The posterior variance after the observation obtained from the embedded, local tie (i.e. x) is

(10) $$\sigma^2_{x+z} = \left(\frac{\sigma_z^2 - 2\rho\sigma_x\sigma_z + \sigma_x^2}{\left(1-\rho^2\right)\cdot\sigma_x^2\sigma_z^2} + \frac{1}{\sigma_T^2} \right)^{-1}$$

Note that equation (10) is a generalization of equation (2) in case *m*=2, because the variance of *z* differs from the variance of *x*. Equation (10) is identical to (2) in case *m*=2 and $\sigma_x = \sigma_z$.

The posterior variance if the firm obtains an observation from an unembedded tie (i.e. *y*) is

(11) $$\sigma^2_{y+z} = \left(\frac{\sigma_z^2 + \sigma_y^2}{\sigma_y^2\sigma_z^2} + \frac{1}{\sigma_T^2} \right)^{-1}$$

Note that equation (11) is a special case of equation (4) if *m*=1 and $\sigma_x = \sigma_z$.The firm will prefer a non-local tie if, analogous to equation (5),

(12) $$L = b\cdot\left(\sigma_{y+z} - \sigma_{x+z}\right) + c_{y|z} - c_{x|z} < 0,$$

where *L* compares the features of information obtained from the two different decisions, as given by σ_{y+z} and σ_{x+z}, with the costs associated with these different options: $c_{y|z}$ and $c_{x|z}$. It is optimal to switch to a non-local, unembedded partner if $L < 0$. We first investigate how the degree of information overlap affects the preference for *y* (i.e. an unembedded tie) or *x* (i.e. an embedded tie). We find that

(13) $$\frac{\partial L}{\partial \rho} \propto -\left(\frac{\sigma_x}{\sigma_z} - \rho\right)\left(\frac{\sigma_z}{\sigma_x} - \rho\right)$$

This equation implies that if variable *z* and *x* are equally precise ($\sigma_z \approx \sigma_x$,), then $\frac{\partial L}{\partial \rho} < 0$. This means that in that case a higher degree of information overlap measured by ρ induces the firm to prefer an observation from the set of unembedded ties as indicated by *y*. However, if *z* or *x* is much more precise than the other one (either $\sigma_z >> \sigma_x$ or $\sigma_z << \sigma_x$), then $\frac{\partial L}{\partial \rho} > 0$ and a higher degree of redundancy will make the firm prefer an either direct or indirect embedded tie (i.e. *x*). Our finding indicates that if one of the sources of information (*x* or *z*) is very precise, a higher degree of correlation between *x* and *z* is beneficial, because the overall accuracy of the combination of *x* and *z* improves with a higher degree of information overlap. We also note that equation (13) indicates that if $-1 < \rho < 0$, the right-hand side is negative. This implies that if a new partner from the set of embedded ties yields some information that contradicts previous information (i.e. z), then this tie becomes more beneficial.

As in our previous analysis we find that higher uncertainty increases the benefits of an unembedded tie (i.e. y) since it yields non-redundant information:[8]

$$\frac{\partial L}{\partial \sigma_T^2} = \frac{b}{2\sigma_T^4}\left(\sigma_{yz}^3 - \sigma_{xz}^3\right) < 0. \tag{14}$$

We also find that the interaction between redundancy and uncertainty depends on the relative size of the information accuracy given by σ_z/σ_x:

$$\frac{\partial^2 L}{\partial \sigma_T^2 \partial \rho} \propto -\left(\frac{\sigma_x}{\sigma_z} - \rho\right)\left(\frac{\sigma_z}{\sigma_x} - \rho\right) \tag{15}$$

This equation reflects once more that the benefits of redundancy depend on the accuracy of information sources.

Throughout this section we assumed that an unembedded tie (i.e. y) yields non-redundant information. In the above we can also introduce a nonzero correlation between y and z measured by ρ^*. The results in equations (13)-(15) would not be affected. In addition, we would be able to show that $\frac{\partial L}{\partial \rho^*} \propto \left(\frac{\sigma_y}{\sigma_z} - \rho^*\right)\left(\frac{\sigma_z}{\sigma_y} - \rho^*\right)$; and that $\frac{\partial^2 L}{\partial \sigma_T^2 \partial \rho^*} \propto \left(\frac{\sigma_y}{\sigma_z} - \rho^*\right)\left(\frac{\sigma_z}{\sigma_y} - \rho^*\right)$. Hence, the benefits of unembedded ties or non-local alliances (i.e. y) also depend on the relative accuracy y and z. If the accuracy is similar, then observation y become less attractive if redundancy measured by ρ^* increases. However, if the accuracy of z (i.e. σ_z^2) and y (i.e. σ_y^2) differ substantially, a higher degree of redundancy (i.e. a higher ρ^*) is beneficial for forming an unembedded, non-local alliance.

DISCUSSION AND CONCLUSIONS

The model that we developed in the above generates a number of interesting new results that are consistent with, yet elaborating on stylized facts regarding the uncertainty of technology development, inter-firm alliances, the information value of ties and, the level of accuracy and redundancy of these ties. As already indicated in the individual sections, these theoretical findings are relevant in the context of the literature on alliances and inter-firm networks with some clear implications for the understanding of the particular choices that a firm makes when it sets up a new alliance.

Given the uncertainty of technological development surrounding firms, a firm operating in such an environment can use alliances through which it gathers information, undertakes joint R&D, and develops new technologies with its partners, to reduce this technological uncertainty. By setting up multiple alliances a firm creates an alliance group for which it is expected to choose an optimal configuration with the lowest possible cost for setting up this multiple partner group. When firms form alliances with the same group of partners during an extended period of time, they and their partners establish a cohesive alliance group characterized by repeated ties, local search for partners, and shared technological resources with technological information overlap and a significant degree of technological similarity of partners in this alliance group of embedded ties. Under these conditions, it pays for an individual firm to reduce the technological uncertainty with which it is confronted by entering into an additional alliance through a tie with a partner from this already well-embedded alliance group. However, it may also be beneficial for a firm to enter into an alliance with a non-local partner, if that partner yields more precise new information on the relevant technology than could be obtained from an embedded partner.

Once a firm becomes embedded in its alliance group, it faces two major limitations when it comes to choosing new partners. One limitation follows from the consequences of over-embeddedness. In that case, a cohesive group of partners can gradually create lock-in effects through which a firm is restricted in choosing a new non-local partner outside its alliance group due to peer pressure for continued local search based on group loyalty. In terms of our model this peer pressure could be reflected in higher costs of forming an unembedded tie. The other limitation follows from long-term technology cooperation within the same group of partners. Due to this long-term technology cooperation, the technological profiles of firms converge, learning opportunities from partners diminish and firms begin to suffer from some degree of technological inflexibility which will ultimately block their view on interesting new technological opportunities that may very well lie outside their existing alliance group.

Our model indicates that, given relatively low search costs for additional local alliances, a firm will ‘ceteris paribus’ prefer to enter into an additional local tie. It is only worthwhile for a firm to establish an alliance with a non-local partner when the value of the information regarding technological development, obtained through this non-local alliance, outweighs the cost advantage of finding an additional embedded partner. However, we also find that if the information obtained from embedded ties is largely redundant or very similar, a focal firm may turn to alliances with non-local partners even if the information obtained from these unembedded ties is less precise. This result, which highlights one of our new theoretical insights, indicates that at some point a firm is willing to exchange precise but redundant information for inaccurate but novel information.

The level of technological uncertainty that a firm faces also has an impact on its preference for setting up either an alliance with a local partner or establishing an alliance with a new, non-local partner. Our model indicates that the higher the level of technological uncertainty in the environment of a firm, the more a firm should consider entering into an alliance with a new, non-local partner instead of forming an embedded alliance. The degree to which local partners are redundant, i.e. the degree to which technology observations gained through alliances are correlated, has a positive effect on the decision of a firm to enter into a new alliance with a non-local, unembedded partner.

Another new theoretical insight from our analysis is that we show that the choice for a non-local partner depends on the interaction between technological uncertainty and the information overlap or redundancy of partners. The benefits of choosing an unembedded partner increases with higher uncertainty, but only if redundancy among the alliance group members is substantial. Similarly, a higher degree of partner redundancy increases the benefits if a firm opts for a non-local tie, but only if the degree of uncertainty is high. This interaction between uncertainty and redundancy implies that the effect of uncertainty on the utility of non-local tie formation is firm specific. The effect depends on the focal firm’s group of alliance partners and in particular its degree of redundancy. Also, the effect of redundancy on tie formation through the set of unembedded ties may vary with the firm if technological uncertainty contains a firm specific component. Hence, the evolution of alliance groups within a certain industry may be very different, depending on the history of alliances of particular firms as this shapes the degree of uncertainty and technological information redundancy among the firms in these alliance groups.

The Bayesian learning model we employ allows us to investigate the role played by information accuracy on the benefits of information overlap. If information from a previous tie and information from both an embedded or an unembedded tie are equally accurate, then when these information sources exhibit overlap, the combination of these two sources of information deteriorates the precision of the estimate of the desired future technology. In addition, the model we advance in this paper reveals that if the information provided by previous ties is much more accurate than the information from an embedded or an unembedded alliance or vice versa, redundancy improves the precision of the estimate of the desired future technology if the two sources of information are integrated. Hence, information redundancy matters for the learning performance of a firm through alliances. Our analysis indicates that an empirical study of the effect of information redundancy of alliances on innovative performance should also incorporate data concerning the accuracy of information provided by alliances. This accuracy is a crucial determinant of whether redundancy is beneficial for a firm or not. Empirical work on information redundancy may also benefit from incorporating uncertainty faced by the firm as a contingency factor as we have shown that the effect of redundancy depends on the degree of uncertainty encountered by the firm.

A natural extension of the framework adopted in this paper, that would however go beyond the scope of the current contribution, could consist of allowing for an alternative technological paradigm with major technological changes over time. Technology could be assumed to be either shaped through R&D by firms in a particular alliance group or to be truly exogenous to that group. In the latter case, firms within that group might have an additional incentive to form alliances with firms involved in developing the new technology based on an alternative technological paradigm. What matters then is the type and amount of information on the radically new technology that the focal firm receives from local and non-local partners and the costs at which this information is obtained. Major changes in technology through alternative trajectories based on a new technological paradigm then induce the focal firm to focus on alliances that provide access to these alternative technological developments. Another interesting avenue for further research concerns the question how learning opportunities derived from embedded and unembedded ties, as considered in this paper, affect the dynamics and structure of the overall network. As with the other potential extension of our framework, we leave this interesting topic for future theoretical and empirical work.

REFERENCES

Ahuja, G. 2000. Collaboration networks, structural holes and innovation: A longitudinal study. *Administrative Science Quarterly,* **45**, 425-455.

Anand, B.N. & Khanna, T. 2000. The structure of licensing contracts. *Journal of Industrial Economics*, **48,** 103-135.

Baltagi, B. 1995. *Econometric analysis of panel data*. Chichester (UK): Wiley.

Baum, J.A.C., Rowley, T.J., Shipilov, A.V. & Chuang Y.T. 2005. Dancing with strangers: aspiration performance and the search for underwriting syndicate partners. *Administrative Science Quarterly,* **50**, 536-575.

Beckman, C.M., Haunshild, P.R. & Phillips, D.J. 2004. Friends or strangers? Firm-specific uncertainty, market uncertainty, and network partner selection, *Organization Science*, **15**, 259-275.

Bower, J.L. &. Christensen, C.M. 1995. Disruptive technologies: Catching the wave. *Harvard Business Review*, **73** (1), 43-54.

Brass, D.J., Butterfield, K.D. & Skaggs, B.C. 1998. Relationships and unethical behavior: A social network perspective, *Academy of Management Review*, **23** (1), 14-31.

Breschi, S., Malerba, F. & Orsenigo, L. 2000. Technological regimes and Schumpeterian patterns of innovation. *The Economic Journal*, **110,** 388-410.

Burgelman, R.A. & Grove, S.A. 1996. Strategic dissonance. *California Management Review*, **38** (2), 8-28.

Burt, R.S. 1992. *Structural holes – The social structure of competition*. Cambridge, MA: Harvard University Press.

Chung, S.A., Singh, H. & Lee, K. 2000. Complementarity, status similarity and social capital as drivers of alliance formation. *Strategic Management Journal*, **21,** 1-20.

Cohen, W.M., & Levinthal, D. 1990. Absorptive capacity: a new perspective on learning and innovation. *Administrative Science Quarterly,* 35, 128-152.

Contractor, F.J. & Lorange, P. (eds.) 2002. *Cooperative strategies and alliances*. Oxford (UK): Elsevier.

DeGroot, M.H. 1970. *Optimal statistical decisions.* New York: McGraw-Hill.

Dosi, G. J. 1982. Technological paradigms and technological trajectories. *Research Policy*, **11,** 147-162.

Dussauge, P.& Garrette, B. 1999. *Cooperative strategy: Competing successfully through strategic alliances*. New York: Wiley.

Duysters, G., Hagedoorn, J. & Lemmens, C. 2003. The effect of alliance block membership on innovative performance. *Revue d'Economie Industrielle*. **103,** 59-70.

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

Foster, R.N. 1986. *Innovation: The attacker's advantage*, New York: Summit Books.

Gargiulo, M. & Benassi, M. 2000. Trapped in your own net? Network cohesion, structural holes and the adaptation of social capital. *Organization Science*, **11** (2), 183-196.

Geels, F.W. 2002. Technological transition as evolutionary reconfiguration processes: A multi-level perspective and a case-study. *Research Policy*, **31,** 1257-1274.

Gomes-Casseres, B. 1996. *The alliance revolution: The new shape of business rivalry*. Cambridge, MA: Harvard University Press.

Gulati, R. 1995. Social structure and alliance formation patterns: A longitudinal analysis. *Administrative Science Quarterly*. **40,** 619-652.

Gulati, R. 1998. Alliances and networks. *Strategic Management Journal*. **19** 293-317

Gulati, R.& Gargiulo, M. 1999. Where do inter-organizational networks come from? *American Journal of Sociology*, **104,** 1439-1493.

Gulati, R., Nohria, N. & Zaheer, A. 2000. Strategic networks. *Strategic Management Journal*, **21,** 203-215.

Hagedoorn, J. 1993. Understanding the rationale of strategic technology partnering: Interorganizational modes of cooperation and sectoral differences. *Strategic Management Journal*, **14,** 371-385.

Hagedoorn, J. 2006. Understanding the cross-level embeddedness of interfirm partnership formation. *Academy of Management Review*, **31,** 670-680.

Harrigan, K. 1985. *Strategies for joint ventures*. Lexington, MA: Lexington Books.

Kale, P. & Singh, H. 1999. Building alliance capabilities: A knowledge-based approach. *Academy of Management Best Paper Proceedings*, Chicago, IL.

Kuhn, T.S. 1977. *The essential tension*. Chicago, IL: Chicago University Press.

Lane, P.J. & Lubatkin, M. 1998. Relative absorptive capacity and interorganizational learning. *Strategic Management Journal*, **19**, 461-477.

Letterie, W., Hagedoorn, J., van Kranenburg, H., Palm, F. 2008. Information gathering through alliances, *Journal of Economic Behavior and Organization*, **66**, 797-819

Leonard-Barton, D. 1995. *Wellsprings of knowledge*. Cambridge, MA: Harvard Business School Press.

Mesquita, L.F. 2007. Starting over when the bickering never ends: Rebuilding trust among clustered firms through trust facilitators, *Academy of Management Review*, **32,** 72-91.

Mowery, D.C., Oxley, J.E. & Silverman, B.S. 1996. Strategic alliances and interfirm knowledge transfer. *Strategic Management Journal*, **17,** 77-91, Winter Special issue

Mowery, D.C., Oxley, J.E. & Silverman, B.S. 1998. Technological overlap and interfirm cooperation: Implications for the resource-based view of the firm. *Research Policy* **27,** 507-523.

Nelson, R. R.& Winter, S.G. 1982. *An evolutionary theory of economic change*. Cambridge, MA: Harvard University Press.

Nohria, N.& Garcia-Pont, C. 1991. Global strategic linkages and industry structure. *Strategic Management Journal*, **12,** 105-124.

Parkhe, A. 1993. Strategic alliance structuring: A game theoretic and transaction cost examination of interfirm cooperation. *Academy of Management Journal*, **36,** 794-829.

Park, S.H. & Ungson, G.R. 1997. The effect of national culture, organizational complementarity and economic motivation on joint venture dissolution. *Academy of Management Journal*, **40,** 279-307.

Podolny, J.M. 1994. Market uncertainty and the social character of economic exchange. *Administrative Science Quarterly,* **39,** 458-483.

Powell, W.W., Koput, K., & Smith-Doerr, L. 1996. Interorganizational collaboration and the locus of innovation: Networks of learning in biotechnology. *Administrative Science Quarterly,* **41,** 116-145.

Powell, W.W., White, D.R., Koput, K., & Smith-Doerr, L. 2005. Network dynamics and field evolution: the growth of interorganizational collaboration in the life sciences. *American Journal of Sociology*, **110,** 1132-1205.

Robinson, D.T., & Stuart, T.E. 2007. Network effects in the governance of strategic alliances. *Journal of Law Economics and Organization,* **23,** 242-273.

Rosenberg, N. 1976. *Perspectives on technology*, Cambridge (UK), Cambridge University Press.

Rosenberg, N. 1996. Uncertainty and technological change. In R. Landau, R. Taylor, G. Wright, eds. *The mosaic of economic growth* Stanford, CA: Stanford University Press. 334-355.

Rosenkopf, L. & Nerkar, A. 2001. Beyond local search: Boundary-spanning, exploration, and impact in the optical disk industry. *Strategic Management Journal,* **22,** 287-306.

Rowley, T., Behrens, D. & Krackhardt, D. 2000. Redundant governance structures: An analysis of structural and relational embeddedness in the steel and semiconductor industries. *Strategic Management Journal*, **21,** 369-386.

Saxton, T. 1997. The effects of partner and relationship characteristics on alliance outcomes. *Academy of Management Journal,* **40,** 443-461.

Sorenson, O. & Stuart, T.E. 2008. Bringing the context back in: Settings and the search for syndicate partners in venture capital investment networks. *Administrative Science Quarterly,* **53,** 266-294.

Stuart, T.E.& Podolny, J.M. 1996. Local search and the evolution of technological capabilities. *Strategic Management Journal,* **17,** 21-38.

Tushman, M.L. & O'Reilly, C.A. 1996. Ambidextrous organizations: Managing evolutionary and revolutionary change. *California Management Review*, **38** (4), 8-30.

Uzzi, B. 1997. The social structure and competition in interfirm networks: The paradox of embeddedness. *Administrative Science Quarterly,* **42,** 35-67.

Walker, G., Kogut, B. & Shan, W. 1997. Social capital, structural holes and the formation of an industry network. *Organization Science*, **8** (2), 109-125.

Wasserman, S. & Faust, K. 1994. *Social network analysis, methods and applications*. Cambridge (UK): Cambridge University Press.

Whittington, K.B., Owen-Smith, J. & W.W. Powell. 2009. Networks, propinquity and innovation in knowledge-intensive industries. *Administrative Science Quarterly,* Forthcoming

Figure 1 An alliance group as a symmetrical network of connected alliance partners

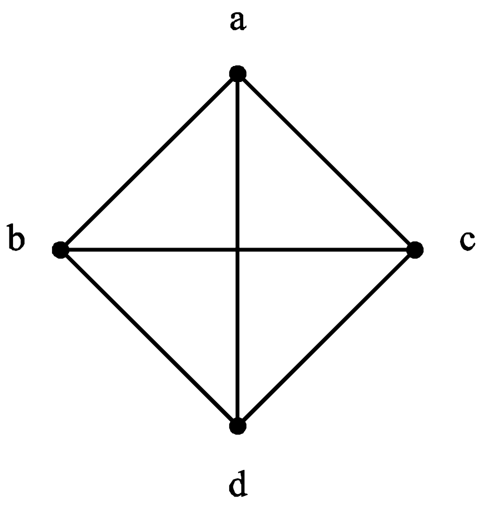
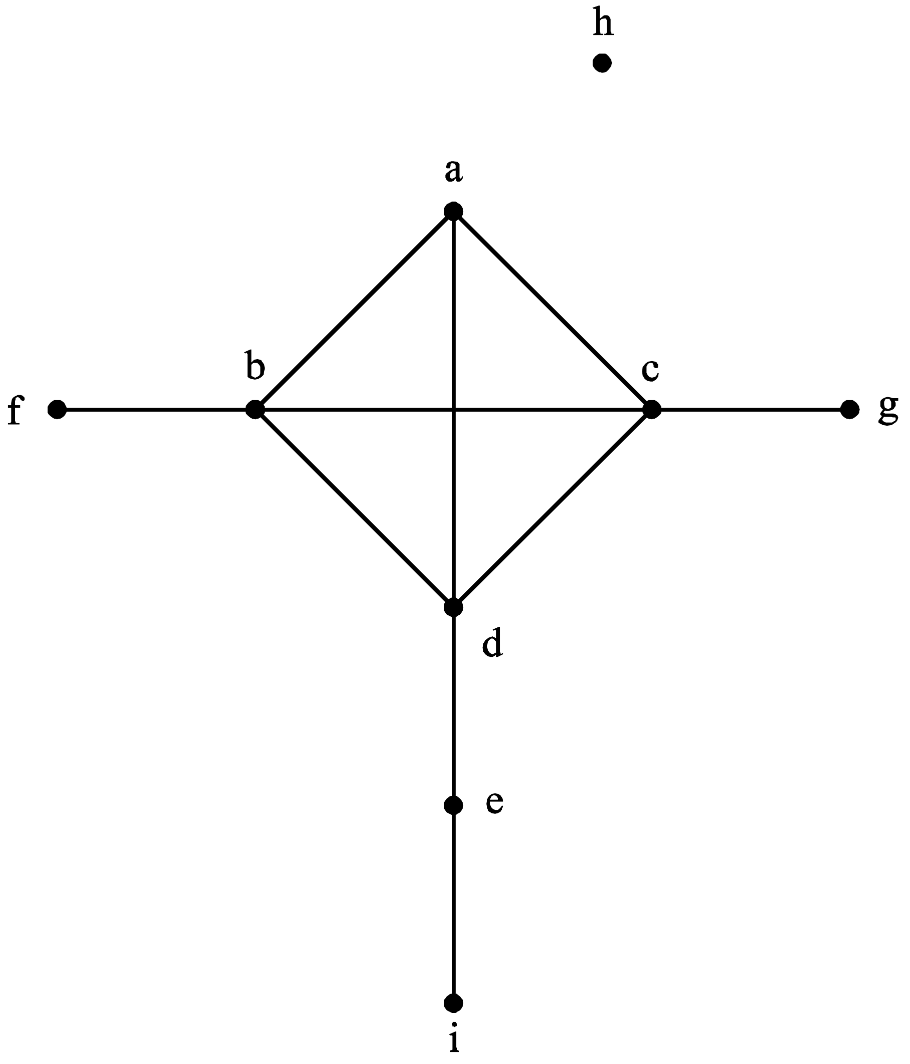


Figure 2 An alliance group as an extended network of directly and indirectly connected alliance partners (with one unconnected firm)



Appendix A

Derivation of Equation (1)

Suppose the technological direction ultimately chosen by the firm is given by the decision parameter d, where it is costly to implement a technology d that does not match T. The costs, when choosing d, are given by $C(T,d)=a|T-d|$, $a>0$. A quadratic cost function could be used as an alternative. The costs are influenced by the extent to which the technology d chosen by the firm fits with the unknown optimal technology represented by the parameter T. The firm minimizes the expected value of $C(T,d)$ by choosing d^{opt}, which is determined by $\min_{d} \underset{T}{E}\, C(T,d)$,where E denotes the expectations operator with respect to T. If T were known with certainty, it is obviously optimal to select $d=T$. However, T is unknown and uncertain. The firm's optimal direction d^{opt} solves $\min_{d} \underset{T,n}{E}\, C(T,d)$. The n under the expectations operator denotes that d is chosen, using the posterior distribution of T after obtaining observations from its environment indicated by n. The firm has the opportunity to collect information about the properties of T by forming alliances with other firms. The observations obtained by the focal firm from its partners are jointly normally distributed with mean T and a particular covariance structure that we depict in sections 2 and 3. Then the posterior distribution of T is normal with mean μ_n and variance σ_n^2 and therefore it is symmetrically distributed around its mean. As a consequence, the optimal strategy of the firm is, given its posterior distribution, given by $d^{opt}=\mu_n$, i.e. the expected value of T. Following DeGroot (1970: 233), the minimized value of $\min_{d} \underset{T,n}{E}\, C(T,d)$ is given by

$\min_{d} \underset{T,n}{E}\, C(T,d) = a\sqrt{\frac{2\sigma_n^2}{\pi}} = b \cdot \sigma_n$. In this expression the parameter b collects terms which are constant. Equation (1) does present the expression for σ_n , but not for μ_n since it does not play a role in our analysis.

Appendix B

Derivation of Equation (2)

The covariance matrix Σ_x^{mA} for the observations x_1 , x_2 , ... , x_m is

$$.\Sigma_x^{mA} = \sigma_x^2 \begin{bmatrix} 1 & \rho & . & \rho \\ \rho & 1 & . & . \\ . & . & . & \rho \\ \rho & . & \rho & 1 \end{bmatrix} = \sigma_x^2 m\rho \overline{J_m} + \sigma_x^2(1-\rho)I_m = \sigma_x^2(1-\rho+m\rho)\overline{J_m} + \sigma_x^2(1-\rho)E_m$$

where $\overline{J_m} = \frac{1}{m} J_m$ and J_m is an m by m matrix with all elements being equal to 1. The matrix $E_m = I_m - \overline{J_m}$ where I_m is the m by m identity matrix. To derive the posterior variance σ_{mA}^2 we first note that $\overline{J_m} \cdot \overline{J_m} = \overline{J_m}$, $\overline{J_m} \cdot E_m = 0$, and $E_m \cdot E_m = E_m$. Using a variance decomposition method well known in the analysis of panel data with random effects (Baltagi, 1995: 14) we find that $\left(\Sigma_x^{mA}\right)^{-1} = \frac{1}{\sigma_x^2(1-\rho+m\rho)} \cdot \overline{J_m} + \frac{1}{\sigma_x^2(1-\rho)} \cdot E_m$. Therefore, the posterior distribution function

$$f(x_1,...,x_m,T) = f(x_1,...,x_m \mid T) \cdot f(T) \propto \exp\left(-\frac{1}{2}(x-\iota T)^T \left(\Sigma_x^{mA}\right)^{-1}(x-\iota T)\right) \cdot \exp\left(-\frac{1}{2}\frac{(T-\mu)^2}{\sigma_T^2}\right)$$

where ι is an m by 1 vector whose elements contain the number 1 and x is an m by 1 vector containing the observations x_i. To determine the posterior variance of T it suffices to collect all terms that involve T^2. These are $\left(\iota^T \left(\Sigma_x^{mA}\right)^{-1}\iota + \frac{1}{\sigma_T^2}\right)T^2$. Using the above, $\iota^T \left(\overline{J_m}\right)\iota = m$ and $\iota^T \left(E_m\right)\iota = 0$, we find that $\left(\iota^T \left(\Sigma_x^{mA}\right)^{-1}\iota + \frac{1}{\sigma_T^2}\right)T^2 = \left(\frac{m}{\sigma_x^2(1-\rho+m\rho)} + \frac{1}{\sigma_T^2}\right)T^2$.

Therefore, the posterior variance of T is equal to

$$\sigma_{mA}^2 = \left(\frac{m}{\sigma_x^2(1-\rho+m\rho)} + \frac{1}{\sigma_T^2}\right)^{-1} = \left(\frac{m}{\sigma_x^2(1-\rho)+m\rho\sigma_x^2} + \frac{1}{\sigma_T^2}\right)^{-1}$$

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[1] The information provided by an unembedded tie is imprecise for the same reasons we mentioned in the context of noise surrounding an observation from the existing alliance group.

[2] The covariance matrix of the observations is given by

$$\Sigma_{x,y}^{mA+1B} = \begin{pmatrix} \sigma_x^2 & \rho\sigma_x^2 & . & \rho\sigma_x^2 & 0 \\ \rho\sigma_x^2 & . & . & . & . \\ . & . & . & \rho\sigma_x^2 & 0 \\ \rho\sigma_x^2 & . & \rho\sigma_x^2 & \sigma_x^2 & 0 \\ 0 & . & 0 & 0 & \sigma_y^2 \end{pmatrix}.$$

[3] It is straightforward to derive the optimal number of unembedded ties by determining

$\min_u \left(b\sigma_{mA+uB} + c_{uB|mA} \right)$ where $\sigma_{mA+uB}^2 = \left(\frac{m}{\sigma_x^2(1-\rho) + m\rho\sigma_x^2} + \frac{u}{\sigma_y^2(1-\rho^*) + u\rho^*\sigma_y^2} + \frac{1}{\sigma_T^2} \right)^{-1}$ and ρ^* denotes the correlation coefficient of the observations of type B firms.

[4] It is also straightforward to extend our model to a case where a firm cannot return to its previous alliance group once it forms an alliance with a non-local partner. However, this situation is more likely to apply when alliances are formed with firms in order to set a certain industry wide technology standard. Then earlier partners are likely to feel betrayed and hence a return to the former alliance group may be cumbersome, with learning alliances this is less likely to occur.

[5] It can be shown that

$(m+1)(1+(m-1)\rho)^2 - (m-1)(1+m\rho)^2 = 2 + 2(m-1)\rho - (m-1)\rho^2 > 0$ since $0 \le \rho < 1$ which ensures validity of the inequality sign in equation (8).

[6] Footnote 3 applies here as well.

[7] The covariance matrix in case of an embedded tie is $\Sigma_{xz} = \begin{pmatrix} \sigma_x^2 & \rho\sigma_x\sigma_z \\ \rho\sigma_x\sigma_z & \sigma_z^2 \end{pmatrix}$. Its inverse is

$(\Sigma_{xz})^{-1} = \frac{1}{(1-\rho^2)\cdot\sigma_x^2\sigma_z^2} \begin{pmatrix} \sigma_z^2 & -\rho\sigma_x\sigma_z \\ -\rho\sigma_x\sigma_z & \sigma_x^2 \end{pmatrix}$. Those for an unembedded tie are equivalent but with subscript *x* replaced by *y* and ρ=0. The posterior variances given in equations (10) and (11) can be obtained using parts of the procedure depicted in appendix B.

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[8] We assume here that the focal firm will look for a potential non-local tie satisfying $\sigma_{xz}^2 > \sigma_{yz}^2$.