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Nooteboom, B.; Gilsing, V.A.

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DENSITY AND STRENGTH OF TIES IN INNOVATION NETWORKS: A COMPETENCE AND GOVERNANCE VIEW

By Bart Nooteboom, Victor A. Gilsing

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Tilburg University

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ABSTRACT

Taking into account both competence and governance issues, and six dimensions of tie strength, this article argues that in networks for exploration there are good reasons, counter to the thesis of the 'strength of weak ties', for a dense structure of ties that are strong in most dimensions. By contrast, in exploitation networks there are good reasons for structures that are non-dense, with ties that are strong in other dimensions than in networks for exploration.

key words: innovation, networks, strength of ties, governance, biotechnology, multi-media

areas of study: industrial organization, strategy, organization

INTRODUCTION

It is a well-know question in the network literature whether in networks for innovation ties are sparse and weak, to allow for variety, flexibility and low cost of exploration, as claimed in the thesis of the 'strength of weak ties', or should be 'cohesive', to facilitate trust and collaboration. This article aims to extend existing arguments for the need for ties to be dense, and to be strong in a number of respects. It combines a competence perspective, for the acquisition and production of knowledge, and a governance perspective, for the management of relational risk. On the governance side, it looks at risks of dependence and risk of spillover, i.e. the risk that in cooperation others adopt one's knowledge to compete.

For risks of dependence, notwithstanding justified, fundamental criticism of transaction cost economics (TCE), the notion of hold-up risk as a result of specific investments remains relevant, and indeed gains new relevance in innovation networks. On the competence side, we need to think through the implications of radical uncertainty, particularly in exploratory (in contrast with exploitative) innovation, concerning the location and identity of sources of information, and the relevance, absorbability, quality and reliability of information. These yield further support for existing arguments, and new arguments, for density and strength of ties. In the analysis we consider six dimensions of tie strength.

We arrive at hypotheses that, for reasons of both competence and governance, in exploration ties need to be dense and strong in most of the six dimensions, while in exploitation ties need to be more sparse and strong in other dimensions.

The article proceeds as follows. First, it summarises the debate on the strength of weak ties, and indicates questions for further analysis. Second, it surveys the theory to be used, for the competence and the governance side. Third, it develops hypotheses concerning density and strength of ties for networks for exploration and networks for exploitation.

THE DEBATE

Views on the strength of weak ties

As is well known in the sociological literature on networks, there are opposing views concerning the 'strength of weak ties'. On the one hand is the view that dense and strong ties ('cohesion' or 'network closure') allow for social control, and facilitate the build-up of reputation, and social capital, in the form of trust and social norms, which facilitate collaboration (Coleman 1988). On the other hand, Granovetter (1973), in his famous article on 'the strength of weak ties', proposed that weak rather than strong ties are appropriate for access to new information. He associated strong (weak) ties with a dense (sparse) structure. In frequent and intense interaction between many actors, in a dense structure, much of the information circulating in the system is redundant. An example Granovetter used was the discovery of new employment opportunities, through acquaintances with which one has only sporadic contacts. Burt (1992) made a clearer conceptual separation between the strength and the density of ties. It is important to acknowledge this, since it is conceivable that sparse ties may be strong and that dense ties may be weak (Reagans and McEvily, 2003). Indeed, the present article will give illustrations of that. According to the thesis of the strength of weak ties, dense structure yields redundancy, when the aim is access to new knowledge. If A is connected to B, and B is connected to C, then A does not need a direct connection to C because he can access information from C through B. The cost of redundancy, in setting up and maintaining ties, increases with the strength of ties. Thus, according to Burt, efficiency can be created in the network by shedding redundant ties and selectively maintaining only a limited set of ties that bridge 'structural holes'. Then, time and energy are saved for developing new contacts to unconnected nodes.

Hansen (1999) made a distinction between acquiring knowledge about and knowledge from others, i.e. between the identification of the location and usefulness of knowledge, and the transfer or sharing of knowledge. He, and earlier Uzzi (1997), argued that strong ties promote the transfer of complex knowledge, while weak ties promote the transfer of simple knowledge.

In this debate, the empirical evidence is mixed. McEvily and Zaheer (1999) found evidence against redundancy in an advice network, for the acquisition of capabilities. Ahuja (2000) found evidence against structural holes, for innovation in collaboration. Hagedoorn and Duysters (2003) found evidence that in a context of exploration firms profit from multipler, redundant ties. Walker, Kogut and Shan (1997) found evidence in favour of cohesion, for innovation in biotechnology. In view of these apparently inconsistent findings, subsequent studies have taken a 'contingency' approach (Bae and Gargiulo, 2003), investigating environmental conditions that would favour the one or the other view (Podolny and Baron 1997; Rowley, Behrens and Krackhardt, 2000; Ahuja, 2000; Podolny 2001; Hagedoorn and Duysters, 2002).

Discussion and new perspectives

In our view, and as argued by Williamson (1999), in the analysis of networks we need to combine a perspective of 'competence', for the acquisition of capabilities and knowledge, and the construction of new knowledge, with a perspective of 'governance', for the management of 'relational risks'. The literature on competence building has neglected the governance of relational risk, and transaction cost theory has neglected issues of learning and innovation. A combination of the two perspectives should yield a more complete understanding of inter-organisational relations (Nooteboom, 2004). We need to look at both potential rewards and risks, as is customary practice. The arguments of Granovetter and Burt in favour of weak ties clearly refer to the competence side of relations, while Coleman's arguments in favour of

cohesion clearly refer to the governance side. In a combination of competence and governance perspectives, there are arguments both in favour and against density and strong ties, in innovation and knowledge transfer (Uzzi, 1996, 1997). Under contingencies that stress matters of competence, in particular exploration of novel opportunities, one may expect an emphasis on weak ties, in the bridging of structural holes. On the other hand, under contingencies that stress matters of governance, one may expect an emphasis on cohesion. This was Ahuja's (2000) argument: structural holes are less likely to be beneficial when overcoming opportunism is critical for success.

However, what goes on is not as simple as this distinction between competence and governance suggests. Uzzi's (1997) and Hansen's (1999) arguments for strong ties in the case of transfer of complex knowledge referred (also) to the competence, not (only) to the governance side. More fundamentally, we recall from the literature on cognition and knowledge that information is not the same as knowledge, that knowledge is highly embedded in 'situated action' (Lave and Wenger, 1991; Brown and Duguid, 1991), and that for information to be transformed into knowledge (including understanding) it has to be absorbed into 'absorptive capacity' (Cohen and Levinthal, 1990). Von Hippel (1988) already showed that transfer of knowledge may require the development of a shared code, in a strong, i.e. long-term, intensive relationship. Thus the question is what the role of density and tie strength are in the location of information as well as its absorption into knowledge, given limitations in absorptive capacity.

For the competence side we need to go some way into theory of knowledge and implications for theory of organization. For the governance side, we need to summarise insights in relational risk and instruments for their governance.

COMPETENCE THEORY

Theory of knowledge

We adopt a 'constructivist' and 'situated action' view of cognition, as most authors do in the management and organisation (MO) literature on organisational cognition and learning (for surveys, see Hedberg, 1981; Cohen and Sproull, 1998; Meindl, Stubbard and Porac, 1998). Note that here cognition is seen in a broad sense, including not only rational evaluation but also emotion-laden value judgements, and heuristics of attribution, inference and decision making that we know from social psychology (Tversky and Kahneman, 1983; Bazerman, 1998). Constructivism entails that while knowledge directs action, it is also (re)constructed from action. Hence the terms 'experiential learning' (Kolb, 1984) and 'activity theory' (Blackler, 1995). This goes back to the work of Vygotsky (1962), and Piaget (1970, 1974), and is consistent with the 'symbolic interactionism' of G.H. Mead (1934), which was introduced into the MO literature by Weick (1979, 1995). According to Piaget, perception, interpretation, understanding and value judgment entail 'assimilation' (Piaget) into cognitive structures developed from previous experience, but in the process there is an 'accommodation' of those structures. Existing cognitive structures constitute 'absorptive capacity'. On the level of organisations, this was recognized by Cohen and Levinthal (1990). Here, absorptive capacity includes organisational capabilities to assimilate information, internally distribute it, and implement knowledge in design, development, production and marketing. It depends, among other things, on R&D.

'Situated action' entails that knowledge and meaning are embedded in specific contexts of action, which yield background knowledge, as part of absorptive capacity, which cannot be fully articulated, and always retains a 'tacit dimension' (Polanyi, 1962). As a result, knowledge may be 'sticky' (Von Hippel, 1994) and not easily pried loose. Generalized

knowledge, in lessons abstracted from situated action, always entails some loss of knowledge and meaning. When such generalized knowledge is applied, it is disambiguated and augmented with features of the specific context of novel application, and is transformed in the process. As a result general, context-independent, formalized, i.e. fully articulated, 'canonical' rules cannot cover the richness, i.e. complexity and variability, of specific action contexts.

Context-dependence entails that definitions generally cannot take the form of universal and necessary and sufficient conditions for categorisation, and therefore meaning apart from context is indeterminate and open-ended. These views on knowledge have been picked up in the literature on 'communities of practice' (Lave and Wenger, 1991; Brown and Duguid, 1991). In the present context, this view is important for its implications for the density and strength of ties needed to locate, assess and adopt knowledge from others. It yields added depth to the thesis that strong ties may be needed (Uzzi, 1997; Hansen, 1999).

Implications for organisation

The constructivist view of knowledge entails 'cognitive distance' between people: to the extent that they have developed their cognitive structures in different action contexts, they will think (perceive, interpret, explain, evaluate) differently (Nooteboom 1992, 1999). Diversity is a crucial condition for learning and innovation, to produce Schumpeterian 'novel combinations', as demonstrated, in particular, in evolutionary economics (Nelson and Winter, 1982). Diversity is associated with the number of agents (people, firms) who are involved in a process of learning or innovation by interaction. Next to the number of agents involved, a second dimension of diversity is the degree to which their knowledge, skills and behavioural norms are different (cognitive distance). People do not need to agree on individual objectives, and their knowledge must differ to make collaboration fruitful. However, in order to combine different skills and knowledge (competence), and to align motivations and solve conflicts (governance), people need to share basic, fundamental assumptions underlying a shared culture (Schein, 1985), concerning the world, man, knowledge, and relations between them. The task of organisation, then, is to sufficiently reduce cognitive distance, in an organisational 'focus', including intellectual as well as moral categories, to enable mutual understanding and alignment of incentives for the achievement of joint purpose (Nooteboom, 1992). A similar cognitive argument for organization as a tool for combining competencies and for governance was offered by Kogut and Zander (1992). Earlier, similar views on the role of organizations to generate shared interpretations or a system of shared meanings were also proposed by Weick (1979) and Smircich (1983).

Organisational focus is closely related to the notion of organisational absorptive capacity (Cohen and Levinthal, 1990). It enables but also constrains organisational cognition, yielding organisational myopia, which needs to be compensated by engaging in outside relations with other organisations, with different, complementary foci, at some cognitive distance. This yields a new purpose for inter-organisational alliances, next to the usual considerations, known from the alliance literature (Nooteboom, 1999). Firms need to make a trade-off between organisational focus for coherence and scope for variety. A wide scope entails limited focus. Limited scope, with limited internal variety and a narrow focus, can be compensated by alliances for external variety. It is proposed that this trade-off is more fundamental than transaction costs for determining the boundaries of a firm. To compensate for organisational myopia, firms need to tap in complementary sources of cognition, at a cognitive distance that is large enough to yield novel insights and small enough to allow comprehensibility. In the present context, crossing cognitive distance requires the building of mutual understanding, which has implications for the strength of ties, as will be argued later.

Exploration and exploitation

To distinguish between different degrees of uncertainty and of the need to access novel sources of information, in our analysis we employ the notion of *exploration* and *exploitation* (March, 1991). Exploitation entails improvements with respect to established practice, while exploration entails the development of new practices. This is related to the distinction between first and second order learning (Bateson, 1972), and between single and double loop learning (Argyris and Schön, 1978). In the literature on innovation networks, the distinction between exploration and exploration was used earlier by Rothermael and Deeds (2004). Exploration and exploitation build on each other: exploration develops into exploitation, and exploration emerges from exploitation, in ways that go beyond the present article. The point here is that networks for exploration and for exploitation may require different structure and strength of ties.

In exploration, there is uncertainty about which technical standards will later yield the 'dominant design', there is much volatility of prototyping, the emphasis in competition lies on technical feasibility and a 'race to the market', there is a great deal of trial and error, and knowledge is often highly tacit. In exploitation, technical development has consolidated in a dominant design, uncertainty in supply and demand has subsided, knowledge becomes more codified and diffused, new players and consumers enter into the emerging market, competition shifts to efficient production and distribution, and the emphasis shifts to a new dominant design in organisation. These differences are summarised in Table 1. It will be argued later, in the specification of hypotheses, that they have implications for structure (density and centrality) and strength of ties.

Table 1 about here

GOVERNANCE THEORY

Transaction costs revisited

Transaction cost economics (TCE) has been fundamentally criticised for its lack of attention to learning and innovation and for its neglect of the role of trust. However, more on the surface level of theory, removed from fundamental behavioral assumptions, its notion of specific or dedicated investments is still of value. To recall: such an investment is valuable only in a specific relationship, and therefore yields switching costs, and thus requires confidence that the relationship will last sufficiently long, or carry sufficient volume of activity, to recoup the investment. In other words, specific investments cause a risk of dependence. One can be 'held up' to the amount of the switching costs.

The relevance of specific investments and the potential for hold-up still apply, arguably even more than before, but in new forms, when we turn to a theory that includes learning, innovation and trust (Nooteboom, 1999). The building of mutual understanding, to cross cognitive distance, may entail a relation-specific investment. When trust is needed, for governance, and it is not present ex ante, prior to a relationship, then it has to be built up in the relationship. This is also likely to constitute a relation-specific investment.

This is linked to Lave and Wenger's (1991) notion of 'legitimate peripheral participation'. Entrants to a community are kept on the periphery for a while, to internalise tacit meanings and norms and values of behavior, in socialisation and habituation. This constitutes an investment specific to that community. Note that duration of a tie, to recoup specific investments, depends on the economic life of the investment. When an investment depreciates quickly, the

corresponding requisite duration of the relation is shorter. We will propose that specific investments in a tie and duration of a tie are relevant dimensions of the strength of ties.

Relational risk

Governance entails the management of relational risk that results from dependence. As in the social network literature, we recognize dependence resulting from structural embeddedness, in networks, and from relational embeddedness, in specific ties. Here, we focus on risks of lock-in and spillover. In relational embeddedness, risk of lock-in includes the 'hold-up' risk from TCE, as discussed above. Linkages with other actors yield access to variety of knowledge, but also a risk of spillover. This is the risk that knowledge that is part of one's 'core competence', which constitutes competitive advantage, may be used in competition, either by a direct contact (relational embeddedness), or indirectly, elsewhere in the network, through a sequence of direct contacts (structural embeddedness). Trust may be needed to give confidence that shared knowledge will not be used for competition (Krackhardt, 1990; McEvily, Perrone and Zaheer, 2003). Direct spillover risk is limited when a direct tie connects nodes with different, complementary competencies, since competition would then entail a shift away from core competence. In relations of complementarity, a risk of indirect spillover, to a competitor via an indirect tie, may still remain.

Spillover risk depends on density of the network. Density has both a potential advantage of knowledge access, and a potential disadvantage of spillover. Note that the assessment of spillover risk requires a trade-off between knowledge adopted by others and knowledge gained from them. The risk is potentially serious only when there is a net loss rather than gain. The risk of spillover also depends on how tacit or documented knowledge is, with the latter spilling over more easily than the former. It also depends on the absorptive capacity of potential competitors, i.e. their ability to effectively understand information they get, i.e. transform it into knowledge, and to implement knowledge in their organisation. That depends on the 'cognitive distance' between actors, i.e. differences in their ability to perceive, understand and evaluate relevant phenomena. Finally, spill-over risk depends on the speed with which knowledge changes: if it is obsolete by the time it has spilled over and has been absorbed and imitated by potential competitors, spillover risk drops out (Nooteboom, 1999).

Hold-up risk may be avoided by not incurring switching costs, i.e. by not engaging in relation-specific investments, including investments in mutual understanding (to cross cognitive distance). Spillover risk may be avoided by not surrendering competitively sensitive information. The penalty for both, however, is that one foregoes opportunities for utilising complementary competences as an engine of learning and innovation. Therefore, rather than avoiding risks of hold-up and spillover, the challenge is to accept and manage them, for the sake of high value-added, innovative relationships.

Governance of hold-up risk

A survey of instruments for governance of hold-up risk is given in Table 2, derived from Nooteboom (1999). Here, a distinction is made between macro and micro, and between self-interested and other-directed sources of collaboration.

Table 2 about here

The distinction between macro and micro sources of collaboration, in Table 2, is also known as the distinction between 'universalistic' or 'generalised' sources versus 'particularistic' sources, made by Deutsch (1973: 55), between impersonal and personalised sources made by

Shapiro (1987), and between structural and relational embeddedness adopted in the network literature. The table further distinguishes between self-interested and altruistic or 'other-directed' sources of co-operation.

The first are associated with the notions of control, deterrence and 'calculus-based trust' (McAllister, 1995; Lewicki and Bunker, 1996). In Table 2, this includes 'opportunity control' and 'incentive control'. Opportunity control entails that the space of feasible action is constrained. Incentive control affects the choice of opportunities, in the space of feasible actions. *Opportunity control* entails control by contract or hierarchy. Here, in the analysis of inter-firm relations, we focus on contracts. Contracts are only useful to the extent that one is able to adequately specify them and monitor conformance. This is problematic especially under the uncertainty of exploration, with its unknowable future contingencies of contract execution. Also, in exploration knowledge is likely to be highly tacit, which would also inhibit the specification of contracts. Hence, in exploration governance requires more informal instruments.

In *incentive control*, partner B behaves well towards A because he is dependent on A for one or more of the following reasons: A has a unique, difficult to replace value to B, B faces switching costs as a result of relation-specific investments, partner A holds a hostage from B, or B has to protect his reputation. The notion of hostage is also taken from TCE. In business, hostages often take the form of information or knowledge that is sensitive, in the sense that it could cause great damage when leaked to competitors. It can also take the form of cross-participation, or the borrowing of staff, with the threat of poaching them.

Now we turn to the other-directed sources of collaboration, in trust that goes beyond calculative self-interest. As is well known from the trust literature, we need to distinguish between 'competence trust', in the ability of people and firms to satisfy expectations, and 'intentional trust', in the commitment of people to perform to the best of their abilities, and not to engage in opportunistic behavior. We hold that, counter to TCE (Williamson, 1993), trust does go beyond calculative self-interest. However, trust has, and should have, limits (Nooteboom 2002).

On the *macro level*, sources of trust lie in established, socially inculcated norms and values of conduct, and pressures of allegiance to groups one belongs to. On the *micro level* of specific relationships, there is a principle of reciprocity, discussed widely in the sociological and anthropological literature on the giving of gifts. Trust may also be based on empathy. This entails that one knows and understands how partners think and feel. It is connected with mutual openness, and acceptance of control by others, which are crucial for the build-up of trust (Zand, 1986). Empathy allows one to assess strengths and weaknesses in competence and intentions, to determine the limits of trustworthiness under different conditions. Identification-based trust goes further: it entails that people think and feel in the same way, sharing views of the world and norms of behavior. This may lead to affect- and friendship-based trust. Routine-based trust entails that when a relation has been satisfactory for a while, awareness of opportunities of opportunism, for oneself and for the partner, is relegated to 'subsidiary awareness' (Polanyi, 1962). Identification and routine can go too far, yielding blind trust and lack of flexibility and innovation.

The relevance of these instruments of governance, in the present context, is as follows. We propose that control, on the basis of contracts, mutual dependence, or hostages, and trust, with its norms of behaviour, empathy, identification, openness and routinisation, yield dimensions of tie strength. Reputation requires density of ties (Coleman 1988).

Governance of spillover risk

Indirect spillover risk may be prevented by demanding exclusiveness: one's partner is forbidden to interact with one's competitors, in the precise area in which one collaborates

with him. The penalty for this is that one cuts the partner off from other sources of learning, in that particular activity. This is to one's own disadvantage. Also, exclusiveness may cause the partner to demand a greater share in jointly produced added value. Therefore it is of great importance to carefully analyse whether spillover really constitutes a risk, in view of tacitness of the knowledge involved, limitations of absorptive capacity, and the speed of knowledge change, as argued before. Note that exclusiveness reduces density of ties.

HYPOTHESES

Structure and strength of ties

As a basis for specifying hypotheses concerning structure and strength of ties in exploration networks, we need to specify relevant dimensions of structure and tie strength. A central feature of structure is density, i.e. the extent that nodes in the network are directly connected. With n nodes, the maximum number of direct ties is n(n-1)/2. Density is defined as the actual number of ties as a percentage of the maximum number. Density is closely related to the notion of redundancy. If A, B and C are all directly connected, then for A one of his ties, say to C, is redundant in the sense that A can also access C indirectly through B. A reduction/increase of redundancy entails reduction/increase of density, but the reverse does not necessarily apply. When density is increased/decreased by the addition/elimination of a non-redundant tie, redundancy is not affected. We propose that next to *density* a second relevant feature of network structure is network *stability*, i.e. the rate of entry and exit of members, and a third is*centrality*, which entails limited density. Stability has implications for the variety of knowledge, which is important for exploration. Centrality may be needed for coordination of division of labour, which is especially important for exploitation. Here, we focus on degree centrality, which arises to the extent that some nodes have more direct ties than other nodes do. An extreme case is a hub-and-spoke structure. A central position yields power, but possibly also constraints on behavior, in view of the many interests it is involved in (Krackhardt, 1999), and it may suffer from information overload. Next, we consider dimensions of tie strength. According to Granovetter (1973: 1361), the strength of (personal) ties entails a combination of 'amount of time, emotional intensity, intimacy (mutual confiding) and the reciprocal services' that characterise the tie. Here, from our earlier theoretical analysis we arrive at an adapted and extended set of dimensions of tie strength. First, we propose *scope* as a dimension of tie strength, defined as the range of activities involved in the tie, which may be related to Granovetter's 'reciprocal services'. Does it involve only knowledge on the location and relevance of knowledge, anywhere in the network, or also the actual exchange or joint production of new knowledge (this distinction was already indicated in the introduction)? Does it involve knowledge only on a small number reputation of players in the network?

Relation-specific investments yield a second dimension of strength. As discussed in the theoretical section, cognitive distance may require specific investment in mutual understanding. To recoup these investments one needs sufficient *frequency* and/or *duration* of interaction. Frequency and duration both appear related to Granovetter's 'amount of time', but frequency may also be related to 'intimacy'. While investment in mutual understanding, frequency and duration facilitate learning they also facilitate spillover. As argued earlier, long duration of a tie may lead to identification, which enhances mutual understanding and trust (Gulati 1995), but may reduce learning potential, particularly if the tie is exclusive, i.e. in the areas of collaboration (scope) there are no direct ties with others.

Finally, there are dimensions of strength related to governance. One is the degree of *control*, on the basis of contracts, hierarchy, mutual dependence and hostages. Another is the

degree of tie-specific trust, on the basis of *bonding* in the form routinisation, shared ethics, empathy or identification. The latter appears related to Granovetters 'emotional intensity', but also to his 'intimacy'. Table 3 summarises our proposal for six dimensions of tie strength, and their comparison with the dimensions proposed by Granovetter.

Table 3 about here

Structure for exploration

First we look at the requirements of exploration for network structure, in particular density of ties. from a perspective of both competence and governance. Next, we we discuss requirements for the strength of ties. The basic argument is that the radical uncertainty involved in exploration requires sufficient density of ties.
The thesis that exploration requires non-dense ties is based on the (implicit) assumptions that:

Players know:

1. What kind of information is relevant
2. The field of sources is stable, allowing for identification, location, and access.

And that:

3. One has the absorptive capacity to absorb the information
4. One is able to judge the quality and reliability of information
5. The costs of redundant ties (related to density) are significant
6. The costs of redundant ties are relevant

In exploration, however, these assumptions do not apply. In exploration, uncertainty is radical, concerning content and reliability of emerging varieties of technology (no dominant design has yet emerged), organisation, future market demand, and the location, content, relevance, and absorbability of information. Problems in the identification of sources of information wese recognised earlier by Argote and Ingram (2000) and Hagedoorn and Duysters (2002). Under such uncertainties (1 and 2), one has to hedge relational bets. One does not yet know what ties will turn out to be redundant, since one does not know what the configuration of relevant elements of knowledge will be. Following from this, we propose two hypotheses.

First, if one does not know what information will be relevant (1), one may have to develop and maintain redundant ties to sources that may turn out to be irrelevant. Second, the argument against redundancy is that if A has a tie with B, who has a tie with C, then a tie between A and C would be redundant, since A can access C through B. However, under the volatility of exploration there is uncertainty concerning the future presence, in the network, of contacts and sources (2), so that ties may drop out (with B) and thereby eliminate indirect access to other sources (C). Hence:

Hypothesis 1a. In exploration, to hedge bets concerning what knowledge is relevant, ties are needed to sources of knowledge that may later turn out to be redundant.
Hypothesis 1b. In exploration, to hedge bets concerning the presence of sources, and the continuity of ties, one has to maintain direct linkages even if they may later turn out to be redundant, to keep options of access open.

Third, if one is not able to adequately understand a given kind of information from a given source (3), one may need an apparently redundant tie to complement one's absorptive capacity. More precisely, if A remains linked to both B and C, even if there is also a link

between B and C, this may help A to understand C by comparing what A understands from C with what B understands from C. In other words, even if a tie is known to be redundant for access to sources of information, it may be needed to understand and absorb knowledge accessed in another relation. This is the case particularly in exploration, where knowledge is emerging, lacks a dominant design and standards, and is still largely tacit. Fourth, if one does *understand* a given source, one may not be able to judge the *reliability* of information (4), so that, like researchers in gathering potentially biased data, one may need a third party for triangulation. Hence:

Hypothesis 2a. In exploration, one may need a third party to complement one's absorptive capacity.
Hypothesis 2b. One may need a third party for triangulation, to test the validity of information.

This connects with the argument from information theory that 'noise' is reduced when accessing multiple and redundant contacts (Shannon, 1957).

Fifth, in exploration the set-up and maintenance costs of ties tend to be limited in size (5). Relevant costs arise only from relation-specific investments since other, more generic investment would be useful also in other ties. In exploration, in contrast with exploitation, specific investments other than in mutual understanding are often limited in size, in activities such as prototyping rather than large outlays for efficient, large-scale production, marketing, distribution, and servicing. Furthermore, in exploration, costs are less of an issue (6), since competition focuses on form, i.e. connecting complementary competencies in the fast development of prototypes, rather than on the price of a ready product, as in exploitation. Hence:

Hypothesis 3a. In exploration, tie-specific investments, and hence the costs of redundant ties, are limited in size.
Hypothesis 3b. In exploration, costs of redundant ties are less relevant (than in exploitation), since competition focuses on technical viability rather than on price.

In sum, we need a thorough trade-off between costs and benefits of redundancy, and in exploration costs may not be high, costs may not have priority, and there are benefits of redundancy, for hedging structural bets and bets on knowledge content, for triangulating knowledge content and reliability, and for aiding the absorption of knowledge.

Now we turn to network stability and centrality. To maintain the variety of cognition needed for exploration, stability should be low, reflecting frequent exit and entry of network participants, for the sake of novel combinations. Note that this reinforces the implications of network volatility, in hypothesis 1b. In incremental innovation in a systemic technology, network *centrality* tends to be high, for the sake of coordination, to ensure that the different components of the system change in tune with each other. However, under conditions of radical innovation, with uncertainty concerning what elements will emerge and survive in what configuration, and in stand-alone conditions, centrality is less relevant. It may also yield an obstacle in attempts to maintain the power invested in established, centralised architecture. Hence:

Hypothesis 4a. In exploration, network stability is expected to be generally low, allowing for entry and exit, for the sake of novel combinations.
Hypothesis 4b. In exploration, network centrality tends to be low

From a governance perspective, in exploration the use of contracts is problematic, as noted before. Uncertainty about contingencies, even in the very near future, precludes their detailed specification. In view of new and dispersed knowledge, it would be difficult to monitor and assess conformance to contracts. How then, is relational risk governed? What other instruments could be taken, from Table 2? We propose that in exploration governance is based on a balance of mutual dependence, hostages in the form of sensitive information, a reputation mechanism, and relation-specific trust. A reputation mechanism is especially strong here, in exploration, in view of the uncertainty about possible future configurations of relations. Since it is impossible to assess who may and who may not in the future be a potential collaborator, one has to be careful in *all* relations. The point now is that *density* of relations is needed for a reputation mechanism. Also, the institutional basis for trust typically lies in professional values, norms, and standards, guarded by professional associations, which also play an important role in reputation mechanisms. A potential downside of density, from the perspective of governance, is that it facilitates spillover. However, under exploration knowledge is likely to be more tacit (relative to exploitation), which does not spill over so easily, and change of knowledge may be so fast that, as argued earlier, spillover risk is likely to drop out. Even if it does not, spillover may still be less of an issue, for the following reason. Since commercialisation is not yet established, and even the product and its technology are uncertain, it may not be clear who will turn out to be a competitor, so that it may not be clear where spillover is to be controlled. Then, since everyone may turn out to be a competitor, one should not give sensitive information to anyone, but that would preclude the learning by interaction that is essential in exploration. In other words, exclusiveness, which would reduce density, is improductive. Hence:

Hypothesis 5a. In exploration, sufficient density of the network is needed for a reputation mechanism.
Hypothesis 5b. In exploration, spillover risk, resulting from network density, is often not an issue.

Ties for exploration

Now we turn to the strength of ties. Our hypotheses follow more or less directly from the earlier theoretical analysis. We noted that Under the wide ranging uncertainty of exploration, ties tend to be strong in the dimension of scope. We also noted that building mutual understanding and trust constitutes a *relation-specific investment*, which requires sufficient *frequency of interaction* and/or *duration*, to make such investment worthwhile. This analysis confirms and elaborates the view, proposed earlier by Hansen (1999) and Uzzi (1999) that exchange of 'complex' information requires strong ties. However, since knowledge changes fast, in exploration, the economic life of the investment is short, so that it should be recouped in a short time and in frequent contactsHow long duration should be depends, among other things, on the size of specific investment for mutual understanding, which depends on the depth and level of specialisation of knowledge, and the degree to which it is tacit. Duration *should* not be too long, for two reasons. The first reason is that it would prevent novel architectures of configurations. This is particularly relevant under systemic conditions, where innovation often takes the form of frequent and rapid architectural change. Here, one might think of the car industry, for example. The second reason is that too durable relations may yield identification that goes so far, in an excess of familiarity, as to reduce innovative potential. However, this depends on how exclusive the relation is. If A and B have a tie, on a certain subject, and the tie bridges a structural hole, with both A and B also having other ties, on the same subject, to different nodes, then their mutual value as sources of knowledge may

be replenished from those outside contacts, so that a long duration does not necessarily kill learning potential. Hence:

Hypothesis 6a. Under the wide ranging uncertainty of exploration, ties tend to be strong in the dimension of scope.
Hypothesis 6b. In exploration, mutual understanding requires specific investment, but of low size and short economic life, so that ties are of moderate strength in specific investment.
Hypothesis 6c. In exploration, due to the need to make speed and to recoup specific investments in a short time, ties are strong in frequency of interaction.
Hypothesis 6d. In exploration, due to the short life of specific investments, and the need to maintain flexibility of configuration, ties are weak in duration.

Concerning the governance side, under the uncertainty of exploration governance by contract and monitoring is often problematic, as argued before, so that ties are weak in terms of *control*, and one has to go more for *reputation* mechanisms and *trust*. Typically, in exploration trust initially is competence trust, in professional knowledge and skill, and this establishes a basis for intentional trust to develop, on the basis of pre-existing professional empathy. Here we find a second argument for *frequency* of interaction (Hypothesis 6c), as needed for the build-up of trust, in empathy, identification and routinisation (Table 2). Such relation-specific, personalized trust entails, and requires a great deal of tie-specific *bonding*, and entails a certain 'emotional intensity' (Granovetter). It is known from the trust literature that trust is stimulated by mutual dependence (Nooteboom, 2002). When one cannot do without each other, one simply has to develop trust in collaboration. As indicated, in exploration such mutual need is high, to search for complementary knowledge, in the race for a viable prototype. Hence:

Hypothesis 6e. In exploration, due to uncertainty, ties are weak in contractual control.
Hypothesis 6f. In exploration, ties are strong in bonding as a basis for trust

In sum, our hypotheses state that in exploration ties need to be strong in terms of scope, frequency and trust/bonding, of some strength in terms of relation-specific investments, for building mutual understanding and tie-specific trust. They are generally weak in contractual control and duration. Here we align with the thesis of the strength of weak ties, to a limited extent: we agree that ties should be weak in these latter two dimensions of strength. A potential danger, for exploration, is that the network becomes too tight and stable, with too durable relations between members of an in-crowd, in a tight 'clan' (Ouchi, 1980), which reduces variety in terms of both people involved and cognitive distance, and yields stagnation.

Exploitation networks

By hypothesis, in a network for exploitation conditions are more or less the reverse of those that apply to a network for exploration. First we turn to network structure. Dominant designs have emerged, and technological and market uncertainty have decreased. Here, considerations of efficiency are crucial, since competition has shifted to competition on price, with new entrants in the emerging market. Due to increased competition on price, there is a need to utilise economies of scale, and this opportunity arises since due to decreased uncertainty on the part of customers the market has enlarged. As a result, there is increase of scale, a shakeout of producers, and resulting concentration. Contingencies here are entry barriers to the emerging market and the extent of economies of scale. The drive for efficiency requires the elimination of redundant relations. Thus, concerning structure:

- There is a requirement for a less *dense* structure. The increased codification of knowledge furthers diffusion without the need for relation-specific investments of mutual understanding. This enables a less dense structure, since now one can identify what competencies are and will remain relevant, who has those competencies, and who is likely to survive in the industry. Investments shift to large-scale production, distribution systems, and brand name, which are all long-term, and increase in size and economic life. In view of such large and often sunk investments, with a long economic life, and to maintain efficient division of labour, network structure is likely to be *stable*. Under systemic conditions, exploitation may require considerable *centrality*.

Concerning strength of ties:

- *Duration* of ties depends on the *relation-specific investments*, which depend on the flexibility of technology: more generic or flexible technology entails that investments are less relation-specific. In increased division of labour for the sake of efficiency, there is an increase in specialisation that makes that relations entail more specific knowledge on a narrower *scope* of issues. Reduced uncertainty and codified, diffused knowledge on a more narrow range of issues enable the specification of contracts and the monitoring of compliance, entailing a shift from *trust* to *control*. Increased specialisation, reduced scope and reduced need for trust reduce *frequency* of interaction, i.e. interaction in the exchange or joint production of new knowledge (purely in terms of transactions, there may be very frequent 'just-in-time' deliveries from suppliers).

Conclusions

On the basis of theoretical considerations of learning and governance, we have specified six hypotheses concerning the structure and strength of ties in exploration networks. They are summarised in Table 4.

Table 4 about here

They can be summed up as follows:

- For exploration, network structure needs to be sufficiently *dense* for three reasons. First, to hedge bets on the future relevance and presence of sources of information. Second, to utilize third parties to aid in the absorption of information and in the judgement of the reliability of information (triangulation). Third, to yield reputation mechanisms, needed in view of the limited feasibility of contractual control. Costs of redundant relations are both of limited size, in view of limited size of relation-specific investments, and of limited relevance, since in exploration competition is less on price than on feasibility and fast prototyping. Structure should not be too *stable*, allowing for sufficient entry and exit, to enable variety of knowledge and flexibility of configuration.
- For exploration, ties are weak in *control*, but strong in terms of *scope*, *frequency* of interaction, *bonding* for personal trust, of limited strength in *investment in mutual understanding.* Trust is needed, next to reputation mechanisms, due to the limited feasibility of contractual control (and lack of hierarchy). Specific investments in mutual understanding require sufficient *duration* to make them feasible and worthwhile. However, duration need not be very long, since in view of fast knowledge change specific investments in mutual understanding have a short economic life. Duration should not be too long for two reasons. First, it should not inhibit fast

architectural innovation, if that is needed, as is often the case in systemic technology. Second, if ties are exclusive, long duration will yield too much identification, killing learning potential. Specific investments are recouped, mostly, on the basis of frequent interaction, which is needed also in view of the large scope of ties, and for building relation-specific trust.

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For further research, the obvious priority is to conduct further empirical tests. As noted at the beginning of this article, the empirical evidence is mixed. Some researchers found evidence against redundancy in an advice network (McEvily and Zaheer, 1999). In collaboration for innovation, Ahuja (2000) found evidence against structural holes, and Hagedoorn and Duysters (2003) found evidence in favour of multiple, redundant ties. For innovation in biotechnology, Walker, Kogut and Shan (1997) found evidence in favour of cohesion. In view of these apparently inconsistent findings, subsequent studies have taken a 'contingency' approach (Bae and Gargiulo, 2003), investigating environmental conditions that would favour the one or the other view (Podolny and Baron 1997; Rowley, Behrens and Krackhardt, 2000; Ahuja, 2000; Podolny 2001; Hagedoorn and Duysters, 2002).

We plead for empirical work that looks at differences in density and strength of ties, in a comparison of networks for exploration and for exploitation in given industries, taking into account the different dimensions of tie strength proposed here, systematically testing the hypotheses proposed here. There, contingencies to be taken into account, partly in relation to differences in industry and technology are, among others: tacitness of knowledge, systemicness of technology, speed of knowledge change, mutual dependence.

In a recent study, Gilsing (2003) looked at the development of multi-media in the Netherlands, with its transformation from networks for exploration to networks for exploitation, which confirmed most of the hypotheses. Here, knowledge in exploration is highly tacit, and the technology is highly systemic. Another area of interest is biotechnology, where one might compare exploration networks of small biotech companies and universities with exploitation networks of biotech companies and large pharmaceutical companies. Here, even in exploration knowledge of products is highly codified, and technology of exploitation is highly stand-alone.

Table 1: features of exploration and exploitation

	Exploration	Exploitation
overall characteristic	volatility	consolidation
type of uncertainty	radical technical and market uncertainty	market risk
focus of activity	prototyping	production/distribution
competition	technical and market viability	price
type of knowledge	more tacit	more codified
diffusion of knowledge	limited	wide

Table 2 Instruments for governance

	macro; universalistic structurally embedded	micro; particularistic relationally embedded
self-interest		
opportunity control	contracts, legal enforcement	hierarchy, managerial 'fiat',
incentive control	reputation	unique partner value, switching costs, hostages
altruism benevolence	values, social norms of proper conduct,, moral obligation, bonds of kinship	personal bonds of empathy, routinisation, identification, affect, friendship

source: adapted from Nooteboom (2002) and Williams (1988).

Table 3: Dimensions of tie strength

In personal networks (Granovetter)	In innovation networks
reciprocal services	scope
	specific investment in mutual understanding
amount of time	duration
intimacy	frequency of interaction
emotional intensity	personal bonding/trust
	formal control

Table 4: networks for exploration and exploitation

Hypotheses	network feature	exploration	exploitation
	network structure:		
1, 2, 3, 5	density	high	low
4a	stability	low	high
4b	centrality	low	often high
	strength of ties:		
6a	scope	wide	narrow
6b	specific investments	limited	often high
6c	frequency of interaction	high	low
6d	duration	limited	often long
6e	contractual control	low	high
6f	personal bonding/trust	high	generally low

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