Networks, irreversibility and knowledge creation

Patrick Llerena & Muge Ozman

Journal of Evolutionary Economics

ISSN 0936-9937
Volume 23
Number 2

J Evol Econ (2013) 23:431-453
DOI 10.1007/s00191-011-0231-7

Volume 23 · Number 2 · April 2013

Journal of Evolutionary Economics

Editors
Uwe Cantner
Elias Dinopoulos
Horst Hanusch
Luigi Orsenigo

Advisory Editors
Kenneth I. Carlaw
Roberto Fontana
Nathalie Lazaric
Charles McCann, Jr.
Andreas Pyka

Abstracted in Social Science Citation Index, Journal Citation Reports/Social Sciences Edition, Social SciSearch, SCOPUS, PsycINFO, EconLit, Google Scholar, EBSCO, CSA, ProQuest, ABS Academic Journal Quality Guide, Academic OneFile, AGRICOLA, Business Source, Current Abstracts, Current Contents / Social & Behavioral Sciences, ECONIS, Gale, International Bibliography of the Social Sciences (IBSS), OCLC, Research Papers in Economics (RePEc), SCImago, Summon by Serial Solutions

Special Issue: Environmental innovation and socio-economic dynamics in institutional and policy contexts
Guest Editors: Simone Borghesi, Valeria Costantini, Francesco Crespi, Massimiliano Mazzanti

EDITORIAL

REGULAR ARTICLES

Springer

Springer

J Evol Econ (2013) 23:431–453
DOI 10.1007/s00191-011-0231-7

REGULAR ARTICLE

Networks, irreversibility and knowledge creation

Patrick Llerena · Muge Ozman

Published online: 30 June 2011

Abstract The aim of this paper is to highlight the effect of irreversibility in partner choice in inter-firm collaborations. In an environment where firms are binded by contractual constraints regarding the duration of partnerships, how does the tacitness and complexity influence the overall knowledge in the industry? Through an agent based simulation model, we compare the knowledge generation in irreversible and reversible systems in two regimes as tacit and codified. The emerging network structures are also analysed. The results reveal that, in tacit regimes irreversible systems generate more knowledge only when product complexity is at an intermediate level.

Keywords Networks · Knowledge · Irreversibility · Product complexity

The work leading to this paper has been supported by the ANR Grant ANCORA (Analyse de la production de Connaissances par la Recherche Académique; ANR-06-APPR-003), in addition to NoE DIME (Dynamics of Institutions and Markets in Europe, EU 6th FP, grant N° 513396) and EU 7th FP, AEGIS (Contract No.225134). In addition, we would like to thank Robin Cowan and two anonymous referees for their comments. The usual disclaimers apply.

P. Llerena
BETA-UMR 7522, University of Strasbourg, CNRS, 61 avenue de la Forêt Noire,
67085 Strasbourg Cedex, France

M. Ozman (✉)
Institut Telecom, Telecom Ecole de Management, 9 Rue Charles Fourier,
91011 Évry Cedex, France
e-mail: muge.ozman@it-sudparis.eu

1 Introduction

The literature on inter-firm networks has deepened our understanding of the various mechanisms which underlie formation of ties between firms, and their performance effects. Among others, there are two regularities observed in various industrial contexts; first, complexity of the knowledge base, and uncertainty augment the motivation for constructing ties (Hagedoorn 1993; Orsenigo et al. 1998; Rosenkopf and Tushman 1998), and second, duration of ties has an effect on performance of firms (Baum et al. 2007).

The duration of relationships between firms has been analysed through the lens of various research streams. While the transaction costs framework focuses on the determinants of contract duration, the strategic management literature has been occupied with how relationship duration affects innovative performance of firms. In both literatures, scope of the alliance (Oxley and Sampson 2004), the extent of relationship specific investments (Joskow 1987), knowledge transferability (Baum et al. 2007) and environmental instability (Kogut 1989) have been observed to play important roles in varying degrees, in determining both the design of contracts, and also in judging the performance of alliances. The literature reveals that one of the tradeoffs faced by firms is concerned with long versus short term collaborations. While long term contracts can be beneficial for firms in terms of transferring tacit knowledge, firms may not prefer to commit their resources for long periods in the face of economic uncertainty. In addition, when scope of alliances are broad, ex-post governance changes can be frequent, which increases the costs of long term contracts (Reuer et al. 2002)

In this paper, we address these issues through an agent based simulation model. In particular, our aim is to compare governance systems in which firms are bounded by long term contracts, and those in which firms are free to change their partners whenever they wish (although they may not prefer to do so). In the model, firms select partners based on the complementarities in resources, they learn from each other, their capabilities change, and networks evolve between them. Under a parameter space defined by different knowledge regimes, which governance system performs better in terms of overall learning levels?

In the first section, we present the theoretical background and clarify our research questions. Second section is allocated to the explanation of the model. Third section gives the simulation results and final section includes some discussions.

2 Background

In the literature, collaboration between firms have been analysed through two main research streams. The first one is transaction cost economics (TCE), which places collaborations as hybrid governance between market based exchange and vertical integration (Williamson 1975; Powell 1990). In this line

Table 1 Summary of the inter-firm collaboration literature from two perspectives: TCE and strategic management

Line of research	Questions addressed
Research on the design and execution of formal contracts	The choice between market based exchange and vertical hierarchy (Williamson 1975) Determinants of contract duration and /or complexity (Crocker and Masten 1988; Joskow 1987; Reuer and Ariño 2007) What determines the type of contract (equity or non equity)? (Lerner and Merges 1998; Colombo 2003; Pisano 1989) Relation between formal contracts and relational governance (Reuer and Ariño 2007; Argyres et al. 2007) Governance changes in alliances (Reuer et al. 2002; Argyres and Liebeskind 1998)
Research on the causes and effects of alliances	Why do firms form alliances? (Hagedoorn 1993; Arora and Gambardella 1990) Partner selection (Gulati 2007; Mowery et al. 1998) Effect of alliances on performance (Echols and Tsai 2005; Rowley et al. 2000)

of research, some of the questions of interest have been related with the determinants of different forms of cooperation (Lerner and Merges 1998; Colombo 2003; Pisano 1989), comparison of relational governance mechanisms with formal contracts (Reuer and Ariño 2007; Argyres et al. 2007), determinants of contract duration and complexity (Crocker and Masten 1988; Joskow 1987; Reuer and Ariño 2007) and ex-post changes in governance types (Reuer et al. 2002; Argyres and Liebeskind 1998).

On the other hand, the second line of research focuses on the causes and effects of strategic alliances from a strategic management perspective (Hagedoorn 1993; Powell et al. 1996). As Hemphill and Vonortas (2003) note however, as far as private incentives to collaboration is concerned, these two lines of research, on formal contracts and the strategic management dimension, are highly related. One of the intersection fields between the two has been the issue of *contract duration* which is the central theme of this paper. In the next section, we focus on contract duration, in the framework of the two lines of research.

Table 1 summarizes the approaches and the questions addressed in the literature on inter firm collaborations.

2.1 Duration of collaboration: complexity, tacitness and instability

2.1.1 Contract duration: research on the design and execution of formal contracts

As it is taken in TCE, one of the main determinants of contract duration is asset specificity (Joskow 1987). When the exchange necessitates parties to make relationship specific investments, long term contracting is a more attractive governance mechanism, in the face of unforeseen hazards that may occur during the execution of the contract. In this sense, longer contracts reduce the ambiguity which maybe caused by the inability of the partners to foresee the future (Simonin 1999), and thus protect against opportunistic behaviour. In addition, the innovation and learning literature stress that in high technology industries, where there is rapid innovation, long term contracts are better for learning (Pangarkar 2003).

While long term contracts can be preferred when there are risks of opportunistic behaviour or when there is a high level of asset specificity, they can also be costly. Particularly, environmental instability increases the likelihood of contract termination (Kogut 1989). In periods of uncertainty, firms value flexibility when committing their resources for long periods. In such environments, deviations from optimal contract incentives significantly raise the cost of long term contracts (Crocker and Masten 1988).

In the inter-firm collaborations literature, complexity has been taken in two ways. While the first one prioritizes the complexity of the contract design (Joskow 1987; Reuer and Ariño 2007), the second one is concerned with the scope of collaborations, with respect to the subject matter of the contract (Pisano 1989; Oxley and Sampson 2004).[1] Alliance scope is usually taken as the range of activities or projects which the relationship encompasses. According to TCE, partnering firms can face difficulties in specifying the allocation of future property rights in alliances of a broader scope. In this sense, broader scope increases the complexity surrounding the alliance, and can result in more frequent changes in the post contract phase (Reuer et al. 2002). In addition, it can increase the uncertainties surrounding the contracts (Reuer et al. 2002; Simonin 1999), since broader scope increases the ambiguity of systems in general (Mosakowski 1997; Reed and DeFillippi 1990). As a result, the complexity of alliance scope can augment the motivation to reduce the time span of the contract.

These trade-offs between long term and short term contracts has been addressed in the strategic management field by focusing on relational governance mechanisms as a substitute for formal contracting (Gulati 2007). Relational governance refers to social mechanisms such as trust, reputation concerns and network embeddedness which accompany the relationship (Gulati 2007). However, whether these mechanisms act as substitutes or complements to formal contracts is currently an issue of debate (Poppo and Zenger 2002; Argyres et al. 2007). Next we turn to how relationship duration is taken in the strategic management discipline.

2.1.2 Relationship duration: strategic management perspective

As far as the time span of alliances is concerned, the prior concern of strategic management literature is the duration of *relations* and its effect on performance. A very rich strand of research adopts a network perspective in analysing this issue. The firm is seen as a node in a complex network character-

[1] In this paper, we adopt this definition of complexity.

izing the industry. The position of the firm in this network, and the evolution of its links are used to investigate the impact of relation duration on performance (Powell et al. 1996).

On one hand, long term relations and being embedded in a network of firms helps to build trust among the parties, facilitates transfer of tacit knowledge since a common language is developed, which increases efficiency in terms of time and costs of negotiation (Gulati 2007; Uzzi 1997). In accordance, some studies show that in industries where knowledge is highly tacit, a clustered network structure facilitates the flow of knowledge (Cowan et al. 2003; Audretsch and Feldman 1996) and embedded relations have a positive effect on various measures of performance (Echols and Tsai 2005; Anderson et al. 2002; Uzzi and Gillespie 2002). It has been shown that tie age contributes positively to the performance benefits of closure (Baum et al. 2007).

On the other hand, short term relations can also be beneficial for firms, to explore novelties from diverse sources, especially when knowledge is codified and the environment is highly instable (Rowley et al. 2000). One point of view argues that firms should act as bridges connecting otherwise disconnected clusters of firms (Burt 1992). Bridging ties yield better performance when they are short term (Baum et al. 2007). But one of the disadvantages of such short term relations is that, the flow of tacit knowledge is constrained, which can mitigate innovative performance, as observed in the case of chemicals (Ahuja 2000).

One of the ways in which firms can cope with the tradeoff between long term and short term relations is being involved in repeated interactions. Repeated interactions between the same firms increase trust and help to develop a common language when knowledge is highly tacit, while giving firms flexibility in terms of committing their resources for long periods. Nevertheless, some authors stress that the costs of repeating contracts can increase the transaction costs (Uzzi 1997; Goerzen 2007). Such transaction costs are not only caused by frequent contract design, rather, they are associated with reputation effects, or the sunk costs incurred once a partnership agreement is made. As a result, even if firms might find it beneficial to change partners, they might not be able to do so in the short term because of these relational constraints.

2.1.3 Summary and questions

Above, we summarised the literature on relationship duration from two perspectives. It is possible to distinguish between various mechanisms of governance in inter-firm collaborations. In one type of governance, the relations are flexible (without binding contractual constraints) but also persistent between the same group of firms (Powell 1990; Jones et al. 1997); in other cases, there is irreversibility in tie formation which maybe caused by asset specificity, or the high costs of post-governance changes. Another type of governance is having short term relations, with a diverse range of partners. Nevertheless, a common observation in both literature strands points to the trade-offs faced by firms in chosing among alternative governance types. In addition, both

Table 2 The relation between contract duration, knowledge characteristics and instability

		Governance type	
		Long term vs. short term contract	*Short term contract with repeated interactions between same firms*
Knowledge dimension	*Tacit*	Long term contracts are better for the development of a common language in transferring tacit knowledge between parties (Pangarkar 2003; Simonin 1999)	Partners can develop a common language for increased efficiency of knowledge transfer when knowledge is tacit (Gulati 2007), but time and costs required for renegotiation are higher (Uzzi 1997)
		The duration of ties contribute positively to the performance effect of network embeddedness (Baum et al. 2007)	
	Complex	When the scope of alliances are broader, likelihood of post contract changes in governance are higher when contracts are long term (Reuer et al. 2002)	Detailed task descriptions are costly when scope of the alliance is broad so firms might prefer complementary relational governance mechanisms (Argyres et al. 2007) which might be convenient with short term repeated interactions.
		There is a positive relation between asset specificity and complexity (Simonin 1999), and asset specificity increases contract duration (Joskow 1987)	
Environment	*Instable*	In periods of uncertainty, firms value flexibility in terms of committing their resources for long periods. In such environments, the cost of long term contracts is higher (Crocker and Masten 1988).	Short term repeated interactions with the same firms have a negative effect on performance when environment is instable (Goerzen 2007)
		Organizational learning literature stresses that exploration has a positive impact on performance, in periods of instability, through establishing short term contracts with distant firms (Rowley et al. 2000)	

frameworks show that, the characteristics of the knowledge base and stability of the environment together influence the choice of governance. With respect to these dimensions, Table 2 summarizes the costs and benefits of long term and short term relations in both literatures, and helps to highlight the major trade-offs that firms face.

The type of governance is usually shaped by factors like the transferability of knowledge, instability of the environment, and the scope of the alliance. However, these conditions which characterise the learning environment, are also intrinsically related with each other in complex ways which augments the trade-offs faced by firms (Simonin 1999; Santoro and McGill 2005). For example, in the beginning of industry life cycles in high technology industries, knowledge is highly tacit, complex, and environment is uncertain. In this case, while long term contracts can be advantageous for learning, it restricts exploration of new knowledge by interacting with diverse partners, who are distant from the firm in technological space.

To address these issues, in this paper, we aim to unravel the relation between tie duration and learning in a simulation model, so as to clarify the interaction effects between tacitness and complexity as far as they effect learning by firms. In particular, we are concerned with the overall learning in an economy in an environment of uncertainty. We compare the learning effects of two governance modes. In one of them, the contracts are long term, irreversible, and firms commit their resources for a certain period of time to the partnership. In the other governance mode, firms are flexible in their partner choice, and they have the option to change their partners in every period. In other words, they can prefer to have repeated interactions with the same partner, or they can change their partners in each period. The main criteria of firms in partner selection are to complement their capabilities in joint production. From partnerships they learn, their capabilities change and their criteria for selection also changes. Firms are heterogeneous in their capabilities and preferences. In comparing the two governance modes, we take the tacitness of knowledge (which determines their learning capabilities in a fixed period), and complexity of the product system as exogenous parameters. We compare the overall learning in the economy in the two distinct governance modes, under the space defined by tacitness and complexity.

3 The model

3.1 A description of the model[2]

There are M goods, K knowledge types, and N firms in the economy. Each firm i is endowed with a knowledge vector, k^i assigned randomly (drawn from

[2]See Ozman (2010) for a more general version of this model, which investigates the impact of knowledge base on network structure.

a uniform distribution) at period t = 0; k^i_j shows the level of firm i's knowledge in type j. The expertise of the firm is the knowledge type that it knows most. There exist a knowledge type j for all i such that $k^i_j > k^i_m\ \forall m \neq j$.[3]

Using its knowledge, each firm produces a particular type of product in each period. But a firm has two options, either it can produce by itself, or combine its knowledge with another firm and produce together. The type of product that firm i produces depend on its expertise type j, and the weight of this expertise in different goods. In other words, the probability that it will produce good type n is proportional to the weight of its expertise type j required by n.[4] We adopt the term *n-type firm* if the firm produces good n. The amount it produces as single is given by $y_n(k_i)$.

3.1.1 Matching

Each firm selects between producing alone or producing jointly with another firm. In making this decision, the firm's criteria is to maximize its output. Therefore, it makes a comparison between its joint output with other firms in the economy. Joint production happens through the integration of knowledge of the two firms. When an *n-type firm* and an *m-type firm* form a pair, we assume that they produce both goods n and m. It is assumed that if two firms i and l collaborate (*n-type* and *m-type* respectively), their joint knowledge in category j is given by

$$k^{pair}_j = \max\left(k^i_j, k^l_j\right)\ \forall j = 1 \ldots\ldots K \tag{1}$$

When an *n-type* firm i forms a pair with an *m-type* firm l, the joint knowledge vector, as given by Eq. 1 enters the production function, of both goods n and m. If we denote the joint knowledge vector by k^{pair} the output is shared equally among firms so that individual output shares are given by

$$y_{nm} = \frac{y_n\left(k^{pair}\right) + y_m\left(k^{pair}\right)}{2} \tag{2}$$

Therefore, firm i compares its single output $y_n(k^{pair})$ with $y_{nm}(k^{pair})$. Every firm has a preference listing (other firms ranked according to the maximum output they can produce with it). Pairing in the population is made in a way that no two firms prefer each other to their current partners. When firms rank each of the others according to maximum joint output, a listing of pairs can be made with respect to falling joint output. The algorithm used involves picking the highest producing pairs one by one. Finally, some firms are left single in

[3] See Cowan et al. (2003) for this knowledge setting. Specifically, $k^i_j = k^h_j$ means that agents i and h have exactly the same knowledge in type j. If $k^i_j > k^h_j$ agent i knows everything that agent h knows in type j, and has some knowledge in addition.

[4] If product n uses 90% of knowledge type j, then there is 0.9 probability that agent i produces good n. With 10% probability it produces one of the other goods, depending on their requirements of knowledge type j.

this process. This algorithm ensures that there are no two firms in the whole population who would both have preferred to be with each other, rather than their current partners (Cowan and Jonard 2001).

3.1.2 Production

We assume that the main input in production is knowledge. For each of the M goods, the production amount is determined by a Cobb Douglas function:

$$y_n(k) = \alpha \prod_j k_j^{\gamma_{nj}} \text{where} \sum_j \gamma_{nj} = 1 \quad n = 1.....M \tag{3}$$

Here, k_j is the amount of knowledge in type j, and γ_{nj} measures the intensity of knowledge type j in good n. Since there are a total of M goods and K knowledge types, the corresponding γ values, for each good and knowledge can be represented by a matrix of size $M \times K$ which shows the respective parameters of the production function. We assume that there are no competing uses for knowledge, so that its opportunity cost is zero, and firms use all their knowledge in production. We also assume that demand is perfectly elastic so that profits increase monotonically with quantity.

3.1.3 Complexity and product relatedness

In the literature, complexity in the knowledge base have been taken in various ways. One of the commonly used frameworks is related to the number of components and interdependence among them (Simon 1969; Zander and Kogut 1995; Kauffman 1993) Wang and von Tunzelmann (2000) define two dimensions of complexity as breadth and depth. Complexity in breadth refers to "the range of areas that have been investigated to develop a particular subject" (p.806). Defined in this way, product complexity in breadth refers to the embodiment of a larger number of components/assemblies which makes up a product. Parallel to this view of complexity, in the context of collaborations, complexity is usually taken as the scope of activities that will be undertaken in the alliance (Oxley and Sampson 2004). In this definition, a complex alliance will be the one in which the range of knowledge fields that are undertaken by the alliance is broader. Parallel to these definitions, in this model, a complex product embodies a wider range of knowledge fields, and the scope of a collaboration is wider when firms use more knowledge types jointly.

In the model presented, the goods in the economy require various proportions of different knowledge types in their production and firms integrate their knowledge to produce these goods (Eq. 3). We use the production parameters to measure both complexity of products, and scope of a partnership. To clarify, let us assume a hypothetical matrix showing production parameters in an industry with 5 goods and 10 knowledge types. Figure 1 shows three matrices of production parameters as an example. In the first diagram, the breadth of products are narrow, because only two knowledge types are included in their production. The diagram in the middle shows the case where the products take

Fig. 1 Product complexity

	K1	K2	K3	K4	K5	K6	K7	K8	K9	K10
P1	0	0	0	0	0	0	0	0	0,5	0,5
P2	0,5	0	0	0,5	0	0	0	0	0	0
P3	0	0	0	0	0,5	0	0	0,5	0	0
P4	0	0	0,5	0	0	0	0,5	0	0	0
P5	0	0,5	0	0	0	0,5	0	0	0	0

Low breadth, low relatedness among products

	K1	K2	K3	K4	K5	K6	K7	K8	K9	K10
P1	0	0,2	0	0,2	0,2	0	0,2	0	0	0,2
P2	0	0	0	0,2	0,2	0,2	0,2	0	0,2	0
P3	0,2	0	0,2	0	0	0,2	0	0,2	0	0,2
P4	0,2	0	0,2	0,2	0,2	0	0	0	0	0,2
P5	0,2	0,2	0,2	0,2	0	0,2	0	0	0	0

Medium breadth, medium relatedness among products

	K1	K2	K3	K4	K5	K6	K7	K8	K9	K10
P1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1
P2	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1
P3	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1
P4	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1
P5	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1

High breadth, full relatedness among products

as input five knowledge types. Finally, the bottom diagram shows the case where draw upon all knowledge types.

In the first case, there is very little relatedness between products in terms of their common knowledge. Therefore, the scope of a partnership in this region will be narrow. In the opposite extreme, when products are highly related to each other in terms of their knowledge content, the alliances will also incorporate a wider range of knowledge types, rendering them more complex than in other regimes. Other cases fall in between these extremes.

To model complementarities between firms in tie formation, this schema of product complexity also permits us to measure the product relatedness in terms of their common knowledge. In the model, the *relevant* complementarities between firms is dictated by the knowledge requirements of production. When the range of knowledge fields required for production is broader, in a closed knowledge space, the relatedness between any two firms' products will be higher in terms of the common knowledge fields used in the collaboration; and therefore, the scope of the partnership will be wider. In other words, as the range of knowledge types that firms use jointly gets wider, complexity increases.

3.1.4 Learning

In this model, the knowledge levels of firms are updated in every period. The learning happens through learning-by-doing, and is the result of the experience in production. Therefore, learning depends on the extent to which firms can make use of their production experience. We assume that agents are myopic, so that they do not consider long term effects of learning from the partners that they select.[5] In the simulations we take into account two different learning functions. In the first case, relative knowledge levels between the two firms determine the extent of learning. In the second case, learning is independent of relative knowledge levels.

3.1.5 Tacit knowledge

When knowledge is tacit, transferring it from one party to the other is more difficult. In this case we assume that the relative knowledge levels between two firms determine the extent of their learning in a particular field.[6] As knowledge becomes more codified, relative knowledge levels has fewer roles since there is already a knowledge base that is explicitly available to all firms in the industry. This will be the case in the next section.

The following function is used to update firm i's stock of knowledge type j :

$$k_j^i(t) = k_j^i(t-1) + \theta_i y(t) g(t) \tag{4}$$

where

$$g(t) = \delta_i(t) \text{ if } k_j^i(t-1) > k_j^l(t-1)$$

else

$$g(t) = \delta_i(t) \frac{k_j^i(t-1)}{k_j^l(t-1)}$$

where θ_i measures the combinative capability of the firm, and $\delta_i(t)$ is an uncertainty effect. Equation 4 implies that learning is measured by how much the firm can make use of production $y(t)$. This is firstly a function of capability of the firm, as given by θ_i. Second, it is a function of the relative knowledge levels between the partner firms.

[5]We assume an environment in which agents consider only the short term joint production amounts, and that they cannot predict the amount of learning that will take place in the long run because of uncertainty.

[6]With regards to how knowledge overlap between firms influence alliances, a major finding in the literature is an inverted-u relationship between technological distance between firms and learning (Mowery 1998; Schoenmakers and Duysters 2006; Nooteboom et al. 2007). Moreover this distance diminishes as firms collaborate with each other (Mowery et al. 1998). Note that, in these models, the *overlap* between total knowledge endowments of firms are looked at. In our model, however, relative knowledge levels measure the extent to which one firm knows more than the other in a *particular field*, and not the overlap in their total knowledge vector (See footnote 2). Because there is more than one field of knowledge, two firms complement each other when one knows more than the other in one field, and vice versa. It is also important to note that the learning used here is the extent to which parties can make use of production, rather than direct transfer between firms. Because it is the knowledge of the high-knowledge firm which is used in production, the low-knowledge firm's learning is limited, i.e. he cannot make full use of production in that knowledge category. Nevertheless, it can complement the other firm in a different knowledge category.

Firstly, if firm i knows less than its partner, the amount of its learning is limited by their relative knowledge levels and its own capabilities. For example, if its learning capability is too high relative to partner, it can even leapfrog the partner.

Secondly, if firm i knows more than his/her partner (firm l) before production, there is only an uncertainty in its ability to make use of production and increase its knowledge. This is because, there is no other partner from whom it can learn from, since it is already the expert. This is given in the first part of the function $g(t)$. In this case, learning can be considered as its making a better use of the production experience. Here, uncertainty is given by the parameter which is different for all firms in each period (the values of parameters are given below in simulations). In this case, the extent to which the firm can add to its knowledge depends on its capability to innovate captured by the parameter θ_i, as well as on the extent of uncertainty, captured by $\delta_i(t)$.

3.1.6 Codified knowledge

In this case, we assume that the relative knowledge of agents has no impact on the extent of learning. This is because there is a pool of explicit knowledge available to all firms in the industry. Therefore whether the firm knows relatively less than his partner has no influence on the extent to which he will learn from her. In this case, Eq. 4 is updated as:

$$k_j^i(t) = k_j^i(t-1) + \theta_i y(t) \delta_i(t) \tag{5}$$

The knowledge types are updated in all the knowledge types that enter the production function of goods n and m, that is, if the firms i and l are *n-type* and *m-type* respectively, knowledge is updated in all subjects in which $\gamma_{nj}, \gamma_{mj} > 0 \forall j = 1 \ldots . K$.

3.1.7 Irreversibility and selectivity

Irreversibility and selectivity shape the process of partner selection. In the reversible case, the matching process explained above is made in each period by each agent. In the irreversible case, once a partnership is formed between two firms, it cannot be ended for a certain period of time. The period of contracts is different for each pair of firms. Consequently, because firms are aware that they will commit themselves for a fixed period, they are more selective in choosing partners. Selectivity refers to the threshold level of ranking, above which a firm will not accept a partnership in its preference listing. Instead it prefers to produce by itself, and wait for the next period to repeat the selection process. For example, when selectivity parameter is 5, the firms accept to form a partnership with only the first 5 firms in their preference list. However, if none of these 5 firms accept to form a link with the firm, then for that period the firm produces by itself, until the next period when it makes an evaluation again. One of the implications of high selectivity in the model is that, firms will form partnerships with other firms who are similar to themselves in terms of level of knowledge. For example, high-knowledge firms will form partnerships with other high-knowledge firms and so on.

4 Simulations

The simulation model consists of a population of firms endowed with different types of knowledge. In each period firms form pairs, by selecting their partner according to their calculated joint production. Paired firms pool their knowledge according to Eq. 1. They produce together according to Eq. 3 and share total output according to Eq. 2. In the second period, they update their knowledge levels according to Eq. 4. Depending on the extent of irreversibility, those firms who can match with their preferred partners commit their resources for a certain period of time. Other firms produce as single, until the next period where they search for new partners again. Pairs are dissolved, and new pairs are formed with the updated knowledge levels.[7]

There are M = 5 goods and K = 10 knowledge types. The choice of these numbers are based on experimentation. Increasing the number of goods by one unit increases the simulation time significantly. Reducing the number of goods run the risk of loss of precision. With a few initial simulations, we confirmed that changing the number of goods and knowledge types do not change the final patterns observed, rather, they affect the absolute values of the results.

Each of the goods is characterized by a vector of knowledge input coefficients (a basic example is shown in Fig. 1). For any good, the breadth of the knowledge base is the range of different knowledge types that its production requires. We measure this by the number of coefficients in the production function that are greater than zero. Goods with minimum breadth use only two types of knowledge inputs, and goods with maximum breadth use all of the knowledge types. Intermediate level of breadth corresponds to the case where the goods are neither the same nor completely different in terms of their knowledge content. This means that they have some knowledge in common, but not all.

We take into account 8 unique knowledge–good configurations, ranging from minimum breadth to maximum, because we think that it provides a sufficient degree of balance between excessive detail on one hand, and too broad results on the other. In the Appendix, an example set of goods is provided for such a set knowledge–good configuration.[8]

Firstly the simulations are run for the reversible case. In a single run, a certain knowledge–good configuration is taken exogenously. In each of these runs there are 1,000 periods. Each of these 8 runs correspond to a unique exogenous knowledge–good configuration. In each of the runs, the same population is

[7] We take into account only bilateral link formation in a single period, but when sufficient time elapses, these bilateral links form a network.

[8] Each of these matrices is an input to a single run (5 goods, 10 knowledge types).

used (same initial knowledge stocks and capabilities). We repeat this procedure (8 runs) 10 times. In each of these 10 repetitions, we use a different population. Therefore, there are 80 runs with different combinations of population and knowledge good configurations. The results presented below are the averages taken over the 10 repetitions with different populations.

Secondly, this procedure is repeated for irreversible case with different selectivity levels. We take into account 4 cases of selectivity, as 1, 5, 15, 30 which refer to the critical rank of the partner in the preference listing of the firm, above which firms do not enter into a relationship. Consequently, we run a total of 80 runs for the reversible case, and 80 * 4 = 320 runs for the irreversible case. These simulations are carried out separately for tacit regime, and codified regime.

The irreversibility parameter is in the range [150,250] periods. The population consists of N = 30 firms. The uncertainty parameter $\delta_{kt} \in [0.95, 1.05]$, and a different value is used for each agent in each period (Eqs. 4 and 5) and the capability parameters are $\theta_k \in$[1.3,1.7]. A single run consists of T = 1,000 periods. The simulation parameters were selected based on mathematical feasibility.

5 Results

We present the results in two parts; the first one gives the knowledge levels, and the second one gives the network density. Finally we analyse the joint implications of network and knowledge dynamics.

5.1 Knowledge dynamics

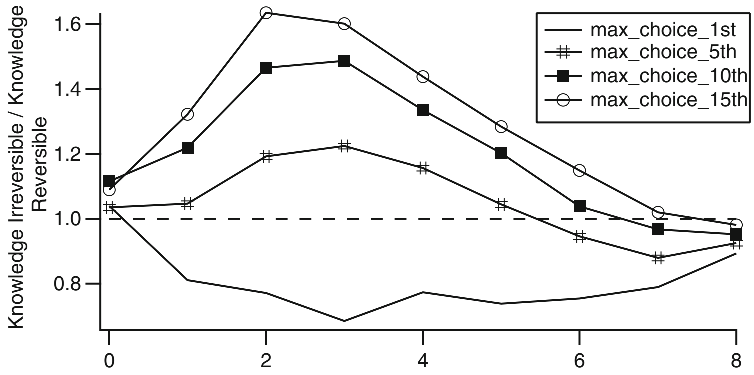
The average knowledge level is measured by considering the final average knowledge of all agents at the end of a simulation run. And then, the averages are taken over the 10 repetitions (see Section 4). It is given by;

$$K_T = \frac{\sum_{j=1}^{N} k_j}{N}$$

$$K_A = \frac{K_T}{10}$$

where K_T is the average knowledge in a single run, and K_A is the average knowledge obtained from the 10 repetitions. In particular, the selectivity of firms, the breadth of the knowledge base and the learning function all have an influence on whether long term contracts or short term contracts are better for average knowledge creation with respect to knowledge breadth and tacitness. We use average knowledge as a measure of performance, since it reveals the extent of total learning from partnerships in different regimes.

Fig. 2 Average knowledge and breadth, tacit knowledge



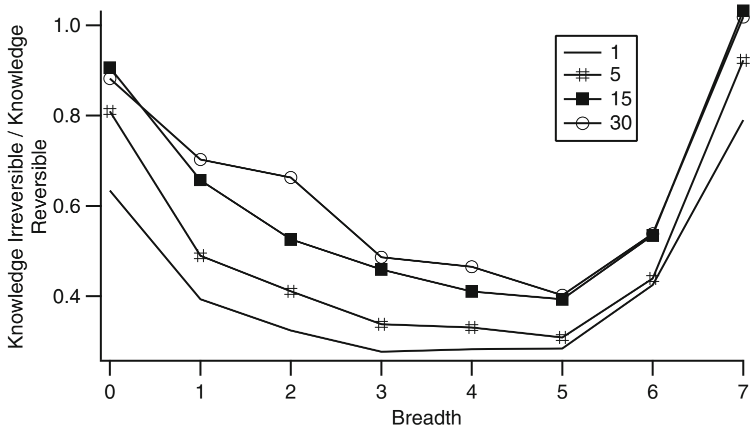
Our first result is that when firms are the least selective, the average knowledge levels are higher in nearly all cases. Least selectivity is when firms form partnerships with whoever they match with, instead of insisting on the highly ranked ones in their preference listing. Figures 2 and 3 respectively show average knowledge in tacit and codified learning cases. It can be seen in the figures that lowest selectivity (30 referring to the case where all firms can form partnerships with all other firms) yields the highest knowledge growth in all the cases. This means that, the more diverse partnerships are formed between firms of different levels of competence, the better it is for overall knowledge generation.[9]

Our second result is concerned with the role of the learning function. When the relative knowledge levels determine the extent of learning (as given in Eq. 4, which refers to tacit knowledge regime) irreversible ties are significantly better in terms of average knowledge generation. This is given in Fig. 2 where the ratio of average knowledge levels in irreversible and reversible cases is above one, except when firms are highly selective. This results confirm the positive effect of long term ties on learning, when knowledge is tacit. On the other hand, in a codified knowledge regime (Eq. 5), which is given in Fig. 3, reversible systems, where firms can change partners frequently yield more knowledge. However, the strength of the difference between irreversible and reversible cases depend on the relatedness between products.

Our third result concerns the effect of product relatedness which turns out to be the most critical parameter determining the outcome in terms of knowledge. In particular, our results highlight a critical region where the level of product relatedness is intermediate, as seen in Figs. 2 and 3. This is the area where products are neither the same, nor too different in terms of their knowledge requirements. In this area, the discrepancy between the performance of tacit and codified regimes in reversible and irreversible systems is the most pronounced. This is to say that, when relatedness is intermediate, industries where knowledge is tacit perform significantly better when ties are long term.

[9]Note that these results concern the overall learning in the economy, rather than the performance of individual firms. In other words, some firms maybe better-off by being more selective, but when all firms are taken into account overall knowledge generation is higher.

Fig. 3 Average knowledge and breadth, codified knowledge



On the other hand, codified-knowledge industries perform significantly better when relations are short term. In other areas where products are completely different, or the same, knowledge levels in irreversible and reversible systems seem to be close to each other in both tacit and explicit industries. An exception to this pattern is where firms are highly selective as given in Fig. 2. Here, even if the knowledge is tacit, short term contracts are better.[10] This happens because only a few firms are lucky enough to form partnerships with their first choices. So mostly, firms remain alone, rather than forming partnerships.

These results can be understood in a better way if one analyses the structure of networks that accompany them. In the next section, we compare the network densities corresponding to different levels of selectivity and breadth in the irreversible and reversible cases.

5.2 Networks

The density of a network is given by:

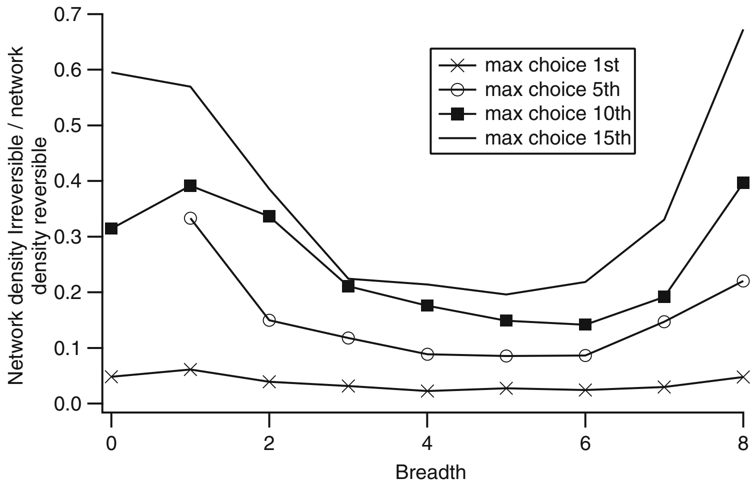
$$d = \frac{\sum_{i=1}^{N} \sum_{j=1}^{N} x_{ij}}{N\,(N-1)}$$

where $x_{ij} = 1$ if there is an edge between i and j and is 0 otherwise and N is the total number of nodes. We take into account network density because it is the most common measure used to understand the intensity of connections in a network. In all the simulation runs, we recorded the final density of networks.

The analysis of networks among firms helps to explain why the irreversible case yields more knowledge when relatedness among goods is intermediate. Figure 4 gives the network density for a tacit knowledge base regime, and Fig. 5 gives the network density in the codified network base regime.

[10]This is to say that firms can revert to other partners easily.

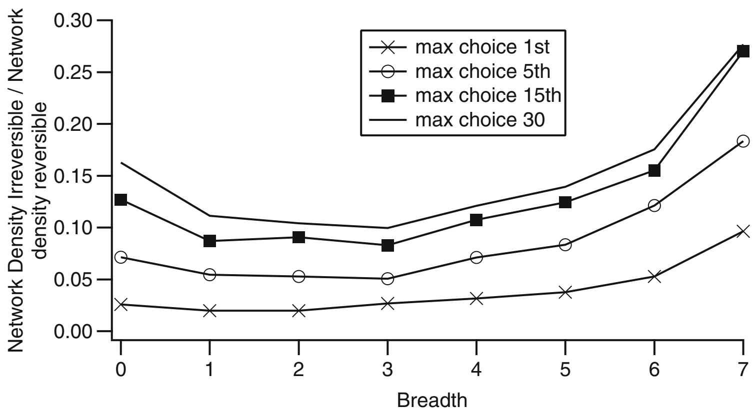
Fig. 4 Network density and breadth, tacit knowledge



In all the cases, network density in the irreversible case is smaller than the network density in the reversible case. This is expected, since long term relations limit the potential to network with different firms, which reduces network density. However, an interesting result is concerned with the tacit knowledge base regime (Figs. 2 and 4). Contrary to the conventional expectations that high network density yields more knowledge, here we see that although network density is significantly lower (Fig. 4) the knowledge levels are higher (Fig. 2). In other words, when products are only partially related, long term relations yield the highest knowledge levels. Below we explain why this result is observed in the simulations.

To explain, it is useful to compare the network densities in the tacit regime. As Fig. 4 shows, density in irreversible case is much lower than the density in the reversible case in intermediate levels of relatedness. This is because, absent contractual constraints, firms change partners frequently. On the other hand, both low relatedness, and high relatedness among products yield less dense networks. In other words, even if they can, firms do not change their partners. Low density can be interpreted in two ways: first, firms prefer to produce alone, or second, they prefer to have repeated interactions with the same partners, even in the absence of contractual constraints. In the latter, they are free to

Fig. 5 Network density and breadth, codified knowledge



dissolve partnerships, but they don't. The results reveal that, when goods are the least related, firms prefer the first case: to produce alone. Little amount of partnerships are formed because there is no common knowledge in the goods, so that firms cannot complement each others knowledge. On the other hand, in the maximum relatedness case, once a partnership is formed it is long term, because firms' knowledge in different types do not change. This means that, they do not acquire new competences during their interactions. All firms learn consistently, in all knowledge types. Because there is no change in expertise patterns, there is also no reason to change partners. Then, our results reveal that high relatedness results in repeated interactions when knowledge is tacit. This reduces network density.

These factors explain why there is a significant difference in network densities in the intermediate region. Here, expertise levels and subjects are continuously changing, because goods have some knowledge in common, which provides motivation for firms to come together. Yet, when two firms come together they can also learn in different types of knowledge, the ones in which their partners are more knowledgeable than themselves. In this way, rapid change in expertise levels result in an environment, in which firms are repeatedly searching for different partners. At the same time, we find that, overall knowledge levels are higher when relations are long term (Fig. 2). Based on our analysis, when firms change partners frequently in a tacit regime, they do not have sufficient time to make use of long term gains from repeated ties. This is why we can conclude that in this region irreversibility is much better for overall learning levels. Therefore, in mid levels of relatedness, firms have a tendency to have short term contracts, although for kerning, long term relations are much better.

These results imply that, when firms are flexible in changing partners, they would do so in a certain parameter range (namely when products have an intermediate level of relatedness, and when knowledge is tacit). However, irreversible ties are much better to increase the learning potential of partnerships. At the same time, when products are too complex or too simple in terms of their knowledge base, firms themselves prefer to keep the same partners, and their relations are either long term or they produce alone. Therefore, we do not see big differences in the average knowledge levels, between irreversible and reversible systems.

6 Discussion

In this paper, we find that the effect of tie duration on overall learning by the producers depends on tacitness of knowledge and the scope of collaborations. A few remarks on how our results link to previous research maybe helpful to clarify the positioning of this paper in the literature. As far as the duration of ties are concerned, one of the common points in both transaction costs literature, and strategic management literature is the trade offs faced by firms depending on the tacitness of the knowledge base, its complexity and the environmental instabilities. One of the established results in the literature on firm collaborations is that, as knowledge becomes more difficult to transfer, long term relations between firms are beneficial for learning. However, as firms commit their resources for long periods, they also lose their flexibility in adapting to environmental changes. Moreover, short term relations with diverse partners can be beneficial to be informed about novelties. In this paper, we show that whether long term and short term relations are better depend also on the level of product relatedness. We measure relatedness by the extent of similarity in the knowledge types they embody. We find that irreversibility in ties matter very little in two cases: first when there is little relatedness among products, and second when they are too related. At the same time, firms have a tendency to change partners frequently when relatedness among products are at an intermediate level. In this case, firms can better complement each other, since some knowledge types are common in products, but not all. as they learn in complementary fields, their expertises change, which renders other partners more attractive in terms of fulfilling new complementarities. However, in a tacit regime, frequent change of partners restricts learning by firms. Therefore, we find that irreversibility in ties is better for overall learning, in this mid-range of relatedness.

Few remarks seem necessary concerning the results and assumptions of this paper. It is important to mention that, as different from other studies in the field, we do not look at the performance of individual firms. Rather, we measure performance by the overall degree of learning in the economy. This is important when interpreting the results of this study, and in comparing it with other studies. Secondly, in this paper we take into account complexity as a means by which one can distinguish between different industries. More particularly, complexity of products can be important in influencing the effects and mechanisms which work in inter-firm networks. In our model, alliances in a complex product system involve a wider range of competences used in production, thereby increasing the overall relatedness between products. We would like to draw attention to the fact that, effect of complexity, although mentioned by many authors, have not yet been tackled in a systematic way in network studies, with few exceptions (Frenken 2006). Finally, in this paper we distinguish explicitly between network relations that are reversible, and those that are not reversible. In the real world, once firms enter into an agreement, the post governance changes are usually costly, as we explained in the first section. We show that, such long term relations in which firms commit their resources, can have positive effects on overall learning in the economy. However, one should always take into account the nature of the product system to understand such effects.

Appendix

Table 3 A sample set of production parameters used in one simulation run

		K1	K2	K3	K4	K5	K6	K7	K8	K9	K10
1	P1	0	0	0	0	0	0.5	0.5	0 0	0	
	P2	0.5	0	0	0.5	0	0	0	0	0	0
	P3	0	0	0	0	0.5	0	0	0	0.5	0
	P4	0	0	0.5	0	0	0	0	0.5	0	0
	P5	0	0.5	0	0	0	0	0	0	0	0.5
2	P1	0	0.34	0.33	0	0.33	0	0	0	0	0
	P2	0	0	0	0.34	0	0.33	0	0	0	0.33
	P3	0	0	0	0.34	0	0.33	0.33	0	0	0
	P4	0	0	0	0	0.34	0	0	0	0.33	0.33
	P5	0.34	0	0	0	0.33	0	0	0.33	0	0
3	P1	0	0.25	0	0	0.25	0	0.25	0.25	0	0
	P2	0.25	0	0	0.25	0	0.25	0	0.25	0	0
	P3	0	0	0.25	0.25	0	0	0	0.25	0	0.25
	P4	0.25	0	0.25	0	0.25	0	0.25	0	0	0
	P5	0	0.25	0	0	0.25	0	0	0	0.25	0.25
4	P1	0.2	0.2	0	0	0.2	0	0	0.2	0.2	0
	P2	0	0	0.2	0.2	0.2	0	0.2	0.2	0	0
	P3	0	0.2	0	0.2	0	0.2	0	0	0.2	0.2
	P4	0.2	0.2	0	0	0	0	0.2	0.2	0	0.2
	P5	0.2	0	0.2	0	0	0	0.2	0.2	0.2	0
5	P1	0.1667	0	0.1667	0	0.1667	0.1667	0	0.1667	0	0.1667
	P2	0.1667	0	0.1667	0.1667	0	0	0	0.1667	0.1667	0.1667
	P3	0.1667	0	0	0.1667	0.1667	0	0.1667	0.1667	0	0.1667
	P4	0	0.1667	0.1667	0	0.1667	0.1667	0.1667	0	0	0.1667
	P5	0	0.1667	0	0	0.1667	0.1667	0	0.1667	0.1667	0.1667

Table 3 (continued)

		K1	K2	K3	K4	K5	K6	K7	K8	K9	K10
6	P1	0	0.1429	0.1429	0	0.1429	0	0.1429	0.1429	0.1429	0.1429
	P2	0.1429	0	0.1429	0.1429	0.1429	0.1429	0.1429	0.1429	0	0
	P3	0.1429	0	0.1429	0.1429	0	0.1429	0.1429	0.1429	0.1429	0
	P4	0.1429	0.1429	0	0	0.1429	0	0.1429	0.1429	0.1429	0.1429
	P5	0.1429	0	0.1429	0.1429	0.1429	0	0.1429	0.1429	0.1429	0
7	P1	0.125	0.125	0.125	0.125	0	0.125	0.125	0	0.125	0.125
	P2	0	0.125	0	0.125	0.125	0.125	0.125	0.125	0.125	0.125
	P3	0.125	0	0	0.125	0.125	0.125	0.125	0.125	0.125	0.125
	P4	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0	0
	P5	0.125	0.125	0.125	0	0.125	0.125	0	0.125	0.125	0.125
8	P1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
	P2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
	P3	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
	P4	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
	P5	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1

References

Ahuja G (2000) Collaboration networks, structural holes and innovation: a longitudinal study. Adm Sci Q 45(3):425–453

Anderson U, Forsgren M, Holm U (2002) The strategic impact of external networks: subsidiary performance and competence development in multinational corporation. Strateg Manage J 23:979–996

Argyres N, Bercovitz J, Mayer KJ (2007) Complementarity and evolution of contractual provisions: an empirical study of IT service contracts. Organ Sci 18(1):3–19

Argyres N, Liebeskind JP (1998) Contractual commitments, bargaining power, and governance inseparability. In: Academy of Management proceedings & membership directory, pp D1–D8

Arora A, Gambardella A (1990) Complementary and external linkages: the strategies of the large firms in biotechnology. J Ind Econ 38(3):361–79

Audretsch DB, Feldman MP (1996) Innovative clusters and the industry life-cycle. Rev Ind Organ 11:253–273

Baum J, McEvily B, Rowley T (2007) Better with age? Tie longevity and the performance implications of bridging and closure. Rotman School of Management Working Paper No 1032282. Available at SSRN: http://ssrn.com/abstract=1032282

Burt RS (1992) Structural holes: the structure of competition. Academic, New York

Colombo MG (2003) Alliance form: a test of the contractual and competence perspectives. Strateg Manage J 24:1209–1229

Cowan R, Jonard N (2001) Knowledge creation, knowledge diffusion and network structure. In: Kirman A, Zimmermann J-B (eds) Economies with heterogeneous interacting agents, Springer

Cowan R, Jonard N, Ozman M (2003) Knowledge dynamics in a network industry. Technol Forecast Soc Change 71(4):469–484

Crocker KJ, Masten SE (1988) Mitigating contractual hazards: unilateral options and contract length. RAND J Econ 19(3):327–343

Echols A, Tsai W (2005) Niche and performance: the moderating role of network embeddedness. Strateg Manage J 26:219–238

Frenken, K (2006) A fitness landscape approach to technological complexity, modularity and vertical disintegration. Struct Chang Econ Dyn 17:288–305

Goerzen A (2007) Alliance networks and firm performance: the impact of repeated partnerships. Strateg Manage J 28:487–509

Gulati R (2007) Managing network resources: alliances, affiliations and other relational assets. Oxford University Press, Oxford

Hagedoorn J (1993) Understanding the rationale of strategic technology partnering: interorganizational modes of cooperation and sectoral differences. Strateg Manage J 14:371–85

Hemphill TA, Vonortas N (2003) Strategic research partnerships: a managerial perspective. Technol Anal Strateg Manag 15(2):255–271

Jones C, Hesterly WS, Borgatti SP (1997) A general theory of network governance: exchange conditions and social mechanisms. Acad Manage J 22:911–45

Joskow P (1987) Contract duration and relationship-specific investments: empirical evidence from coal markets. Am Econ Rev 77(1):168–85

Kauffman S (1993) The origins of order. Oxford University, New York

Kogut B (1989) The stability of joint ventures: reciprocity and competitive rivalry. J Ind Econ 38:183–198

Lerner J, Merges RP (1998) The control of technology alliances: an empirical analysis of the biotechnology industry. J Ind Econ 46:125–156

Mosakowski E (1997) Strategy making under causal ambiguity: conceptual issues and empirical evidence. Organ Sci 8(3):414–442

Mowery DC, Oxley JE, Silverman BS (1998) Technological overlap and interfirm cooperation: implications for the resource based view of the firm. Res Policy 27:507–23

Nooteboom B, Haverbeke W, Duysters G, Gilsing W, Oord A (2007) Optimal cognitive distance and absorptive capacity. Res Policy 36:1016–1034

Orsenigo L, Pammoli F, Riccaboni M, Bonaccorsi A, Turchetti G (1998) The evolution of knowledge and the dynamics of an industry network. Journal of Management and Governance 1:147–175

Oxley JE, Sampson RC (2004) The scope and governance of international R&D alliances. Strateg Manage J 25:723–749
Ozman M (2010) The knowledge base of products: implications for organizational structure. Organ Stud 31:1129–1154
Pangarkar N (2003) Determinants of alliance duration in uncertain environments: the case of the biotechnology sector. Long Range Plan 36:269–284
Pisano GP (1989) Using equity participation to support exchange: evidence from the biotechnology industry. J Law, Econ Organ 5(1):109
Poppo L, Zenger T (2002) Do formal contracts and relational governance function as substitutes or complements? Strateg Manage J 23(8):707
Powell WW (1990) Neither market nor hierarchy: network forms of organization. Res Organ Behav 12:295–336
Powell WW, Koput KW, Smith-Doerr L (1996) Inter-organizational collaboration and the locus of innovation: networks of learning in biotechnology. Adm Sci Q 41:116–145
Reed R, DeFillippi RJ (1990) Causal ambiguity, barriers to imitation, and sustainable competitive advantage. Acad Manage Rev 15:88–102
Reuer J, Ariño A (2007) Strategic alliance contracts: dimensions and determinants of contractual complexity. Strateg Manage J 28:313–330
Reuer JJ, Zollo M, Singh H (2002) Post-Formation dynamics in strategic alliances. Strateg Manage J 23:135–151
Rosenkopf L, Tushman, ML (1998) The coevolution of community networks and technology: lessons from the flight simulation industry. Ind Corp Change 7:311–346
Rowley T, Behrens D, Krackhardt D (2000) Redundant governance structures: an analysis of structural ad relational embeddedness in the steel and semiconductor industries. Strateg Manage J 21:369–86
Santoro MD, McGill JP (2005) The effect of uncertainty and asset co-specialization on governance mode in biotechnology alliances. Strateg Manage J 26:1261–1269
Schoenmakers W, Duysters G (2006) Learning in strategic technology alliances. Technol Anal Strateg Manag 18(2):245–264
Simon HA (1969) The architecture of complexity, in the sciences of the artificial. MIT, Cambridge, pp 192–229
Simonin B (1999) Ambiguity and the process of knowledge transfer in strategic alliances. Strateg Manage J 20:595–623
Uzzi B (1997) Social structure and competition in interfirm networks: the paradox of embeddedness. Adm Sci Q 42(1):35–67
Uzzi B, Gillespie JJ (2002) Knowledge spillover in corporate financing networks: embeddedness and the firm's debt performance. Strateg Manage J 23:595–618
Wang Q, von Tunzelmann N (2000) Complexity and the functions of the firm: breadth and depth. Res Policy 29:805–818
Williamson, OE (1975) Markets and hierarchies: analysis and antitrust implications. Free Press, New York
Zander U, Kogut B (1995) Knowledge and the speed of the transfer and imitation of organizational capabilities: an empirical test. Organ Sci 6(1):76–92