Density And Strength Of Ties In Innovation Networks: A Competence And Governance View

Bart Nooteboom and Victor A. Gilsing

ERIM REPORT SERIES *RESEARCH IN MANAGEMENT*	
ERIM Report Series reference number	ERS-2004-005-ORG
Publication	2004
Number of pages	29
Email address corresponding author	b.nooteboom@fbk.eur.nl
Address	Erasmus Research Institute of Management (ERIM) Rotterdam School of Management / Rotterdam School of Economics Erasmus Universiteit Rotterdam P.O.Box 1738 3000 DR Rotterdam, The Netherlands Phone: +31 10 408 1182 Fax: +31 10 408 9640 Email: info@erim.eur.nl Internet: www.erim.eur.nl

Bibliographic data and classifications of all the ERIM reports are also available on the ERIM website: www.erim.eur.nl

ERASMUS RESEARCH INSTITUTE OF MANAGEMENT

REPORT SERIES
RESEARCH IN MANAGEMENT

BIBLIOGRAPHIC DATA AND CLASSIFICATIONS		
Abstract	This article studies density and strength of ties in innovation networks. It combines issues of 'competence' with issues of 'governance'. It 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. In exploitation, there are good reasons for structures that are non-dense, with ties that are strong in other dimensions than in networks for exploration. Evidence is presented from two longitudinal empirical studies of the emergence and development of networks in the multimedia and pharmaceutical biotechnology industries.	
Library of Congress Classification (LCC)	5001-6182	Business
	5546-5548.6	Office Organization and Management
	HD 30.28	Strategic management
Journal of Economic Literature (JEL)	M	Business Administration and Business Economics
	M 10 L 2	Business Administration: general Firm Objectives, Organization and Behaviour
	L 1	Firm Strategy
European Business Schools Library Group (EBSLG)	85 A	Business General
	100B 240 B	Organization Theory (general) Information Systems Management
	270 A	Strategic management
Gemeenschappelijke Onderwerpsontsluiting (GOO)		
Classification GOO	85.00	Bedrijfskunde, Organisatiekunde: algemeen
	85.05 85.08	Management organisatie: algemeen Organisatiesociologie, organisatiepsychologie
	85.10	Strategisch beleid
Keywords GOO	Bedrijfskunde / Bedrijfseconomie	
	Organisatieleer, informatietechnologie, prestatiebeoordeling	
	Innovatie, netwerken, betrokkenheid, bedrijfsleiding, biotechnologie, multimedia	
Free keywords	innovation, networks, strength of ties, governance, biotechnology, multi-media	

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

Bart Nooteboom
Rotterdam School of Management
b.nooteboom@fbk.eur.nl
Adelheidstraat 82
2595 EE The Hague, The Netherlands
tel +31-703478605

Victor A. Gilsing
Technical University Eindhoven
v.a.gilsing@tm.tue.nl

ABSTRACT

This article studies density and strength of ties in innovation networks. It combines issues of 'competence' with issues of 'governance'. It 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. In exploitation, there are good reasons for structures that are non-dense, with ties that are strong in other dimensions than in networks for exploration. Evidence is presented from two longitudinal empirical studies of the emergence and development of networks in the multimedia and pharmaceutical biotechnology industries.

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

areas of study: industrial organization, strategy, organization

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

This article studies density and strength of ties in innovation networks. It combines issues of 'competence' with issues of 'governance'. It 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. In exploitation, there are good reasons for structures that are non-dense, with ties that are strong in other dimensions than in networks for exploration. Evidence is presented from two longitudinal empirical studies of the emergence and development of networks in the multimedia and pharmaceutical biotechnology industries.

This article offers an analysis of some of the claims advanced in the social network literature. The central claim, which we endorse, is that the embeddedness of firms in networks has important implications for their functioning. This has acquired added importance in the view that networks are important, in particular, for learning and innovation between firms. It is from that perspective that we re-examine claims made for the effects of network structure. In the social network literature, there is a strong focus on static efficiency as the criterion for optimal network structure. Here, we also look at dynamic efficiency, i.e. learning performance. The social network literature also offers rather universalistic normative implications, irrespective of context. Some recent studies have indicated that the optimality of network structure is strongly dependent upon the environmental context (Rowley, Behrens and Krackhardt, 2000; Ahuja, 2001; Duysters and Hagedoorn, 2002). We will also argue that the purpose of a network and contingencies concerning technology and institutions have implications for the optimal configuration of a network.

In his famous article on 'the strength of weak ties', Granovetter (1973) 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 he 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 the dense structure, apart from the strength of ties, which yields redundancy, when the aim is access to new knowledge. In dense networks one needs to expend many resources on the maintenance of ties (even if they are weak), while there is a high chance that ties in this dense structure carry the same information and hence form 'redundant contacts'. Burt then suggests that 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. For the identification of knowledge loose and non-redundant ties may be best, as argued by Granovetter and Burt, but for the transfer of complex and highly tacit knowledge strong ties may be needed. In this article we will further unpack this need of strong ties for the transfer of complex knowledge.

The considerations of Granovetter, Burt, and Hansen clearly refer to the competence side of relations. Coleman (1988) proposed that a dense structure with strong ties allows for social control, and enables the build-up of reputation, and social capital, in the form of trust and social norms. These considerations are relevant for the governance side of relations. In our analysis, we combine a perspective of 'competence', in the development of knowledge and skills, and a perspective of 'governance', in the control of 'relational risk'. For the perspective of governance, we employ elements from transaction cost economics (TCE; Williamson ,1975, 1985). The need for such a combination of competence and governance perspectives has been stressed, among others, by Williamson (1999), Nooteboom (1999) and Dosi and Marengo (2000). 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 view of inter-organisational relations

If we take into account the difference between locating and transferring knowledge, and the difference between simple and complex knowledge, and we take into account both competence and governance, we meet arguments for both weak and strong ties, and the aim of this article is to sort this out.
We will argue that in exploration, from the perspective of both competence and governance, there are good reasons, counter to the propositions from Granovetter (1973) and Burt (1992), for a dense structure of ties that are strong in one sense, though weak in another sense, while in exploitation there are good reasons for structures that are sparse, with ties that are strong in another sense than in networks for exploration. Hence we need to distinguish between different dimensions of the strength of ties.

In our analysis, from the perspective of learning and innovation, we build on the innovation literature, and we employ the notion of *exploration* and *exploitation* (Holland, 1975; 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). An urgent issue, in the literature on organisational learning, is how efficiency of exploitation can be combined with exploration. In particular, exploitation requires organisational routines, defined by Feldman and Pentland (2003: 96) as 'repetitive, recognizable patterns of interdependent actions, involving multiple actors'. However, routines should also be, and according to Feldman and Pentland in fact are, subject to change, in exploration. There is room for such exploration because in routines, exercised in 'communities of practice' (Lave and Wenger, 1991; Brown and Duguid, 1991) there is a margin of ambiguity and variability, since actual practice is too rich, with context-dependent knowledge, and too variable, to be completely specified by context-independent 'canonical rules'. However, it is not explained by what process such change (exploration) on the basis of functioning (exploitation) occurs. For such explanation, we employ Nooteboom's (2000) proposal of a 'cycle of discovery', to clarify how routines may change in their functioning, how exploitation and exploration build on each other, and how this goes together with integration and disintegration of organisational structures.
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 features are summarised in Table 1.

Table 1 about here

We proceed as follows. First, we discuss issues of competence, i.e. relevant features of knowledge and learning. Second, we discuss relational risk and instruments for its governance. Next, this yields an extension of relevant dimensions of the strength of ties. From the analysis, we develop a distinction between network requirements for exploration and for exploitation. Finally, to test the resulting hypotheses, we present evidence from two empirical studies of the emergence and development of networks in the multimedia and pharmaceutical biotechnology industries, both in the Netherlands

THEORETICAL ANALYSIS

Competence

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 and skills are different. This entails the notion of 'cognitive distance' (Nooteboom, 1999). The notion of cognitive distance is based on a 'constructivist' and 'situated action' view of cognition that we use, 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. Particularly important is the idea that absorptive capacity is cumulative: more of it helps to develop more of it.

'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). 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 application, and is shifted in the process. This underpins the idea, indicated in the introduction, that 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.

When we turn to organisational cognition, an issue, in the literature, has been whether that does not entail a category mistake, because, purportedly, cognition by definition entails a mind, and organisations do not have minds. How can organisations learn other than individual people learning in organisations, and other than by the dubious analogy of organisations employing processes akin to learning by individuals? Here, it is useful to employ the distinction, proposed by Gilbert Ryle, between 'know that' and 'know how', which is also known as the distinction between declarative and procedural knowledge, recognized in the MO literature by Cohen and Bacdyan (1994). In fact, the distinction goes back further, to the distinction in ancient Greek between 'episteme' and 'techne'. In organisations, declarative knowledge (know-that, episteme) may be stored in individual minds, and in organisational records, but there is no organisational mind. Procedural knowledge (know-how, techne), however, typically arises in joint organisational routines. It is hardly problematic to say that a group has, or may develop, a collective ability. Cook and Yanow (1993) used the example of an orchestra's ability to play a concert. They proposed that organisational culture is central to the notion of organisational cognition. What is learned, on the level of organisation, lies in a set of intersubjective meanings, beliefs, and values, expressed in language, metaphors, acts, symbols, ceremonies, myths, in other words culture, in the anthropological sense, which satisfy needs for identification but also exert pressures towards conformance. Organisational culture provides fundamental 'basic assumptions' (Schein, 1985), or basic cognitive categories, concerning man, nature, knowledge, and relations

between them. In other words, organisational culture is an institutional arrangement that enables and constrains actions and sense making, and includes relations of power and processes of exclusion (Contu and Wilmott, 2003). This cultural concept of organisations connects with the notion, proposed by Weick (1979, 1995) of organisation as a 'sensemaking system', the notion of Smircich and Morgan (1982) and Smircich (1983) of organisation as a 'system of shared meanings', and the notion of organisation as an 'interpretation system' (Choo, 1998). Organisations are cognitive entities in the sense that they guide cognition within them, again in the wide sense of perception, interpretation, understanding and value judgments. Kogut and Zander (1992) and Nooteboom (1992) used this notion in a response to transaction cost economics. Transaction cost economics proposed that mutual dependence, as a result of relation-specific investments, creates problems of relational risk, in opportunistic behaviour, which may require integration under organisational hierarchy to enforce monitoring and conflict resolution. However, under conditions of uncertainty, in innovation and learning, with increasing professionalisation of work, and in view of the indeterminacy of meanings resulting from the situated action perspective, hierarchy cannot yield adequate control by sanctions and monitoring. Kogut and Zander and Nooteboom argued that organisations set cognitive frameworks not only for guiding attention, perception, and interpretation (competence), but also for setting behavioural values, in a moral order, as a basis for behavioural norms that facilitate collaboration, constrain opportunism, build trust, and limit and resolve conflicts of interest (governance). Norms and values of behavior tend to be internalised, to a greater or lesser extent, by people, as part of tacit knowledge, assimilated in socialisation and habituation, as part of 'legitimate peripheral participation' (Lave and Wenger, 1991).

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. The task of organisations then is to sufficiently reduce such distance, in an organisational 'focus', including intellectual as well as moral categories, to enable the achievement of joint purpose. Note the difference between crossing and reducing cognitive distance. It is the difference between empathy and identification. Empathy entails the ability to understand, in so far as needed for effective communication, what others say and do, and identification entails commonality of thought, with shared mental categories. Organisational focus is closely related to organisational absorptive capacity. It not only 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 identity and scope of internal competencies. A wide scope, with a wide focus, entails limited identity. A limited scope, with a narrow focus and stronger identity, can be compensated by alliances. It is proposed that this trade-off is more fundamental than transaction costs for determining the boundaries of a firm.

The narrowness of organisational focus, and possibilities to combine exploitation and exploration, depend on three features of the exploitation system:

a. The *complexity* of division of labour, defined as the *number* of component activities and the *density* of direct ties of mutual dependence between them. Structure is *simple* when complexity is low.
b. The *modularity* of the system, on the basis of clear and stable constraints on activities, along such ties of dependence, in the form of *standards*, needed to maintain systemic integrity. The opposite would be ambiguity and variability of constraints, by which activities need to be continually coordinated.
c. The *tightness* of constraints, i.e. the scope for variety in contributions from component activities. Structure is *loose* when tightness is low.

We call exploitation 'systemic' when it has features a and b (complex and tight), and stand-alone in the opposite case (simple and loose). An example of the first is an oil refinery, and an example of the latter is a consultancy company. In case of feature b (modularity), component activities can be

autonomous, and can be replaced, as long as they satisfy the constraints on interfaces in the position they take in the structure. If exploitation entails a systemic structure, simultaneous exploration is constrained by the many and tight constraints on component activities. Exploration would soon yield a breaking of constraints on interfaces, yielding many unknown repercussions in the dense structure of dependencies, such as change of content of linked activities, which may in turn trigger change elsewhere, possibly resulting in wide ranging architectural change (Henderson and Clark 1990). Management would rightly be wary of accepting that risk and cost, unless there were a clear and proven potential of the novelty that would justify them.

Then, to combine exploitation and exploration, particularly when exploitation is systemic, there are two options: separation in place and separation in time. With separation in place, exploration would take place in a department that is de-coupled from exploitation, and this is what we find in many organisations, with, typically, a separation between production (exploitation) and R&D. Then, the problem is how to ensure that exploration is based on experience in exploitation, which is particularly important from the perspective of 'activity theory', according to which learning is based on practice, and to ensure that the outcome of exploration will be exploitable. With such separation in place, an organisation needs to combine a narrow focus for exploitation with a wide focus for exploration, which may jeopardize its identity as an organisation. Separation in time entails that a firm oscillates between exploitation and exploration, adjusting its structure as it moves from one to the other. Yet another solution is to try and make exploitation more stand-alone, with fewer and looser ties. However, no matter how narrow the focus is, in an organisation or part of it, people will never have identical cognition, since their cognition is constructed not only in their participation in the organisation as a whole, and in specific subcultures in the organisation, such as 'communities of practice', but also in their participation in outside cultures, such as those of professional and other social groups, including circles of private life. Nevertheless, organisational focus, i.e. an organisation's set of categories of perception, interpretation, and evaluation, yields a certain cognitive alignment, in a reduction (though not elimination) of cognitive distance. Variety of cognition, e.g. between different communities of practice, or between units of exploitation and units of exploration, would need to be coordinated by certain meanings and rules for communication and for alignment of purpose and style of interaction.

In processes of learning and innovation, in interaction between firms, cognitive distance, now in terms of difference in organisational focus, yields both an opportunity and a problem. The opportunity lies in diversity: the novelty value of a relation increases with cognitive distance. However, mutual understanding (absorptive capacity) decreases with cognitive distance. If learning performance from interaction is the mathematical product of novelty value and understandability, the result is an inverse-U shaped relation with cognitive distance. Optimal cognitive distance lies at the maximum of the curve. One can increase mutual understanding, but this entails an investment that may be largely or partially specific to a relation, so that by the logic of transaction cost theory the relation would need to last sufficiently long to make that investment worth while. Later, this will yield one of our arguments why especially in exploration, where knowledge is new and understanding cannot be taken for granted, ties require some strength, in the sense of investment in mutual understanding, and that relations must last sufficiently long to recoup that investment. Between firms, mutual identification increases, from whatever point they started, and cognitive distance is reduced, to the extent that they have engaged in continued interaction, especially when that interaction was exclusive. In other words, their foci start to overlap, in a shared epistemological and normative framework. This reduces the novelty value of a partner's cognition, with a reduction of the performance of learning. This suggests that while familiarity breeds trust (Gulati, 1995), it may also reduce learning potential, so that for the purpose of learning ties should not be too strong in terms of duration. In sum, next to optimal cognitive distance there is also something like an optimal duration of ties for learning: long enough to build mutual understanding and trust, but not so long as to run out of steam for learning. Empirical evidence for the hypotheses of optimal cognitive distance and optimal duration is presented in Wuyts et. al. (2003).

Governance

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 spill-over. In relational embeddedness, risk of lock-in includes the 'hold-up' risk from TCE. That is relevant here for several reasons, one of which is that it has implications for the intensity of a tie, in terms of its duration and frequency of interaction. Hold-up risk results from dependence as a result of relation-specific investments, defined as investments that have value only (or largely) in a specific relation. This yields switching costs: when the relation breaks, the investments have to be made anew in a new relation. For such investments to be made, the relation should be expected to last sufficiently long, and be sufficiently intensive, in frequent interaction, to recoup specific investments. Lock-in yields a temptation for the partner to expropriate value, in opportunistic behavior. Lock-in may also arise from structural embeddedness. Here one is locked into a community by (threat of) constraining coalitions of members of the community. There might also be network-specific investments, which can be used within but not outside the network. For specific investments we include the usual types, offered by TCE: location specificity of facilities, physical asset specificity (installations, tools, instruments), human asset specificity (training), dedicated capacity, brand name specificity, and time specificity. In the current context of learning, we add specific investments in absorptive capacity, for mutual understanding, and in building up relation-specific trust. Investment in mutual understanding is important, in particular, under conditions of exploration, in the emergence of unfamiliar, new, and often highly tacit knowledge.

Linkages with other actors yield access to variety of knowledge, but also a risk of spill-over. 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). Note that this risk therefore depends on density of the network. Thus, density has both a potential advantage of knowledge access, and a potential disadvantage of spill-over. Note that the assessment of spill-over 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 spill-over 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 and implement knowledge spill-overs. 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, spill-over risk drops out (Nooteboom, 1999).

Relational risks require governance to limit them and to create trust. Counter to TCE (Williamson, 1993), we hold that trust can go beyond calculative self-interest, in loyalty and 'benevolence', and yet be viable in markets, although we acknowledge that such trust should not be unconditional, and is subject to limits (Nooteboom, 2002). In the notion of trust, 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. A survey of instruments for governance, as 'sources of collaboration', is given in Table 2. 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), and between impersonal and personalised sources made by Shapiro (1987). The first arise from structural embeddedness, or they provide institutions for relational embeddedness, such as laws, norms, values, standards, and agencies for their enforcement. This yields 'institution-based trust'. This kind of trust requires that we trust those institutions to support trustworthiness of people and organisations. The 'micro' sources arise in specific relations, in relational embeddedness, and are often personalised.

The table further distinguishes between self-interested and altruistic or 'other-directed' sources of co-operation. We first discuss the self-interested sources. They are associated with the notions of deterrence and 'calculus-based trust' (McAllister, 1995; Lewicki and Bunker, 1996). In our reconstruction, 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. In inter-firm relations, *opportunity control* entails control by contract. Contracts are only useful to the extent that one is able to adequately specify them and monitor conformance to them. Even under the best of institutional conditions, legal ordering cannot be closed, including all relevant future contingencies, to carry their implications to the present ('presentiation') and cover them in the contract (Macneil, 1980). This is problematic especially in innovation, 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. 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. Large size and density of a network enhance reputation mechanisms. This is especially important when contracts are not feasible, as in innovation. 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. On the *macro level*, they lie in established, socially inculcated norms and values (macro). They include pressures of allegiance to groups one belongs to, and values and norms inculcated by socialisation into those groups. Of course, one can never be sure ex ante to what extent a stranger without reputation has actually internalised such norms and values. Here, Williamson (1993) was right in saying that under such conditions of behavioral uncertainty one must take the possibility of opportunism into account. However, that does not automatically imply that one should always go for control by deterrence, in opportunity and incentive control, even if they are feasible and effective.
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). Earlier, we suggested that trust has, and should have, limits. 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, proposed by Nooteboom (1999), 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). One takes the relation for granted and does not continuously think about opportunities to gain extra advantage. As Herbert Simon has taught us long ago, routinised behavior is rational in view of bounded rationality, since it allows us to focus our limited capacity for attention and rational evaluation on matters that are new and have priority. Routines are rational also in the sense that they are based on proven success in past behavior. On the other hand, their lack of awareness creates the problem that they may no longer be adequate when conditions change. However, when results or perceived events exceed certain tolerance levels, triggered by emotions routines are often summoned back from subsidiary into focal awareness, to be subjected to rational scrutiny.

Dimensions of tie strength

Following the discussion of relevant aspects of competence and governance, we argue that those entail that the context of collaboration has profound implications for how a network is structured and how it functions in view of a division of labour among its members. In particular, we claim that in innovation networks can vary in different dimensions of tie strength, depending on the context. First, we turn to network structure, in structural embeddedness. From a perspective of competence, recall that cognitive diversity has two dimensions: the number of cognitive frameworks in a network, which we may call variety, and cognitive distances between them. The first is determined by the *size* and *density* of the network. However, they also enhance spill-over risk. By definition, a highly systemic activity entails large network size and density. A more stand-alone activity allows for smaller and less dense networks. As another feature of network structure we propose network *stability*, which has implications for how variety develops in time. Another well-known feature of structure is *centrality*, of which there are several types. 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. Centrality may be needed for the coordination of activities. A central position yields power, but possibly also constraints on behavior, in view of the many interests it is involved in, and it may suffer from information overload. In view of the latter, structure may need to be hierarchical. From a perspective of governance, size and density affect possibilities of lock-in by coalitions, reputation mechanisms, and shared norms of ethical behavior (see Table 2).

Next, we turn to tie strength, in relational embeddedness. 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 the perspective of our theoretical analysis we review the 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 of issues, or on a wider range of issues, concerning technology, markets, organisation, and reputation of players in the network? Strength of ties also depends on cognitive distance, i.e. the difficulty to absorb knowledge. Greater distance entails more *investment in mutual understanding*. This may also be related to Granovetter's 'reciprocal services', or to his notion of 'intimacy/mutual confiding'. To the extent that this investment takes time and is specific, ties need to entail 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, frequency and duration facilitate learning they also facilitate spill-over. As argued earlier, long duration of a tie may lead to identification, which enhances mutual understanding and trust, 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.

From the perspective of governance, ties require instruments for the management of relational risk of lock-in and spill-over, specified in Table 2, and these yield yet other dimensions of tie strength. Governance may entail *control*, of opportunity or incentive, by contract, mutual dependence, or hostages. They may also entail *trust*, beyond control, in personalized relations, with a great deal of mutual openness, based on empathy, identification, or routinised behaviour. This appears related to Granovetters 'emotional intensity', but also to his 'intimacy'. Table 3 summarizes our proposal for six dimensions of tie strength, and their comparison with the dimensions proposed by Granovetter.

Table 3 about here

Networks for exploration and for exploitation

First we look at the implications of exploration for network structure, in particular density and redundance of ties, from a perspective of both competence and governance, and later we discuss the strength of ties. In networks for exploration, there is uncertainty concerning future dominant designs, in both technology and organisation, and hence also concerning the configuration of future networks for exploitation. One needs access to other actors who might offer complementary knowledge, but one does not know what elements of knowledge will turn out to be relevant when a dominant design develops. Also, one does not know what actors will survive by that time. Therefore, we claim, the network has to be *dense*, and this is where we start to diverge from the claims proposed by Granovetter and Burt. They assumed, implicitly, that one knows:

1. What knowledge will be relevant
2. Who has what knowledge
3. Who will survive to provide direct or indirect knowledge

And that:

4. One is able to absorb that knowledge

In exploration, however, one does not yet have such knowledge and absorptive capacity, and therefore one has to hedge relational bets. One has to maintain direct linkages even if they may later turn out to be redundant, to keep options of access open, covering for the risk that some ties will drop out and thereby eliminate indirect access to other sources. One does not yet know what will turn out to be redundant, since one does not know what the configuration of relevant elements of knowledge will be. In exploration, uncertainty is diffuse and wide ranging, so that interaction entails many issues, including technology, organisation and perhaps also future market demand, the availability of competent suppliers and so on. One does not know in advance what ties will turn out to yield access to the best source for what dimensions of knowledge. Even if a tie is known to be redundant for access to sources of knowledge, it may be needed to assess, understand and absorb knowledge accessed in another relation. 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. This connects with the argument from information theory that 'noise' is reduced when accessing multiple and redundant contacts (Shannon, 1957). In other words, a dense structure enables firms to 'triangulate' among their multiple sources and thus better assess their value, and to better absorb knowledge from them. Nooteboom (1999) identified several further roles for 'third parties' that will not be discussed here.

The argument against redundant relations, from Granovetter and Burt, was that their set-up and maintenance yield excess costs. However, relevant costs are only relation-specific investments in mutual understanding, 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 production, marketing, distribution, and servicing. Furthermore, in exploration, costs are less of an issue, 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. 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.

To maintain the variety of cognition needed for exploration, network *stability* is expected to be generally low, allowing for entry and exit. In incremental innovation under systemic conditions, network *centrality* may be high, for the sake of coordination, to ensure that the different components of the system change in tune with each other. 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.

From a governance perspective, in exploration the use of contracts is problematic. 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 professional and relation-specific trust. A reputation mechanism is especially strong here, 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 yield an important connection, one has to be careful in *all* relations. The point now is that *density* of relations is needed for a reputation mechanism. 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.

Now we turn to the strength of ties. First of all, we already noted above that in exploration uncertainty is wide ranging, covering many possible issues of technology, market and organisation, and as a result ties tend to be strong in the dimension of *scope.* We also noted that building mutual understanding might require a *relation-specific investment*, which requires sufficient *frequency of interaction* and/or *duration*, to make such investment worthwhile. 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, in frequent contacts, and duration, though it should be sufficient, *need* not be long. How 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 both A and B also have other ties, on the same subject, to different nodes, apparently unafraid of spill-over risks, 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.

As argued before, under the uncertainty of exploration governance by contract and monitoring is often problematic, 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, 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 *mutual openness* (Zand 1972), and entails a certain ‘emotional intensity’ (Granovetter). It is known from the trust literature that trust is stimulated by mutual dependence. 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.

In sum, our hypothesis is that in exploration ties tend to be strong in terms of scope, frequency and trust/mutual openness, of some strength in terms of relation-specific investments, depending on the complexity and tacitness of knowledge, and some duration, depending on how systemic the technology is. They are generally not strong in control, and duration should be limited, depending on how exclusive relations are.

A potential problem now is that density of the network, investment in mutual understanding, frequency of interaction, and trust and openness may yield a high risk of spill-over. However, at this

stage, in exploration, with large uncertainty on what dominant design will emerge, and to what products it will lead, in what markets, knowledge often is 'pre-competitive', so that spill-over risk may be limited. Also, it may be difficult to assess who will in future turn out to be a potential competitor. Restricting relations for fear of spill-over would soon entail no relations at all. Finally, knowledge may change so fast as to eliminate serious spill-over risk. Another potential danger 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. To counter this, as discussed above, ties should not last too long, especially when technology is systemic and innovation is frequent and architectural, and network stability should not be large, offering a certain volatility of network membership, for the sake of novel combinations. This, we think, is where the thesis of the strength of weak ties comes into its own.

In sum, our hypotheses for a network for exploration are as follows:

- Network structure needs to be sufficiently *dense* for three reasons. First, to enable a hedging of bets on the selection of partners. Second, to utilize third parties to aid judgement of the meaning and value of knowledge (triangulation), and to aid in its absorption. Third, to yield reputation mechanisms, needed in view of the limited feasibility of contractual control. Cost of redundant relations is both limited, 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. Networks also need to provide values, norms, and standards, as an institutional basis for trust, needed next to reputation. Structure should not be too *stable*, and should allow for sufficient entry and exit, to enable frequent architectural innovation, if that is important.
- Ties are generally weak in *control*, but strong in terms of *scope*, *frequency* of interaction, *trust and mutual openness*, and *investment in mutual understanding.* Trust is needed, next to reputation mechanisms, due to the limited feasibility of contractual control. 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.

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 size of economies of scale. The drive for efficiency requires the elimination of redundant relations. Thus 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*.

Now we turn to the strength of ties. Implications of these investments for the *duration* of ties depend on the extent to which they are relation-*specific investments*, which depends 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).

The different conditions for networks for exploration and exploitation are summarised in Table 4.

Table 4 about here

Admittedly, the distinction between exploration and exploitation is stark, and intentionally so, to clarify the extremes. However, it is too stark to cover the complexity of reality. This is already reflected in the variability of some parameters, since they depend on further contingencies of technology, market, and institutions: systemic/stand-alone, tacitness of knowledge, speed of knowledge change, flexibility of technology, economic life of investments, economies of scale, entry barriers, legal institutions, institutions for trust, etc. This is in line with our claim that network requirements are to some extent context-specific.

Furthermore, we need to consider the connection between exploitation and exploration. According to Nooteboom's (2000) 'cycle of discovery', exploration is based on exploitation, consistent with the 'activity theory of knowledge', along the following lines. First, application is shifted to new contexts (e.g. market conditions), in a process of 'generalisation', leading on to 'differentiation', i.e. marginal adjustments that preserve existing architecture, in an attempt to fit to the new conditions, followed by experimentation with novel elements adopted from different practices encountered in the new context ('reciprocation'), yielding hybrids, which may then provide the incentives and insights for more radical innovation, in new architectures of old and new elements ('novel combinations'), which then develop into new 'dominant designs'. When exploration develops into a dominant technical design, there is a shift, in the movement towards exploitation, to the development of a dominant design for production and distribution. In these transitions between, and combinations of exploration and exploitation, hybrid forms of network may arise.

In view of the possible problems of combining exploitation and exploration inside a single organisation, there may be a division of labour, with some firms focusing on exploitation and others on exploration. This may yield networks for exploitation and networks for exploration, with an intermediate, connecting network. Such a structure is known in the biotechnology industry, and that is one of the reasons why in the present study that industry was selected for empirical study. We are not sure how to hypothesize the features of such an intermediary network.

Combinations of exploitation and exploration may be made in a core network for exploitation, with the corresponding features specified in Table 3, connected to peripheral networks for exploration, with their corresponding features. This may be compared with the separation in place between departments for exploitation and exploration within a firm. That would yield a sparse and stable core, often with high centrality, with ties that are strong in size of investments, duration and control, combined with a less stable, more dense, less centralized fringe of ties that are weak in these dimensions and strong in others (scope, frequency, trust/openness).

There may also be separation in time, where exploration networks in the transition to consolidation in dominant designs, with preparations for market expansion, are transformed into exploitation networks,

with larger scale organisations, elimination of redundancy, emergence of centrality, larger specific investments, less informality, fewer personalised relations, more distrust, and more formal control. To investigate what actually happens we now turn to the empirical part of the study.

EMPIRICAL STUDIES

Methodology

The methodology used for our empirical studies is that of using two contrasting longitudinal case studies that were chosen for the expectation that they would yield networks for both exploitation and exploration, so that our hypotheses concerning such networks, specified in Table 4, could be tested against observations. The emergence of multimedia was chosen because an initial analysis suggested that here there appeared to be a transition from exploration to exploitation, in a 'separation in time'. Biotechnology was chosen because it was known to entail a division of labour, with exploration in universities and small biotech companies, and exploitation in large pharmaceutical companies, in a 'separation in place'. This allowed us to investigate how exploitation and exploration might be connected, in such separation in place.

The multimedia case

Over the 1990's two innovation patterns occurred in the Dutch multimedia industry. One emerged in the early 1990's, and peaked around the mid 1990's, with its main focus on technological exploration. A second innovation pattern emerged from around 1995, and peaked around the start of the new century. In this pattern the focus was more on exploitation, in a fast development of multimedia products for a growing mass-market. Thus, here we find a case of separation in time, with a network transforming itself from exploration to exploitation.

Innovation pattern 1:Technological exploration
Innovation in the Dutch multimedia industry started to take off after the adoption of Internet as the worldwide standard for on-line communication, around 1990. Before the advent of Internet, the technological knowledge base was scattered over a variety of separate technologies such as information -, communication -, audiovisual- and data-transmission technologies. These technologies were mostly stand-alone, and most exploration was done by large, R&D-intensive firms, each in its own domain. The arrival of Internet yielded the insight that for its full utilisation a fundamental restructuring of these various technologies was required, in technological convergence. Continuous progress in the field of digitalisation provided a technical opportunity for this. Thus, Internet, together with perspectives for digitalisation, provided powerful incentives to actively search for convergence of these technologies, in new applications. This led to an increasing number of new entrants, from the early 1990's onwards, who focused on the opportunities offered by technological convergence. These new entrants complemented the search activities of the large, R&D-intensive firms, creating a newly emerging innovation trajectory. An innovation pattern developed in collaboration between small, specialized multimedia firms and specialized suppliers of hard-& software. Their joint exploration and search activities resulted in an increasingly *systemic* integration of technologies such as information technology, communication technology, screen display technology and language technology. The development of a multimedia-application required the integration of different technologies for which change in one required adaptations in others. As a result, strong interdependencies developed to effectuate technological integration. Firms needed to cooperate in hard- and software, in joint development, where no single firm disposed over the necessary knowledge of all technologies. This created a complex search-process: when exploring the convergence of different technologies, one had to consider first which technologies had relevance, and next to consider all of these potential relevant technologies simultaneously, due to their interdependence. This search process took place by much trial-and-error, with a great deal of *tacit* knowledge on which search directions to explore and how to explore them. This inhibited a more structured approach to the search process, making it difficult to create a division of labour. To 'organise', then, for the rapid exchange of this tacit knowledge, informal networks of symmetric relations developed. Coordination of these relations was mainly through a 'free-souls mentality', which entailed a large degree of informality, *openness, trust, lack of*

formal control, and lack of concern for spill-over risks. In this network, it was rational not to be obsessed with appropriability, but rather to stay connected with the exploration activities going on and to 'live and let live' in order to keep up to date with the rapidly changing knowledge base. Empirical evidence of this 'free-souls mentality' was found, for example, in the network of firms that cooperated in the technological exploration of multimedia image processing technology in the period around 1996-1998. When asked what they perceived as the most important benefit of cooperation when exploring this new technology, 60 – 65 % of the firms mentioned access to and exchange of knowledge, and only 5–10 % indicated that they worried about the risk of spill-over (Oerlemans and Meeus 1999). Spill-overs within this network were frequent, but were both outgoing and incoming, and not engaging in this flux was not an option. There were ample opportunities for hold-up, but these also did not cause any great concern. This mentality of give and take developed due to the fact that firms needed each other, and there were no alternatives. Then one will simply have to make it work, on the basis of trust. Trust was engendered by mutual respect among professionals struggling with shared problems. An informal safeguard against free-riding and spill-over was that in order to keep up with the rapidly changing knowledge base, all partners had to do their part, in give and take, to keep up with the development of their absorptive capacity, and shared tacit knowledge, to benefit from what partners develop. Also, give and take was supported by a strong reputation mechanism in overlapping communities with frequent contacts. To deal with this uncertainty at both the input side (what to use) and the output side (whom to supply to) of the search process required a *dense* network structure with *low centrality* and *low stability*, with a large number of new entrants. Ties were strong in terms of *frequency* of interaction, mutual openness, on a variety of issues (*large scope* of interaction), and were of fairly *short duration* (from a few weeks to a few months). This combination of dimensions of tie strength created the possibility for an easy recombination of ties so that the systemic knowledge base could be explored rapidly.
In sum, this network matched the hypotheses for an exploration network under systemic conditions (Table 4) perfectly.

Innovation pattern 2: Technological exploitation
Increasingly, different elements of the knowledge base in multimedia technology became more codified, for example by means of downloadable software from the Internet. In combination with a growing market for on-line applications, this led to the development of a second, more incremental, exploitation-oriented innovation trajectory with a dual learning object: the understanding of customer needs as well as keeping up-to-date with the constantly changing technological knowledge as explored in learning regime 1. Empirical evidence of this dual learning was that, according to an extensive survey on multimedia firms by Peelen et.al. (2000), between 65-70 % of all multimedia firms especially invested in a better understanding of customers (through improvements in marketing, communication and customer focus) as well as in knowledge on (adjacent) technologies.
As a result, a second type of innovation pattern emerged around 1995 that consisted of firms from more traditional industries such as printing, advertising, audio-visual production, IT or pr/advertising. The network structure reflected a growing division of labour: communication with customers was done by a centrally positioned 'main-contractor' with a reliable reputation (*high centrality*), surrounded by a *stable* structure of firms with specialised competencies for solving various technical issues. The focus of this network was on quick delivery of standard products such as e-mail and websites, enabled by an increasingly *codified* knowledge base.
The dominant mode of organising consisted of a relatively *non-dense* network of ties, mainly between the core firm and the various supplying firms. These relations were of *long duration*, with *frequent* interaction to accommodate the integration and delivery process, mostly concerning specific, specialised issues, in *limited scope*, related to this integration and delivery process. As analysed, these supplying firms only had direct ties among one another when needed in view of the integration process. For appropriation, the network needed to be able to deliver a 'turn-key solution' that required from the involved firms that they could understand one another well and could count on one another.
In sum, the systemicness of the knowledge base in combination with demand for quick delivery of relatively standard products yielded a relatively non-dense and stable network, with high centrality, with durable ties, and frequent interaction, that integrated all required, complementary skills.

Governance was based on mutual dependence, reputation built on past performance, and trust in intentions, all supported by the fact that most of the partners came from within a region. Spill-over risk was governed by mostly *exclusive* relations. Over the 1990's, this system turned out to be self-reinforcing. When relations endured and experience accumulated, firms grew closer in terms of cognition and trust-in-intention and could therefore speed up their single-loop learning. This further enhanced possibilities to appropriate, which reinforced the existing network structure and further deepened the learning regime embedded in this network.
In sum, this network confirmed most, but not all, of the hypotheses for an exploitation network for systemic technology, specified in Table 4: a non-dense, stable structure, with high centrality, with ties that were strong in terms of duration and weak in terms of scope. Counter to the hypotheses, ties were strong in frequency, and governance was not based so much on formal control as on mutual dependence, reputation, and high trust and mutual openness, supported by regional embedding. This deviation from hypotheses can be explained by the fact that although the network was oriented towards exploitation, there was still a great deal of incremental innovation, in single-loop learning, to optimise and fine-tune novel configurations of technology and service.
Some players, such as notably publishers, had to make radical changes to their core activities and organisational 'focus'. This highlights another deviation from theory. Nooteboom's (2000) cycle of discovery had suggested that firms start to explore by voluntarily seeking novel contexts of practice, in 'generalisation'. In this case, publishers were forced to explore, or lose out completely, by the novel context of Internet being forced upon them. They had been (and to some extent still are) holding back, using Internet only for presenting their traditional products in new ways, rather than for configuring novel products, in mixed media, in full utilisation of the opportunities offered by digitilisation. As a result, entrepreneurial spirits within publishing companies, frustrated by this conservatism, spun off their own ventures, thus contributing to the entry of new players in the earlier exploration network.

The biotechnology case

From the early 1990's towards the early years of the 21st century, there is a 'new breed' of Dutch biotechnology firms. The number of entrants rose from 4 in 1992 to 10 in 1998, making 50 in total. Most of these Dedicated Biotechnology Firms (DBF's) saw R&D as their core activity and they specialised, through contract research, in general platform technologies with a potential of wide variety of applications in the pharmaceutical industry as well as in non-pharmaceutical applications such as agriculture and food. There are many technological spill-overs by means of licences to different parts of the biotechnology sector both inside the Netherlands and internationally. Especially platform-technologies generate such spill-overs in pharmaceutical applications such as e.g. genomics, combinatorial chemistry, high-throughput screening and bio-informatics. These technologies also have a potential for application in a wide variety of non-pharmaceutical applications such as plant breeding, food-processing (e.g. diagnostic kits), speciality chemicals, other applications of bio-informatics, and biological catalysis (Enzing and Kern, 2002). DBF's that specialise in platform technologies generally do not have the ambition to become an independent producer of pharmaceuticals. Rather, they aim to provide tools and services to pharma firms that are involved in drug discovery and development. The advantage of this dual structure of exploration and exploitation model is its potential for rapid commercialisation with (hopefully) fast cash-flows.
In the course of the 1990's, a 'knowledge-exploration value chain' emerged in the field of general platform technologies in the Netherlands, which can be schematically depicted as follows:

Science ⟷ ***DBF's*** ⟷ ***Large Pharma firms***

Within this value chain we can identify 2 main types of innovation patterns:
Innovation pattern 1 **:** embedded in a network of DBF's with academia.
Innovation pattern 2 **:** embedded within a network of one or more DBF's with a large pharma firm.

Here, DBF's, as intermediaries between exploration and exploitation, perform a key role in commercialising scientific knowledge. They connect a 'basic-science environment', with its emphasis

on new knowledge, with a 'techno-economic environment' that emphasises economic value (McKelvey, 1997). In this way, DBF's are faced with a dual selection environment, which stresses scientific excellence on the one hand, and economic performance on the other hand. We now analyse both innovation patterns in turn.

Innovation pattern 1 :Technological exploration

Innovation pattern 1 is embedded in a network that is made up of relations between DBF's and (public) research institutes, with a strong focus on exploring new knowledge. The knowledge base on general platform technologies was mainly of a *stand-alone* nature, due to its strong scientific base in molecular biology and genetic engineering. Due to some high quality research at Dutch universities, there were opportunities for Dutch DBF's, although mainly pertaining to some niches (Degenaars and Janszen, 1996). Although the final outcome of this search process was highly *codified* knowledge (through publications), the search process of scientific discovery itself was characterized by a lot of trial & error and was highly specific to individual persons and research communities. This process entailed many tacit elements that were difficult to codify, such as the formulation of hypotheses, test set-up, accurate execution, interpretation of test results, reformulation of hypotheses and so on. It was characterized by serial, incremental improvements that led to the accumulation of tacit knowledge within stable research groups of academics and DBF's (Casper, 1999). In this network, a clear spatial concentration could be observed, especially around the universities of Amsterdam, Groningen, Leiden, Utrecht, Nijmegen, Wageningen, Maastricht and Delft. The mainly tacit search process entailed that personal contacts, with *high specific investments in mutual understanding* and *frequent interaction* were necessary to allow for an effective transfer of this tacit knowledge (Allansdottir et.al., 2002). In addition, physical proximity enabled easy access to a talent pool of skilled workers, which enabled knowledge spill-overs by the mobility of researchers. In addition, opportunities were generally diffuse, which required regular checks and adaptations of the search process into the most promising search direction. The importance of physical proximity was further indicated by the fact that most patents were assigned to inventors from within the Netherlands (Enzing and Kern, 2002). So, we find an innovation pattern characterised by substantial exploration and searching around a specific area of expertise, resulting in a high level of cumulativeness of tacit and mainly stand-alone knowledge shared throughout a network of academics and biotech-firms.

To deal with this complex search process a *dense,* and dispersed (*little centrality*) network emerged between universities and research institutes on the one hand and DBF's on the other hand. This network was built up relations of fairly *long duration* (lasting years), a *high frequency of interaction,* in *mutual openness,* although limited to a fairly *narrow scope* of mostly scientific issues. Spill-overs within this network were frequent, and mutual understanding was fairly specific, creating a risk of hold-up. Governance was based on a combination of *formal control,* with contracts, supported by monitoring by peer control and review, and on mutual dependence.

This confirms some but far from all our hypotheses for exploration networks. Confirmed are the density and non-centrality of structure, and ties that are strong in terms of frequency of interaction, specific investment in mutual understanding, and mutual openness. In contrast with the hypotheses are: considerable stability of the network, the long duration of ties, narrow scope, and governance by formal control. While there is much mutual openness, trust is not so clear. How can this be explained? Narrow scope of ties can be explained by the fact that the knowledge involved was highly stand-alone and specialised, and there was no need to explore also on subjects such as organisation, production, marketing and distribution. One of the theoretical arguments against the use of contracts, in exploration, was based on the assumption that then knowledge is highly tacit. Here, we find that in processes of development the skills involved are highly tacit, but the outcomes are highly codified, and those can be, and are, subjected to formal monitoring and control. Concerning the duration of ties, note that the theoretical analysis predicted the need for *sufficient* duration of ties, to make specific investments in mutual understanding worth-while, and here the need for in-depth understanding of highly specialised knowledge required high levels of such investment. Also, in view of the stand-alone technology short ties were not as important, for innovation by reconfiguration of elements in a system, as under the systemic technology of multi-media. However, duration did seem excessive. The theoretical argument against stable structure and ties of long duration was that those would jeopardize

the diversity of knowledge needed for radical innovation. Did that occur? In the theoretical discussion it was noted that durable ties would not necessarily lead to inertia, provided that they are not exclusive, and nodes in some way obtain fresh insights from outside sources. This is precisely what showed up in further analysis.
Further analysis showed that the network might be seen as a 'core' network, complemented by a *non-stable, dense* periphery of ties with *short duration*, outside the Netherlands, tapping into state-of-the-art knowledge from outside universities and firms. This was mostly in codified form, such as papers, which were relatively easily accessible from a distance, and could be governed by formal means such as licenses and research contracts. The high rate of change of knowledge made that such distant sources of knowledge succeeded one another on a regular basis, which required the constant monitoring for new potential sources. So, the strength of these ties was *low in duration*, with only very limited interaction on a *narrow scope* of issues, mainly restricted to the contents of the license. Substantial technological interdependencies were absent so that ties could be replaced without the risk of creating bottlenecks in adjacent technological areas.
In sum, in innovation pattern 1 a dual network structure emerged, built up of a dense and stable network of local ties strong in frequency, specific investments, duration and control, supplemented with an instable fringe of short ties with no specific investments and little frequency of interaction, which are, at times, strong only in control (in case of contracts or licensing). The core network deals with complexity and the periphery offers variety. In the core, dense, local relations provide stability for the development of an in-depth understanding and triangulation. In the periphery, there are varying levels of entry/exit and low strength (in all dimensions except, occasionally, formal control). The value of knowledge originating from the outside sources was assessed by the members of the core network.

Innovation pattern 2: Business exploration

Innovation pattern 2 was concerned with business exploration, i.e. the development of commercially viable products rather than with exploring new knowledge, in a network of relations between DBF's and large pharma firms. The rationale underlying this network was as follows. Large pharma-firms were exploitation oriented, but needed to keep up to date with a rapidly changing knowledge base, with all its diversity, built up from various scientific disciplines. At the same time, business opportunities pertained to niches and were also difficult to define up-front, making it difficult for pharma firms to decide which fields of knowledge to invest in and which to ignore. To deal with the variety of expertise and the diffuseness of opportunities, the pharma firm contracted, in *formal control*, a number of DBF's that offered a variety of specialised expertise. This enabled the pharma firm to explore various opportunities at the same time without the need to make substantial investments and commitments.
Since knowledge is highly *stand-alone*, specialised and specific to the DBF's, the network is made up of mainly bilateral relations between large pharma-firms and DBF's, with little interaction among those. In other words, there was *high centrality* of the pharma firm, and *little density*, in a hub-and-spoke structure. From the viewpoint of a large pharma firm, he was basically subcontracting research to a DBF and his interest lay not in the research process itself, but in the codified knowledge coming out of it, for which he had sufficient absorptive capacity, so that *little specific investment* for understanding was needed, and *frequency of interaction was limited* (between twice a month and twice a year). Hence, they faced little hold-up risk, and ties did not *need* to be of long duration, at least from the perspective of the pharma firm. In fact, *duration was generally fairly long*: between 2 and 5 years. However, the pharma firm evaluated contracts with DBF's on a regular basis. Depending on the outcome of such an evaluation, the contractual relation was durable up to the point that opportunities proved to be viable. If not, relations terminated and parties separated. In other words, network structure was in fact *fairly stable*, but *not necessarily so*. Since the DBF's could not absorb or implement the pharma firm's core activities of lengthy clinical testing, and large-scale production and distribution of end products, risk of spill-over to DBF's was very limited. Thus, from the perspective of the pharma firm there was no need for exclusive ties. *Openness and trust were very limited*, in view of codified knowledge and formal control, and interaction was limited to a *narrow scope* of activities.
In sum, apart from some ambiguities, this network conformed to the hypotheses for a network of exploitation, with a structure of low density, considerable stability, and high centrality, and ties that

are strong in formal control, fairly strong in duration, and weak in frequency, specific investments in mutual understanding, trust and openness. The ambiguities concern the stability of structure and the long duration of ties, while from the perspective of the pharma firm there was little reason, due to limited specificity of investment and limited systemicness of the technology.
From the perspective of the DBF, however, the situation looks quite different. A DBF seems to have to make fairly specific investments, to understand the needs of the pharma firm, and to know who to deal with, and how, in its large organisation. And how about spill-over risk? Could sensitive information on its knowledge spill over to a competing DBF that is also a spoke of the pharma hub? To what alternative pharma firm does a DBF have access, and what are its switching costs? It seems that while the pharma firm can easily switch between DBF's, the DBF's are more captive. In fact, dependence appears to be rather one-sided, making the DBF vulnerable. Perhaps the stability of the network and the long duration of ties is a concession to the DBF's. However, we are not surprised to see that in this arrangement the profitability of the DBF's is generally low. In this structure they can maintain their profitability only if they can offset their dependence by a unique and scarce competence that is in high demand among several pharma firms. Alternatively, they should also engage in production of specialties, in niche markets for which dependence on a large pharma firm is less.

CONCLUSIONS

We started this article with a number of claims that were based on a constructivist, situated action theory of knowledge. One claim was that the optimality of network structure is a function of the context. In this article we have examined the context from a learning and innovation perspective, distinguishing networks for exploitation, exploration, and combinations between them, and allowing for further contingencies of technology and market, such as, in particular, systemic versus stand-alone technology, more tacit versus more codified knowledge, the complexity of knowledge and the degree to which relation-specific investments need to be made for mutual understanding.

A second claim was that in the analysis of networks attention needs to be paid to issues of both competence, in learning, and governance, in the management of relational risk. In the latter, risks should be included of hold-up and spill-over. A third claim was that, counter to the thesis of the 'strength of weak ties', there are good arguments, from competence and governance, that for exploration network structure needs to be dense and ties need to be strong in some dimensions, while for exploitation structure should be less dense, and ties should be strong in different dimensions. For this, we developed new dimensions for the strength of ties, although some correspondence could still be found with the dimensions suggested by Granovetter. We proposed six dimensions, as follows: scope of activities involved in the tie, size of relation-specific investments for mutual understanding, frequency of interaction, duration of the tie, formal control and trust/openness. We argued that, in general, in exploration ties are strong in scope, specific investments for mutual understanding, trust/openness and frequency, while duration should be 'sufficient' but not too long. 'Sufficiency' depends on the size and economic life of specific investments in understanding, on the need to maintain flexibility of configuration, which arises especially in a systemic environment, and on the exclusiveness of relations. In exploitation, by contrast, ties are generally strong only in control and duration, and weak in other dimensions. So, if we were to count dimensions of strength, in exploration ties would be stronger rather than weaker than in exploitation.

Our hypotheses were tested in empirical analyses of the Dutch multimedia and pharmaceutical biotechnology industry. The first offered an example of a separation of exploration and exploitation in time, with network structure evolving from the first to the second, and a systemic technology. The second offered an example of a separation of exploration in place, with exploration in networks of universities and biotech firms, exploitation in pharma firms, and biotech firms in a (not very lucrative) linking position, and stand-alone technology.

Most of the hypotheses were confirmed. The innovation pattern in the multimedia industry that focused on technological exploration confirmed our hypothesis that network structure is dense and ties are strong in scope, investment in mutual understanding, frequency of interaction, trust/mutual

openness, and limited in duration. This enabled a rapid exploration of a systemic knowledge base through a rapid recombination of ties. The second innovation pattern in multimedia of technological exploitation largely confirmed our idea of a network in exploitation, characterized by a low density and ties that were strong in terms of duration but showed limited strength in terms of scope, frequency of interaction, specific investments in mutual understanding and trust/openness.

In the pharmaceutical biotechnology industry we identified two innovation patterns. The innovation pattern that engaged in technological search and exploration confirmed our hypothesis of a high network density and high tie strength in terms of frequency of interaction. However, in contrast to our hypotheses were the findings that the strength of ties was high in terms of duration, formal control, and openness, but low in scope, and limited in trust. This yielded interesting lessons. Narrow scope could be understood from the fact that technology was stand-alone and highly specialised, and in its focus on science there was little need to include issues of organisation, production, marketing and distribution. Formal control could be understood from the fact that while especially process knowledge was highly tacit, as assumed in the theory, performance could well be judged on the basis of the codified outcomes of the process, thus allowing for enforceable contracts. Long duration could still be understood, according to the underlying theory, as resulting from high specific investments in mutual in-depth understanding in a complex field of knowledge. However, according to theory they would jeopardise the variety of knowledge needed for exploration. Interestingly, closer analysis showed that the core network of durable ties was complemented by a peripheral network of more volatile ties, to access outside state-of-the art knowledge. This confirms the original idea that long duration may not have negative effects on exploration, provided ties are not exclusive, and the nodes involved tap into outside sources which are more variable, in ties of short duration. The innovation pattern that engaged in exploitation again confirmed all relevant hypotheses.

The lessons from disconfirmation can be summarised as follows:

1. While in exploration much knowledge is tacit, as originally assumed, the knowledge output that is exchanged may be highly codified, as in scientific research. This enables the use of contracts and monitoring for governance, in contrast with our hypotheses.
2. In contrast with our hypotheses, in exploration ties of long duration may not only be needed, in view of high and highly specific investment in mutual understanding, but may also be warranted, provided that ties are not exclusive, and the nodes involved also tap into outside sources that are more variable and of short duration.
3. Counter to our hypotheses, in exploration ties can be weak in scope, particularly in scientific exploration, where knowledge is highly specialized and stand-alone, and issues of organization, production, marketing and distribution are not (yet) relevant.

Note that these lessons do not weaken our overall argument against the thesis of the strength of weak ties. We hypothesized that in exploration ties would be strong in scope, investment in mutual understanding, trust and openness, of intermediate strength in duration, and weak in control. Now we find that they may be strong in duration and control, and weak in trust and scope. What pattern of tie strength arises depends on contingencies, such as the tacitness of knowledge exchanged, the systemicness of knowledge, and on whether exploration is scientific or technological. This further confirms the thesis that optimal structure depends on conditions. However, in exploration ties remain strong in most dimensions.

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: sources of collaboration

	macro; universalistic	micro; particularistic, relation-specific
self-interest		
opportunity control	contracts, legal enforcement	hierarchy, managerial 'fiat',
incentive control	reputation	dependence: unique partner value, switching costs, hostages
altruism benevolence	values, social norms of proper conduct,, moral obligation, sense of duty, bonds of kinship	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	trust/mutual openenness
	formal control

Table 4: networks for exploration and exploitation

network features	exploration	exploitation
network structure:		
density	high	low
stability	limited*	high
centrality	low	often high
strength of ties:		
scope	wide	narrow
duration	limited*	often long
frequency of interaction	high	low
control	low	high
trust/openness	high	generally low

* especially when technology is systemic

References

Ahuja, G.
2000 'Collaboration networks, structural holes and innovation: a longitudinal study', Administrative Science Quarterly , 45: 425 – 455

Allansdottir, A., A. Bonnaccorsi, A. Gambardella, M. Mariani, F. Pammolli and M. Riccaboni
2002 Innovation and competitiveness in biotechnology, Enterprise papers 7-2002, DG-Enterprise, European Commission, Brussels

Argyris, C. and D. Schön
1978 Organizational learning, Reading, MA.: Addison-Wesley.

Bateson, G.
1972 Steps to an ecology of mind, San Francisco: Chandler Publishing Company.

Bazerman, M.
1998 Judgement in managerial decision making, New York: Wiley.

Blackler, F.
1995 'Knowledge, knowledge work and organizations: An overview and interpretation'. Organization Studies, 16/6: 1021-1046.

Brown, J.S. and P. Duguid
1991 'Organizational learning and communities of practice: Toward a unified view of working, learning, and innovation', Organization Science, 2/1: 40-57.

Burt, R.
1992 'Structural holes: The social structure of competition', in N. Nohria and R. Eccles (eds.), Networks and organizations: Structure, form and action, Boston: Harvard Business School Press: 57-91.

Casper, S.
1999 High technology governance and institutional adaptiveness: do technology policies usefully promote commercial innovation within the Geman biotechnology industry, NIAS Working Paper, Wassenaar

Choo, C.W.
1998 The knowing organization, Oxford: Oxford University Press.

Cohen, M. D. and L. S. Sproull (eds.)
1996 Organizational learning, London: Sage.

Cohen, M.D. and P. Bacdayan
1996 'Organizational routines are stored as procedural memory', in M. D. Cohen & L. S. Sproull (eds.) (1996). Organizational learning, London: Sage, 403-430; first printed in Organization Science, 5/4, in 1994.

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

Coleman J.S.
1988 'Social capital in the creation of human capital', American Journal of Sociology, 94: 95-120.

Contu, A. and H. Wilmott
2003 'Re-embedding situatedness: the importance of power relations in learning theory', Organization Science, 14/3: 283-296.

Cook, S.D.N. and D.Y. Yanow
1993 'Culture and organizational learning', Journal of Management Enquiry, 2/4: 430-459.

Degenaars, G.H. and F.H.A. Janszen
1996 Biotechnology on the way to the year 2000, A future perspective for Dutch industry (in Dutch), report for the Dutch Ministry of Economic Affairs, Erasmus University Rotterdam.

Deutsch, M.
1973 The resolution of conflict: constructive and destructive processes, New Haven: Yale University Press.

Dosi, G. and L. Marengo
2000 'On the tangled intercourses between transaction cost economics and competence-based views of the firm: a Comment', in: N. Foss and V. Mahnke (eds.), Competence, Governance and Entrepreneurship, Oxford: Oxford University Press

Enzing, C.M. and S. Kern
2002 End report life sciences impact (in Dutch), report for the Dutch Ministry of Economic Affairs, TNO-STB, Delft

Feldman, M.S. and B.T. Pentland
2003 'Reconceptualizing organizational routines as a source of flexibility and change', Administrative Science Quarterly, 48: 94-118.

Geenhuizen, M. van
1999 'How small biotechnology firms survive in the Dutch pharmaceutical industry: an exploratory analysis', in: R.P. Oakey (ed.), New technology-based industries in the 1990's, London: Paul Chapman: 200–212

Granovetter, M.S.
1973 'The strength of weak ties', American Journal of Sociology, 78: 1360-1380.

Gulati, R.
1995 'Familiarity breeds trust? The implications of repeated ties on contractual choice in alliances', Academy of Management Journal, 38: 85-112.

Hagedoorn, J. and G.M. Duysters
2002 'Satisficing strategies in dynamic inter-firm networks - the efficacy of quasi-redundant contacts, Organization Studies, 23: 525-548.

Hansen, M.T.'
1999 'The search-transfer problem: The role of weak ties in sharing knowledge across organization subunits', Administrative Science Quarterly, 44/1: 82-111.

Hedberg, B. L. T.
1981 'How organizations learn and unlearn', in P. C. Nystrom and W. H. Starbuck (eds.), Handbook of organizational design, New York: Oxford University Press: 3-27.

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

Holland, J. H.
1975 'Adaptation in natural and artificial systems', Ann Arbor: University of Michigan.

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

Kolb, D.
1984 Experiential learning: Experience as the source of learning and development, Englewood Cliffs, NJ: Prentice-Hall.

Lave, L. and E. Wenger
1991 Situated learning: Legitimate peripheral participation, Cambridge: Cambridge University Press.

Lewicki, R.J. and B.B. Bunker
1996 'Developing and maintaining trust in work relationships', in R.M. Kramer and T.R. Tyler (eds), Trust in organizations: Frontiers of theory and research, Thousand Oaks: Sage Publications: 114-139.

Macneil, I.R.
1980 The new social contract: an inquiry into modern contractual relations, London: Yale University Press.

March, J.
1991 'Exploration and exploitation in organizational learning', Organization Science, 2/1: 101-123.

McAllister, D.J.
1995 'Affect- and cognition based trust as foundations for interpersonal cooperation in organizations', Academy of Management Journal, 38/1: 24-59.

McKelvey, M.
1997 'Co-evolution in commercial genetic engineering', Industrial and Corporate Change, 6/3: 503-532

Mead, G. H.
1934 Mind, self and society; from the standpoint of a social behaviorist, Chicago: Chicago University Press.

Meindl, J.R., C. Stubbart and J. F. Porac (eds.)
1996 Cognition within and between organisations, London: Sage.

Nooteboom, B.
1992 'Towards a dynamic theory of transactions', Journal of Evolutionary Economics, 2: 281-99.
1999 Inter-firm alliances: Analysis and design, London: Routledge.
2000 Learning and innovation in organizations and economies, Oxford: Oxford University Press.
2002 Trust: forms, foundations, functions, failures and figures, Cheltenham UK: Edward Elgar.

Oerlemans, L.A.G. and M.Y.H. Meeus
2000 Clusters and Innovative Research programmes' (in Dutch), ESB dossier 'Clusters in Beeld', Economisch Statistische Berichten.

Peelen, E., R.M. Jansen, S.H.A. Kerbkamp and J.W.N. van Velzen
1998 'The Amsterdam multi-media sector and suggestions for its growth policy' (in Dutch), University of Amsterdam.

Piaget, J.
1970 Psychologie et epistémologie, Paris: Denoël.
1974 Introduction a l'épistémologie génétique, Paris: Presses Universitaires de France.

Polanyi, M.
1962 Personal knowledge, London: Routledge.

Rowley, T., D. Behrens and D. Krackhardt
2000 'Redundant governance structures: an analysis of structural and relational embeddedness in the steel and semiconductor industries, Strategic Management Journal, 21: 369 – 386

Schein, E. H.
1985 Organizational culture and leadership, San Francisco: Jossey-Bass

Shannon, C.E.'
1957 'A mathematical theory of communication, Bell System Technical Journal, 27: 379 - 423

Shapiro, S.P.'
1987 'The social control of impersonal trust', American Journal of Sociology, 93: 623-658.

Smircich, L.
1983 'Organization as shared meaning', in L. R. Pondy, P. J. Frost, G. Morgan and T. C. Dandridge (eds.), Organizational symbolism, Greenwich Conn: JAI Press: 55-65.

Smircich, L.E. and G. Morgan
1982 'Leadership: The management of meaning', Journal of Applied Behavioral Science, 18: 257-273.

Tversky, A. and D. Kahneman
1983 'Probability, representativeness, and the conjunction fallacy', Psychological Review, 90/4: 293-315.

Vygotsky
1962 Thought and language, edited and translated by E. Hanfmann and G. Varkar, Cambridge MA: MIT Press.

Weick, K.F.
1979 The social psychology of organizing, Reading, MA: Addison-Wesley.
1995 Sensemaking in organisations, Thousand Oaks CA: Sage.

Williams, B.
1988 'Formal structures and social reality', in: D. Gambetta (ed.): Trust; making and breaking of cooperative relations, Oxford: Blackwell: 3-13.

Williamson. O. E.
1975 Markets and hierarchies: Analysis and anti-trust implications, New York: The Free Press.
1985 The economic institutions of capitalism; Firms, markets, relational contracting, New York: The Free Press.
1993 'Calculativeness, trust and economic organization', Journal of Law and Economics, 36: 453-86.

1999 ‘Strategy research: Governance and competence perspectives’, Strategic Management Journal, 20: 1087-1108.

Wuyts, S., M.G. Colombo, S. Dutta and B. Nooteboom
2003 Empirical tests of optimal cognitive distance, Research Report, Erasmus Institute for Research in Management, Erasmus University Rotterdam.

Zand, D.E.
1972 'Trust and managerial problem solving’, Administrative Science Quarterly, 17/2: 229-239.

Publications in the ERIM Report Series Research* in Management

ERIM Research Program: "Organizing for Performance"

2004

Learning And Governance In Inter-Firm Relations
Bart Nooteboom
ERS-2004-003-ORG
http://hdl.handle.net/1765/1122

Organisational Learning And Multinational Strategy
Bart Nooteboom
ERS-2004-004-ORG
http://hdl.handle.net/1765/1123

Density And Strength Of Ties In Innovation Networks: A Competence And Governance View
Bart Nooteboom and Victor A. Gilsing
ERS-2004-005-ORG

Innovation, learning and cluster dynamics
Bart Nooteboom
ERS-2004-006-ORG

Empirical Tests Of Optimal Cognitive Distance
Stefan Wuyts, Massimo G. Colombo, Shantanu Dutta, and Bart Nooteboom
ERS-2004-007-ORG

---

* A complete overview of the ERIM Report Series Research in Management:
https://ep.eur.nl/handle/1765/1

ERIM Research Programs:
LIS Business Processes, Logistics and Information Systems
ORG Organizing for Performance
MKT Marketing
F&A Finance and Accounting
STR Strategy and Entrepreneurship