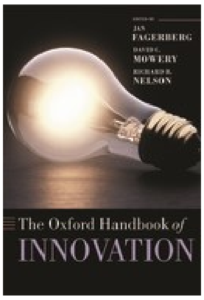

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CHAPTER

3 Networks of Innovators

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Abstract

The goal of this article is to assess the state of scholarly research on the role of networks in the innovation process. It begins with a review of the factors that have triggered the increased salience of networks. It then turns to a discussion of the analytical leverage provided by the tools of network analysis. It next reviews a number of empirical studies of the contribution of networks to the innovative output of firms. It takes up the issue of knowledge transfer, examining how the codification of knowledge can shape what is transmitted through networks. Furthermore, this article briefly discusses the governance of networks, and then concludes with an assessment of what types of organizations and settings derive the greatest impact on innovation from participation in networks.

Keywords: scholarly research, innovation, network analysis, empirical studies, knowledge transfer
Subject: Organizational Theory and Behaviour, Innovation, Business and Management
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3.1 Introduction

IN February of 2001, two rival consortia published rough draft (roughly 90 per cent complete) sequences of the human genome in *Nature* and *Science*. The “public” Human Genome Project consisted of five key institutions and eleven collaborators,[1] supported by the US National Institutes of Health, Department of Energy, and the Wellcome Trust in the United Kingdom. The rival “private” consortia, led by the biotech firm Celera, included both commercial firms and academic researchers from the University of California, Penn State, Case Western, Johns Hopkins, Cal Tech, Yale, Rockefeller, as well as scientists in Spain, Israel, and Australia. These projects have been acclaimed for their remarkable scientific achievement; they were also the product of considerable organizational innovation. In contrast to the Manhattan Project or Project Apollo, both of which were hierarchically organized, national projects, the Human Genome Project (HGP) and the Celera team were pluralist, multiorganizational, multinational confederations. These two groups were intensely rivalrous, but collaborated intensively within their own groups (Lambright 2002). HGP involved management by two government agencies and a private British

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p. 57 foundation that coordinated activities in government labs, universities, and non-profit institutes in the US and England. As the lead firm, Celera's organization was more focused, but its research team included scientists and state-of-the-art equipment at private firms, public and private universities, and non-profit institutes in four countries.

Both projects were organized as large-scale networks, and their rivalry spurred each side to engage in a high-stakes learning race. While the cost, scale, and distributed nature of these projects may have been unusual, the form of organization—collaboration across multiple organizational boundaries and institutional forms—is no longer rare. Indeed, many analysts have noted that the model of networks of innovators has become commonplace over the past two decades (Powell 1990; Rosenbloom and Spencer 1996; Roberts and Liu 2001; Chesbrough 2003).

Collaboration among ostensible rivals was once regarded as a provisional or transitional step taken to enter new markets, spread risks, or to share early stage R&D costs (Mowery 1988). Such forays were often followed by mergers as the transitory activities became incorporated inside the boundaries of the firm. Recent studies suggest, however, that various forms of interorganizational partnerships are now core components of corporate strategy. Even where these linkages endure for relatively lengthy periods of time, they do not entail vertical integration (Gomes-Casseres 1996; Hagedoorn 1996; Noteboom 1999; Ahuja 2000*a*). Contemporary studies of industrial performance are replete with reports of a significant upsurge in various types of interorganizational collaboration. While these collaborations can take a number of forms (including research consortia, joint ventures, strategic alliances, and subcontracting) and span a wide range of key functions, a National Research Council analysis of trends in industrial research and development (R&D) suggests that the innovation process has undergone the most significant transformation over the past decade (Merrill and Cooper 1999). In a survey of the period 1960–98, Hagedoorn (2002) finds a sharp growth in R&D collaborations, beginning in the late 1970s and continuing through the mid-1990s.

A National Research Council assessment of eleven US-based industries, purposefully diverse in character and technology but all resurgent in the 1990s, observes in every sector an increased reliance on external sources of R&D, notably universities, consortia and government labs, and greater collaboration with domestic and foreign competitors, as well as customers in the development of new products and processes (Mowery 1999: 7). Other surveys also point to the enhanced centrality of interorganizational collaboration, especially in R&D. For example, National Science Foundation data show a marked increase in the number of international alliances between US and Western European countries between 1980 and 1994; but by the mid-1990s, the formation rates for intranational alliances linking US firms with their domestic competitors outpace international linkages (National Science Board 1998). The former collaborations were motivated largely by concerns with market access, while the latter focus more on the development of new technologies.

p. 58 Similarly, there is now ample research illustrating the growing links between US firms and universities (Powell and Owen-Smith 1998), and greater involvement by firms and government labs in research joint ventures (Link 1996, 1999). In the realm of science, Hicks and Katz (1996) find that research papers are much more likely to be co-authored and involve authors with multiple institutional affiliations that span universities, government, and industry. Distributed networks of practice are the organizing basis for many technical communities, suggesting both that sources of knowledge are now more widely dispersed and that governance mechanisms are emerging to orchestrate distributed knowledge. The open source software movement is but one highly visible example of this trend (O'Mahony 2002; Weber 2003), which illustrates how advances in information technology have greatly facilitated virtual networks. In short, as Mowery

(1999: 9) observes, "the diversity of institutional actors and relationships in the industrial innovation process has increased considerably." Complex networks of firms, universities, and government labs are critical features of many industries, especially so in fields with rapid technological progress, such as computers, semiconductors, pharmaceuticals, and biotechnology.

Our goal in this chapter is to assess the state of scholarly research on the role of networks in the innovation process. We begin with a review of the factors that have triggered the increased salience of networks. We discuss different types of networks, distinguishing between networks that are based more on contractual or market considerations, and those that are based on less formal, and more primordial relationships, such as common membership in a technological community or a regional economy. We then turn to a discussion of the analytical leverage provided by the tools of network analysis. This stream of research, which spans sociology, social psychology, organizational behavior, and business strategy, highlights key distinctions between highly clustered, dense networks, steeped in overlapping ties and high in trust, and weak-tie networks, that provide access to novel, non-redundant information. We next review a number of empirical studies of the contribution of networks to the innovative output of firms. We take up the issue of knowledge transfer, examining how the codification of knowledge can shape what is transmitted through networks. We briefly discuss the governance of networks, and then conclude with an assessment of what types of organizations and settings derive the greatest impact on innovation from participation in networks.

Research on the relationship between networks and innovation is a relatively recent area of inquiry. While there is a good deal of work underway, direct analyses measuring the impact of interfirm networks on performance are limited. Much of the extant research focuses on the effects of networks on patenting, access to information, and the generation of novel ideas. Moreover, the studies often examine high-tech industries, where investment in R&D is pronounced. Attention to the consequences of network ties for the financial performance of firms is relatively rare.

p. 59

3.2 Why have Networks Grown in Importance?

The advantages of a heterogeneous group of contacts are well established in both social theory and network analysis. A strong tradition of theory and research, running from Simmel (1954) to Merton (1957) to Granovetter (1973) to Burt (1992), makes abundantly clear that there are informational, status, and resource advantages to having broad and diverse social circles. Below we review an array of recent empirical studies that demonstrate how interorganizational relationships lead to various benefits with respect to information diffusion, resource sharing, access to specialized assets, and interorganizational learning. In science and technology-based fields, the advantages that accrue from diverse sources of information and resources are considerable. Not surprisingly, then, as the commercialization of knowledge has assumed greater importance in economic growth, collaboration across organizational boundaries has become more commonplace. Interorganizational networks are a means by which organizations can pool or exchange resources, and jointly develop new ideas and skills. In fields where scientific or technological progress is developing rapidly, and the sources of knowledge are widely distributed, no single firm has all the necessary skills to stay on top of all areas of progress and bring significant innovations to market (Powell and Brantley 1992; Powell, Koput, and Smith-Doerr 1996; Hagedoorn and Duysters 2002). In such settings, networks can become the locus of innovation, as the creation of knowledge is crucial to improving competitive position.

Collaborative networks have long been central to the production process in craft-based industries (Eccles 1981), in industrial districts (Brusco 1982; Piore and Sabel 1984), and in fields such as aerospace where assembly depended upon key inputs from diverse participants. The growth of knowledge-intensive industries has heightened the importance of networks in R&D as well as product development and distribution. A persistent finding from a diverse set of empirical studies is that internal R&D intensity and technological sophistication are positively correlated with both the number and intensity of strategic alliances (Freeman 1991; Hagedoorn 1995).

For organizations in rapidly developing fields, heterogeneity in the portfolio of collaborators allows firms to learn from a wide stock of knowledge. Organizations with broader networks are exposed to more experiences, different competencies, and added opportunities (Beckman and Haunschild 2002). Such access creates an environment in which "creative abrasion," the synthesis that is developed from multiple points of view, is more likely to occur. In this view, "innovation occurs at the boundaries between mind sets, not within the provincial territory of one knowledge and skill base" (Leonard-Barton 1995: 62). By having
p. 60 access to a more ↳ varied set of activities, experiences, and collaborators, companies broaden the resource and knowledge base that they can draw on. By developing more multiplex ties with individual partners, either through pursuing multiple collaborations or expanding an existing R&D partnership into downstream development, companies increase the points of contact between them. When relationships are deepened, greater commitment and more thorough knowledge sharing ensue. Organizations with multiple and/or multifaceted ties to others are likely to have developed better protocols for the exchange of information and the resolution of disputes (Powell 1998). Parties that develop a broader bandwidth for communication are, in turn, more capable of transferring complex knowledge. In science-driven fields such as biotechnology, organizations that develop ties to different kinds of organizations and carry out multiple types of activities with these organizations are central players in industry networks (Powell et al. 2004). These centrally positioned organizations are both capable of pulling promising new entrants into the network and collaborating with a wide assortment of incumbents. Moreover, research shows that in biotechnology, organizations lacking such connections fail to keep pace and fall by the wayside (Powell et al. 2005).

3.3 Varieties of Networks

The literature on networks emphasizes that they are most pronounced in the domain between the flexibility and autonomy of markets and the force and control of organizational authority (Powell 1990). Networks thus combine some of the incentive structures of markets with the monitoring capabilities and administrative oversight associated with hierarchies (Mowery, Oxley, and Silverman 1996). For our purposes, we include networks based on formal contractual relations, such as subcontracting relationships, strategic alliances or participation in an industry-wide research consortium, and informal ties, based on common membership in a professional or trade association, or even a looser affiliation with a technological community.

One can differentiate networks with respect to their duration and stability, as well as whether they are forged to accomplish a specific task or evolve out of pre-existing bonds of association. Networks vary from short-term projects to long-term relationships, and the different temporal dimensions have important implications for governance. Some networks are hierarchical, monitored by a central authority; while others are more heterarchical, with distributed authority and strong self-organizing features. Grabher and Powell
p. 61 (2004) focus on temporal stability and forms of ↳ governance to differentiate four key types: informal networks (based on shared experience); project networks (short-term combinations to accomplish specific tasks); regional networks (where spatial propinquity helps sustain a common community); and business networks (purposive, strategic alliances between two parties). These types do not represent essentialist categories; rather they may overlap and interweave with one another. Consider these forms as useful coordinates to locate networks with respect to different combinatory elements.

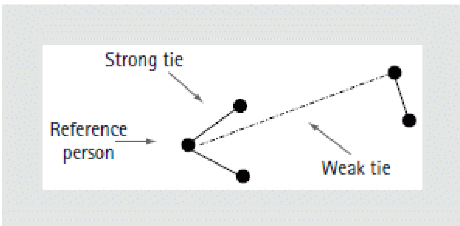
Several key concepts provide potent analytical tools that apply across different types of networks and permit assessment of their effects. First, consider the differences between strong and weak ties

(Granovetter 1973). In interpersonal terms, a strong tie is a person with whom you interact on a regular basis, while a weak tie is an acquaintance, or a friend of a friend. Strong ties are important for social support, but much of the novel information that a person receives comes from weak ties. Strong ties are based on common interests, consequently most information that is passed reinforces existing views. Weak ties introduce novelty in the form of different ideas or tastes, and by introducing new information they are, for example, invaluable in job searches and other circumstances where a small amount of new information is highly useful. Weak ties have a longer reach, but a much narrower bandwidth than strong ties. The latter are more cohesive, and often prove to be more effective at the exchange of complex information. Figure 3.1 illustrates the difference between strong and weak ties.

Much of the research on interfirm networks extrapolates from interpersonal relations.[2] In general, this is a plausible analytical move; however, it elides the question of whether relationships at the firm level are dependent on ongoing interpersonal ties, and whether the business relationship would be harmed or severed if the key participants were to depart. The extent to which interorganizational ties are contingent upon relations among individuals is a key question for scholarly research, as well as a critical challenge for business strategy (Gulati 1995; Powell 1998).

A second notable contrast is the distinction between networks as bridges and as structural holes (Burt 1992). p. 62 Bridges are points of connection between parties that ↳ lack ties, such as when A knows B, and C knows B but not A. B is the bridge between A and C, thus the gateway to a linkage between A and C. Granovetter (1973) argued that bridges are the links that make weak ties possible. Burt (1992) deepened the argument by moving from the who question (i.e., which position in a network is best situated) to the question of how certain structural arrangements generate benefits and opportunities. He coined the term "structural holes" as a potential connection between clusters of units that are not connected. The possibility of making such a connection provides leverage, or opportunities for arbitrage. Those positioned to take advantage of structural holes can broker gaps in the social structure. See Figure 3.2 for illustration.

Fig. 3.1

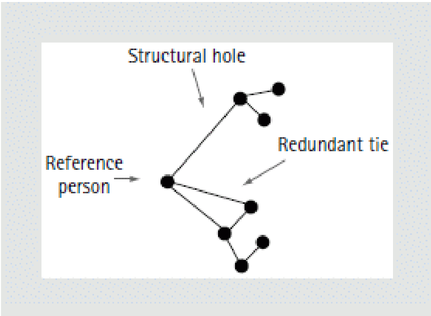


Strong and weak ties

There is debate as to whether strong or weak ties, or bridges or structural holes, offer greater opportunities for innovation (Ahuja 2000*a*; Ruef 2002). Clearly, variation in network structures is associated with different content in relationships. Strong ties between two parties may restrict information gathering in terms of the breadth of search, but the information that is exchanged is "thick," or detailed and rich. Weak ties are thinner and less durable, but provide better access to non-redundant information. There is also disagreement as to whether networks can be designed or "pruned" to produce "optimal" shapes, without triggering repercussions. Whether location in a network is highly malleable or not, position in a network both empowers and constrains opportunities.

A third point of contrast is between networks formed intentionally across a market interface to accomplish a task and emergent networks that grow out of ongoing relationships. The former may be considered an instrumental or strategic relation, while the latter stems from more primordial relations, such as common ethnicity, friendship, or location. These different starting points matter, but in the fluid world of networks, the point of origin does not fix the evolution of a relationship. Consider two cases. There is a global trend toward vertical disaggregation in manufacturing, as firms are relying on suppliers for design and component inputs p. 63 ↳ in a variety of industries (see Womack, Jones, and Roos 1990, for autos; McKendrick, Doner, and Haggard 2000, for disk drives). Often these outsourcing decisions are driven by the need to reduce costs, save time, and enhance flexibility, while the large firm concentrates on those activities in which it has some form of competitive advantage. But as many analysts have noted, there is no natural stopping point in this relation (Sabel 1994; Helper, McDuffie, and Sabel 2000). The subcontractor can end up involved in design issues, doing critical R&D, or become central to efforts to improve quality. What began as a choice to outsource can, in some circumstances, become either a deep, mutually dependent collaboration or a highly ambiguous and opportunistic partnership. Helper et al. (2000) and Dyer and Nobeoka (2000) illustrate the marked trend for automobile subcontracting to evolve into interdependent, bilateral relationships.

Fig. 3.2



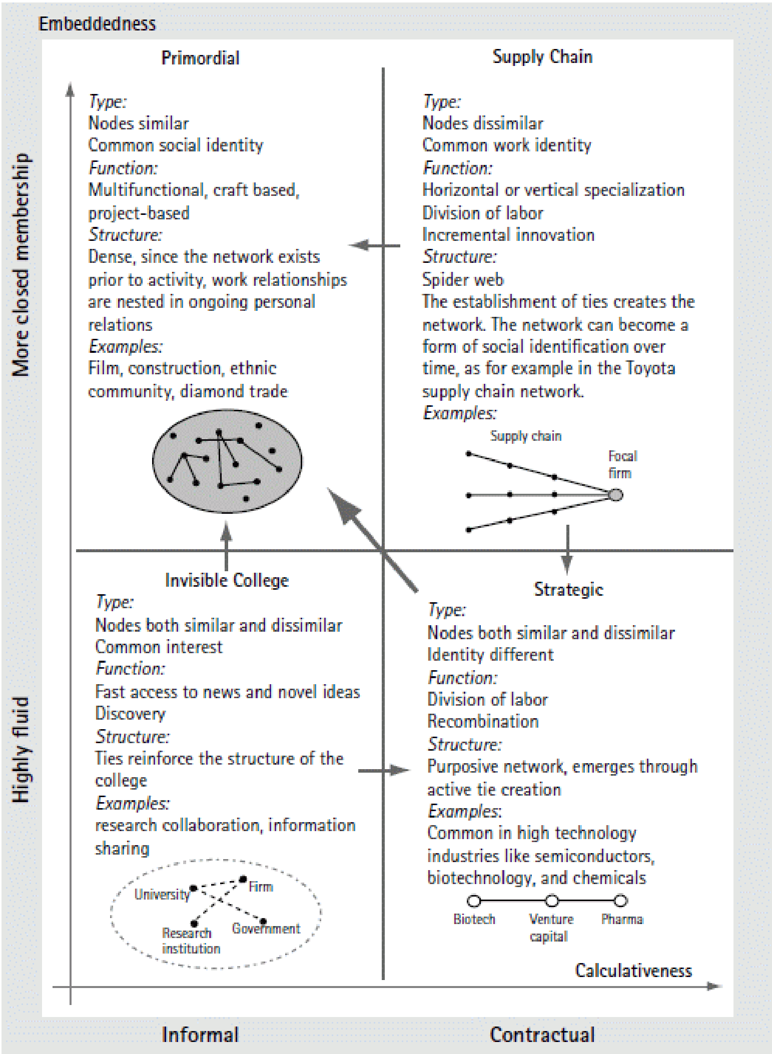
Structural holes and redundant ties

Or consider the contemporary life sciences, where many R&D partnerships emerge out of ongoing intellectual relationships—co-authorships, mentor–mentee relationships, and common training (Murray 2002). These informal personal relationships may, however, come to involve significant intellectual property in the form of patents, and thus become highly formalized contractual agreements between organizations. We offer these examples as illustrations that networks forged out of strategic purposes can take on strong relational elements, while more personal ties can become contractual and highly specified. While it is possible to assign networks to either a transcational (i.e., based on a consideration of business opportunities without regard to prior social relations) or relational (i.e., embedded in ongoing social relationships) category, it is inappropriate to assume that relations remain fixed. As networks evolve, there is considerable give and take. Intense competition can render calculative strategic alliances more embedded, while the prospect of great financial reward can turn a "handshake" relationship between individuals into a formal legal linkage between firms.

Figure 3.3 provides a typology of different forms of networks, with the horizontal axis representing degree of purposiveness, ranging from informal to contractual. The vertical axis represents the extent of embeddedness, varying from open, episodic, or fluid to recurrent, dense connections among a fairly closed group (Granovetter, 1985). We illustrate each of the four cells with examples of types of innovation networks. In the lower left cell we place informal networks, such as a scientific invisible college, that emerge out of shared experience orcommon interest. Although these relations tend to be temporary and short-lived, the gray arrows are intended to show that these informal linkages can evolve into formal business alliances or more enduring primordial relations, where participation is more constant and less fluid. The primordial network in the upper left cell is characterized by a common social identity, continuous participation, and close ties. All these features are often found in professional networks, craft-based occupations, ethnic communities, and industrial districts. The upper right cell is typified by involvement in

p. 64 a common project. Membership in such a network is typically restricted and often ↳ governed by a "lead" firm. A supply-chain network or a large construction project are apt examples. The gray arrows are meant to illustrate that supply-chain relations can evolve into either occupational communities and industrial districts or into formal business partnerships. The most purposive and instrumental type of network is the strategic alliance, represented by the lower right cell. We turn now to a discussion of the relationship between these forms and the innovation process.

Fig. 3.3



Network typology

p. 65

3.4 Empirical Studies of the Role of Networks in Innovation

3.4.1 Formal Ties

Most empirical studies of the relationship between networks and innovation focus on formal ties established among organizations. This streamof research documents a strong positive relationship between alliance formation and innovation, across such diverse industries as chemicals (Ahuja 2000*a*), biotechnology (Powell et al. 1996, 1999; Walker, Kogut, and Shan 1997; Baum, Calabrese, and Silverman 2000), telecommunications (Godoe 2000), and semiconductors (Stuart 1998, 2000). The diversity of the research contexts suggests the effects of network structure may be generalizable. Nevertheless, most research has focused on high technology industries, and uses patents as a proxy for innovation. More direct measures of innovative outputs are needed. Some of the important themes that emerge from this research highlight specific tie characteristics, technological uncertainty, and network evolution. In addition, researchers have emphasized the increased benefits in the form of resources and knowledge that alliances provide to entrepreneurial firms.

Tie characteristics. One line of research focuses on how different types of ties influence the benefits derived from alliances. Vinding (2002) identified 548 Danish manufacturing firms that developed one or more new products over a two-year period. In interviews with a subset of the companies, he finds that the impact of a collaboration on innovation is significantly related to both the type of partner and the pattern of previous collaborative relationships. The importance of prior interaction with partners points to the significance of relationship building, and how elements such as trust and cognitive understandings require time to develop. Domestic partners were found to have a greater positive impact on innovative performance than foreign partners, possibly due to the higher costs, both psychological and financial, associated with more distant collaborations. Vinding's research emphasizes benefits derived from strong local ties. Similarly, in a ten-year (1980–90) case study of the R&D portfolio of a Norwegian telecommunications organization, Godoe (2000) reports comparable results with respect to strong ties. His analysis suggests that radical innovations were more likely to emerge from intimate and prolonged interaction. But in the Norwegian case, the affiliations were not local, but instead based on membership in international telecommunications associations.

Powell et al. (1999) emphasize that experience with collaboration and centrality in the network derived from a diverse set of ties are important determinants of innovation among biotechnology firms over the period 1988–99. Their analyses suggest that centrality and experience resulted in more patenting. The most consequential connections in terms of patenting were R&D partnerships. The diversity of ↳ network ties also had a positive influence on rates of patenting. Powell et al. (1999) found that while network experience had a positive influence on patenting, the rate of increase diminished with additional experience, suggesting possible declining returns to network connectivity. The question of whether there are limits to connectivity needs to be investigated further.[3] These results suggested a "cycles of learning" process in which R&D collaborations generate attention that attracts other partners, who collaborate in developing novel ideas. This enhanced diversity of affiliations increases a firm's experience at managing collaborations and transferring knowledge, and increases their centrality in the industry network. Greater centrality is associated with a higher rate of patenting, and both centrality and higher volumes of patenting trigger subsequent R&D partnerships, restarting the cycle for centrally placed firms.

p. 66

Most research has looked at the presence or absence of a formal collaboration. Ahuja (2000*a*), however, developed a more nuanced analysis including both direct and indirect ties, and the level of indirectness. Drawing data from a sample of 97 firms in the global chemicals industry, he used the number of patents as a measure of innovative output, while collaboration was measured through formal ties. More distant connections through affiliates of partners were coded as weak or indirect ties. The results show that both direct and indirect ties have a positive influence on innovation, though the impact of indirect ties is smaller than the impact of direct ties. The number of direct ties also negatively moderates the impact of indirect ties. In contrast to Burt's (1992) arguments about the arbitrage opportunities available through non-redundant contacts, Ahuja shows that a network with many structural holes can reduce innovative output, as measured by rates of patenting. A key advantage of close-knit networks may be due to their superior ability to transfer tacit knowledge (Van Wijk, Van den Bosch, and Volberda 2003). In an analysis of the exchange of information across project teams in a large multinational computer company, Hansen (1999) also illustrates that complex knowledge is transferred most easily through tightly knit networks.

Entrepreneurial firms. One active area of research concerns the effects of networks on survival chances of newly founded firms. Larson's (1992) ethnographic study of how a startup firm grew and prospered by drawing on external resources and support for key business functions illustrates how relationships are forged and sustained as startup firms grow. While not explicitly looking at innovative output, Larson added insight into the signal importance of networks in obtaining resources necessary to fuel a startup firm's success. Shan, Walker, and Kogut (1994) examined whether biotechnology startup firms' cooperative relationships with other firms had a positive effect on patenting. Their results offer support for the argument that collaborative relationships increased innovation, because formal cooperative relationships explained innovative output, while innovative output did not account for the pattern of alliances. The
p. 67 salience of alliances for young and small firms is further ↳ emphasized in Stuart's (2000) study of innovation in the semiconductor industry. His dataset includes 150 firms, followed by the consultancy firm Dataquest over the period 1985–91. Drawing on sales figures, patterns of strategic alliances, and patenting activity, Stuart shows that firms possessing technologically sophisticated alliance partners patented at a substantially greater rate than those that lacked such ties. Firms establishing strategic alliances with large partners also grew at a higher rate than firms without access to such partners. The returns to networks with regard to patenting were greatest for both young and small firms.

Baum, Calabrese, and Silverman (2000) pursue a similar question, asking how the composition of a startup firm's alliance portfolio affects its performance. Using data on 142 biotechnology firms founded in Canada between 1991 and 1996, they find a positive effect of alliance formation on startup innovation. Network efficiency, defined as the diversity of information and capabilities per alliance, showed a large positive effect on the number of biotech patents. Alliances with direct competitors had a negative effect on innovation, however. These results were moderated when the rival biotechnology firm had a larger share of the relevant market or if the rival biotechnology firm was highly innovative. Of the various performance measures used, the number of patents and the volume of R&D expenditures were most significantly influenced by rates of alliance formation.

Network dynamics. Drawing on Cohen and Levinthal's (1990) ideas about absorptive capacity, Powell et al. (1996) argued that firms utilize external collaborations to stay abreast in rapidly developing technological fields. But organizations cannot be passive recipients of new knowledge. “What can be learned is crucially affected by what is already known” (Powell et al. 1996: 120). To understand the “news” generated externally, organizations have to make “news” internally. In this fashion, the rate of acquisition of skills and resources from the outside is closely linked to the generation of expertise internally. In their work on the global biotechnology industry, they find that firms that develop experience at managing collaborative R&D relationships garner faster access to centrally positioned organizations. As experience at collaborating grows, firms widen the network of organizations with whom they partner. As a firm's experience with collaboration and its diversity of partners increase, the more central and visible the firm becomes in the industry. This centrality leads, in turn, to growth in the size of the firm, and to the ability to coordinate more alliances, creating a feedback cycle. This cycle of learning has been shown to be associated with positive financial performance (Powell et al. 1999), and a greater ability to collaborate with diverse kinds of organizations, which permits firms to retain a leadership position in the industry (Powell et al. 2005).

The general picture that emerges from research in organizational sociology and business strategy is one in which networks and innovation constitute a virtuous cycle. External linkages facilitate innovation, and at
p. 68 the same time innovative outputs attract further collaborative ties. Both factors stimulate organizational ↳ growth, and appear to enhance further innovation. Ahuja (2000*b*) and Stuart (2000), for example, demonstrate that firms with many prior patents are more likely to form alliances than firms lacking patents, suggesting a recursive process of innovation and growth in which collaborative ties play a central role. Further attention needs to be given, however, to such issues as the effects of the duration of linkages, experience with collaboration, and the consequences of broken ties on rates of innovation.

Technological uncertainty. Two additional aspects of the innovation process involve the relationship between strategy and alliance formation and the level of technological uncertainty in the field. Eisenhardt and Schoonhoven (1996) studied the population of semiconductor firms launched in the US between 1978 and 1985, and found that the more risk-taking a company's strategy, the more alliances a company formed. One explanation is that as firms gain credibility for developing pioneering technologies, access to financial and other resources for developing innovative technology is secured through alliances. An alternative view is that alliances are necessary to share the attendant risks in high-velocity environments. Sarkar, Echambadi, and Harrison's (2001) analysis of managers in a range of high-tech industries revealed that an active strategy of alliance formation enhanced performance, as measured by market share, sales growth, market development, and product innovation. They also report that managers who perceived the environment as more uncertain were more likely to pursue alliances. In addition, smaller firms derived more value from network linkages than larger firms, presumably because smaller companies viewed the technological landscape as more uncertain.

Rosenkopf and Tushman (1998) examined the role of technical communities in the flight simulation industry, where cooperative technical organizations play a critical role in developing standards and advancing the state of the art. In a study covering the years 1958–92, they found long periods marked by incremental change punctuated by shorter eras of ferment. They show that the rate of founding of technical networks increases during periods of discontinuity, and stabilizes into core "cliques" when ferment declines and a dominant design emerges. Subsequent technological change disrupts dominant cliques, and triggers the formation of new networks, restarting the cycle. Thus, both technological strategy and industry evolution are linked to patterns of network formation, with external networks assuming greater importance during periods of technical discontinuity and for firms with more risk-taking strategies. The importance of industry technical committees in standards setting has also been emphasized in the computer industry (Farrell and Salomer 1988) and videocassette recorders (Cusumano et al. 1992).

The overall conclusion of this group of studies is that networks provide access to more diverse sources of information and capabilities than are available to firms lacking such ties, and, in turn, these linkages increase the level of innovation inside firms. Younger and smaller firms may benefit more from
p. 69 collaborative relationships ↳ than do larger firms. Most notably, firms with a central location within networks generate more innovative output. Both direct and indirect ties provide a positive contribution to innovation, but the effect of indirect ties is moderated by the prevalence of direct ties. The evidence for the benefits of structural holes is not uniform; where structural holes might be beneficial is in the search for new information, but the knowledge transfer process appears to be facilitated by closer-knit networks. From the view of the dynamics of collaboration, successful external relations appear to beget more ties, which fuel firm growth and innovation. Clearly, there are limits to this cycle, but research has not addressed this question in depth thus far.

The majority of the studies reviewed in this section have been carried out using patents as the dependent variable and formal relationships as the independent variable. Patents provide a measure of novelty that is externally validated through the patent examination process, hence they are a useful indicator of knowledge creation (Griliches 1990). But patents have some limitations. Some kinds of innovations are not patented, and there is variation in the extent of patenting across industries. (See Chapter 14 by Malerba on inter-industry variation in innovation processes.) On the other hand, the focus of many of these studies—semiconductors, chemicals, biotechnology—is in fields where patenting is commonplace, and competitors in these sectors are active patentors. The attention to these high-technology industries raises questions, however, as to the generalizability of the results to other less knowledge-intensive industries.

One study that speaks to differences across industries is Rowley, Behrens, and Krackhardt's (2000) analysis of strong and weak ties in the steel and semiconductor industries. This study made a notable effort to distinguish between strong affiliations, where alliances entailed significant resource commitments and regular interactions, and more "arm's-length" transactions, where there was a rapid exchange, and the relationship was characterized by less frequency and depth. For example, equity alliances, joint ventures, and R&D partnerships were categorized as strong ties, while licensing, patent agreements, and marketing relations were classified as weak ties. Recognizing that weak ties serve as bridges to novel information, while strong ties are useful for both social control and the exchange of tacit knowledge, they find divergent results. In the steel industry strong ties are positively associated with performance; while in semiconductors weak ties are more efficacious. They suggest these findings reflect the importance of search and product innovation in semiconductors, and a focus on improvements in the production process for steel.

Much of the research on buyer–supplier relations and subcontracting has focused on more traditional industries, such as automobiles or textiles. To be sure, these industries make considerable use of technological advances, but they are less science-driven. As a consequence, the sources of relevant knowledge are not as widely dispersed. Strong ties thus tend to predominate over weak ties. But the content
p. 70
of those ties can evolve, changing from contractual to relational. Consider ↳ subcontracting relations, particularly one of the more notable examples—the Toyota auto production network. Researchers stress how the density of overlapping ties that connect this chain of production facilitates knowledge sharing, mutual learning, and fast responsiveness (Dyer 1996; Dyer and Nobeoka 2000). But the trust and reciprocity that characterize this dense network are the outcome of a long developmental process. In the 1950s and early 1960s, when Japanese firms competed on the basis of lowest cost, relationships with subcontractors were hierarchical and asymmetric. As firms increasingly competed on the basis of quality and innovation, however, complex multitiered supply relationships underwent significant change. These relationships can remain hierarchical in two key respects: the larger lead firm often has a significant financial stake in a supplier or affiliate, and it initiates the production process. But the asymmetry has been sharply reduced. Suppliers, in an effort to remain competitive, make significant investments in new equipment, constantly upgrade workers' skills, and take on more critical aspects of the assembly process (Helper et al. 2000). In turn, the larger firms offer long-term contracts, share employees and provide technical assistance, and make financial investments to fund equipment upgrades.

Too explicit a focus on formal, contractual linkages, however, neglects themyriad informal ties that connect organizations. All kinds of informal interactions take place between organizations, including participation in ad hoc industry committees, or executive education programs, conferences, trade association activities, and the like. Personnel mobility and common educational backgrounds may also foster informal linkages across firms. Such informal connections may be the basis on which more formal, contractual alliances are forged. Indeed, the success of formal affiliations may hinge on the strength of informal ties. Thus we turn to a discussion of non-contractual relations.

3.4.2 Informal Ties

Informal patterns of affiliation have long been a central topic in sociology and anthropology, where studies of friendship networks, advice and referral networks, and communities are common. There is also a well-established strand of research in organization theory that points out how informal relations within organizations are often not closely aligned with formal authority (Dalton 1959; Blau 1963). A small line of work focuses on the impact of informal networks in large, multinational companies (Ghoshal and Bartlett 1990; Hansen 1999). Relatively few studies, however, link informal ties to the innovation process, and there is scant research on informal interorganizational relations.

Scholars have often argued that the sharing of complex information is enhanced by embedded ties, which p. 71 suggests that informal ties have the potential to make a ↳ significant contribution to innovation. There is a strong sense among researchers that informal relations undergird formal ties. Powell et al. (1996) argue that, in the life sciences, "beneath most formal ties lie a sea of informal ties." Nevertheless, many organizations are largely unaware of the extent to which formal activities are buttressed by informal connections (Cross, Borgatti, and Parker 2002).

One of the key studies of informal networks among firms was Von Hippel's (1987) work on the sharing of proprietary information among US steel mini-mill producers. Based on interviews with plant managers and other engineers with direct knowledge of manufacturing processes, he found that the trading of proprietary knowledge with both cooperating and rival firms was commonplace. Hewas initially surprised that proprietary knowledge was so "leaky," but he came to recognize that information exchange was highly reciprocal and conditioned on expectations that requests for help would be met. Much of the information that was shared focused on production problems, matters of pollution control and safety, and issues dealing with industry-wide concerns. But when relationships among engineers in rival firms were particularly close, more proprietary information was exchanged. Von Hippel also found that engineers had strong norms of membership in a professional community that cut across firms, and that information trading was a means to secure reputation and status in that community. He provides numerous examples of how the sharing of complex information by engineers contributed to the productivity of mini-mills.

The cluster of individuals that share a similar set of skills and expertise has been dubbed a "community of practice" (Wenger 1998), or a "network of practice" (Brown and Duguid 2001). Similar in some respects to a technical community, or a sophisticated hobby club, these loose groups are engaged in related work practices, though they do not necessarily work together. Such fluid groups are important to the circulation of ideas. Saxenian (1994) observed ample sharing of proprietary knowledge among engineers in Silicon Valley, many of whom have as strong a commitment to their peers within the same occupational group as to their companies. Saxenian argues that informal knowledge sharing, widely institutionalized as a professional practice in Silicon Valley, is one of the crucial factors contributing to its fertile innovative climate. Cohen and Fields (1999) stress that professional ties in Silicon Valley are forged in complex collaborations between entrepreneurs, scientists, firms, and associations, focused on the pursuit of innovation and its commercialization. This collaborative process generates and refines the intangible raw material of technical change—ideas.

Kreiner and Schultz (1993) analyze the importance of informal ties through indepth interviews with university researchers and industry research directors in the Danish biotech field. They stress that successful collaborative R&D alliances within the Danish biotech industry are often based on informal ties. A barter economy, where materials, laboratory tests, chemicals, etc. are exchanged, was pervasive in this p. 72 sector. They show that norms of sharing information on the frontier of research aid ↳ in the formation of more formal networks. As in the mini-mills, information exchange is not under managerial control, even though such reciprocal flows can be channeled by managerial actions.

Many studies of informal relationships stress the significance of trust. Tsai and Ghoshal (1998) studied the association between intrafirm networks and innovation in fifteen business units of a multinational electronics company. They found, not surprisingly, that social ties led to a higher degree of trustworthiness among business units. Trust increased resource-exchange and combination between the businessunits, which contributed to product innovation. The importance of trust also looms large in Uzzi's (1997) analysis of the difference between "arm's-length" ties ("a deal in which costs are everything") and embedded ties ("you become friends with these people—business friends. You trust them and their work. They're part of the family"). Uzzi conducted interviews and ethnographic observations at twenty-threewomen's betterdress firms in the New York City apparel industry. His study is notable not only for the quality of his data, but also for his attention to the performance consequences of different kinds of exchange relations. Uzzi found that organizational performance increases with the use ofembedded ties to network partners, as these ties were superior at conveying complex, context-dependent knowledge. He argued, however, that a balance between a firm's embedded ties and a firm's arm's-length ties needed to be struck, because a network structure comprising only arm's-length ties or embedded ties decreased organizational performance.

The significance of a balanced network structure, mixing formal and informal affiliations, is also emphasized in Ruef 's (2002) analysis of entrepreneurship. He found that individuals positioned in heterogeneous networks, comprising both strong and weak ties, are more likely to be regarded as innovative by peers, in comparison to entrepreneurs in more homogeneous networks. Rosenkopf has found a similar interweaving of formal and informal relations in her research on industry-wide expert communities in the areas of flight simulation and mobile phones. Rosenkopf, Metiu, and George (2001) analyze joint participation by cellular service firms in technical committees, finding that such membership facilitates subsequent formal interfirm alliance formation. The effect of participation in technical committees decreases when firms have already established prior alliances, suggesting that the effect of informal ties is more catalytic when firms do not already have established alliance partners.

3.4.3 Multi-Party Relationships

Most studies of networks and innovation have examined either dyadic ties, or a focal firm in the context of an overall network. Rosenkopf and Tushman's (1998) work on expert communities emphasized the

importance of studying multi-party ↳ relationships that connect technical professionals across organizations. Akera (2001) uses archival data to map the importance of the IBM user group Share in the early days of computing, offering a portrait of a large multi-party collaboration. Share was formed soon after IBM's release of the first mainframe computer in 1953, to enable IBM's costumers to swap programs, and collaborate on programming so that duplicative effort was avoided. Some of the main innovations that came out of Share provided the basis for both systems programming and operating systems, which today form the backbone of modern computer use. Share conveyed information about hardware changes that substantially improved the design of IBM computers and peripherals. One of the main contributions of the Share network was the creation of technical standards, but a second-order effect was also the diffusion of knowledge across companies and between users.

A modern analogue to Share is the Linux community, founded as a group of users trying to develop an alternative to the operating system supplied by Microsoft. The network of Linux programmers has proven effective in developing software in a highly distributed fashion. In the beginning, most programmers had never met each other and only knew each other virtually—by the username they used when coding. The Linux community has a very modest organizational structure, relying on a combination of interpersonal networks and an individual's reputation as a skilled programmer to serve as the admission ticket to the network (O'Mahony 2002; Weber 2003). One difference between the Share network and the Linux network is that corporate interests drove the Share network, while Linux has been primarily driven by the end users.

Nevertheless, in both cases, the decomposability of programming tasks is an important factor in facilitating distributed networks.

Another large network that has been widely studied is the network of scientists, often termed invisible colleges (Crane 1972). An invisible college is an informal network of researchers who form around a common problem or paradigm. By studying invisible colleges, Crane (1972) hoped to understand how knowledge grows and how the structure of scientific communities affects the expansion of knowledge. There are now numerous studies of scientific networks, mapping the structure of co-authorship and citations (Newman 2003 provides a good overview), though few attend explicitly to the issue of innovation. David (2001), however, develops a formal model to show that the liberal sharing of knowledge within the scientific community is a major driver of scholarly innovation. One of the historic characteristics of scientific communities is that information and research results have been distributed openly among members of the relevant community. The shift toward increasing research commercialization by universities has led some scholars to question whether the innovative benefits of invisible colleges will persist, or if commercial interests will block informal knowledge sharing among scientists (Powell and Owen-Smith 1998; Owen-Smith 2003). Chapter 8 by Mowery and Sampat on university–industry interfaces offers a more detailed discussion of the role of universities in the innovation process.

p. 74 Another line of research that has attended to scientific and technological networks, dubbed Actor–Network Theory (ANT), examines how particular definitions or configurations of science and technology triumph over alternative conceptions. Actor–Network Theory is unique in its treatment of artifacts and technologies, as well as people and organizations, as members of a network (Callon 1998; Latour 1987). The primary contribution of ANT to the relationship between networks and innovation is to show that not only can networks facilitate innovation, but they also constrain it by determining the kind of innovations produced, their subsequent interpretation, and their final use (Callon 2002).

A related line of work that looks at networks as systems of activity is the marketsas-networks approach, developed by Scandinavian marketing researchers (Håkansson and Snehota 1995). This approach examines the multiple relationships among organizations, and shows how these different aspects of interorganizational relationships transform and evolve over time. For example, supplier networks may change frequently, with different elements of production being either outsourced or insourced (Waluszewski 1995). The resources that are exchanged among the partners in a production network are constantly changing. What determines whether an entity is a resource depends on the situation, and its use in combination with other resources. Resources are, thus, always polyvalent in both use and value. The participants in a production network, both individually and collectively, develop bonds characterized by trust and commitment. These bonds also have an organizing effect on networks, as they shape the identities of actors, and account for different levels of commitment among participants. This rich vein of qualitative research has not explicitly focused on innovation, however.

The various studies of multi-party networks tend to emphasize the processual aspects of collaboration. This attention to content is welcome, but it sometimes comes at the expense of measuring the output of relationships, particularly how the sharing and processing of information by members of a network can determine the generation of novelty. A fuller understanding of the innovation process needs to examine the topic of information sharing, a subject to which we now turn.

3.5 Knowledge Transfer

The role of knowledge transfer is clearly central to the innovation process. Research has highlighted two different aspects of the knowledge-transfer process, each of which influences innovation, albeit in different respects. One explanation for the exchange of information through networks emphasizes the importance of p. 75 complementary ↳ assets in the division of innovative labor (Mowery, Oxley, and Silverman 1996). If firm A is good at producing a specific component and firm B is capable of using that component to produce an engine, they collaborate in a joint production in which their capabilities reinforce one another. In biotechnology, for example, small firms with close ties to university scientists may excel at drug development, but lack the skills and resources to manage or fund costly clinical trials. By working closely with a research hospital and an established firm that has a limited pipeline of new medicines, the parties collaborate in a division of labor that is mutually rewarding, and can result in the participants learning from one another, and accomplishing tasks they could not do individually.

A second form of knowledge sharing occurs when existing information within a network is recombined in novel ways. Indeed, novelty is often the unanticipated result of reconfiguring existing knowledge, problems, and solutions (Nelson and Winter 1982; Fleming and Sorenson 2001). As a consequence of such collisions or transpositions, firms can generate something they were unable to create on their own. Both forms of knowledge transfer depend on some manner of successful exchange of ideas, however.

An oft-used distinction is drawn between tacit and explicit knowledge (Cowan, David, and Foray 2000). Interest in tacit knowledge stems from Polanyi's (1956) argument that we frequently know a good deal more than we can express verbally. Explicit knowledge is highly codified, as in blueprints, recipes, manuals, or in the form of training. Tacit knowledge lacks such extensive codification (Nonaka and Takeuchi 1995). Valuable, productive knowledge often demands considerable effort to acquire, and such knowledge is frequently altered in the process of acquisition and application. Perhaps the most vivid example is the continuing effort of US automakers to acquire, understand, and implement the Japanese system of lean production (Womack, Jones, and Roos 1990; Dyer and Nobeoka 2000). Knowledge of complex production technologies is rarely obtained in a fully digestible form; understanding inevitably entails learning by using. The distinction between codified and tacit is key because the latter demands considerably more trial-and-error learning to apply the new knowledge in a different setting.

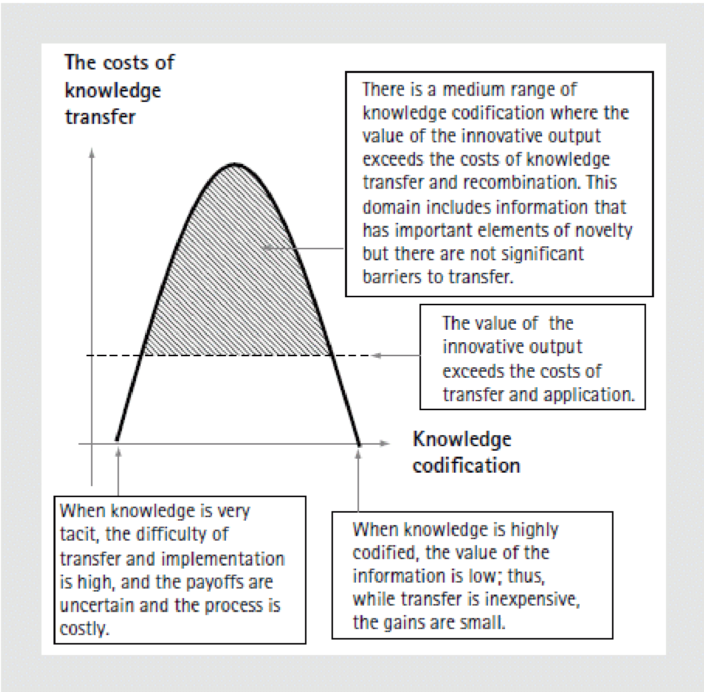
Many studies point to the relatively easy transferability of explicit knowledge in contrast to tacit knowledge. Simonin (1999) shows that knowledge transfer within alliances is negatively affected by both the nature of knowledge and differences in organizational culture. He observes important differences in knowledge exchange between long and short-lived alliances. Older alliances develop a common language and shared mental models between partners, suggesting a learning curve within alliances where the negative effects of lack of experience and knowledge complexity subside as the alliance matures. Thus, as an alliance ages and participants develop relationship-specific understanding, there is the opportunity to convey more subtle forms of information more effectively. Complex tacit knowledge can become more explicit as partners develop a wider bandwidth of communication.

p. 76 If knowledge tacitness is a limiting factor in the transfer of knowledge, then the cost of transferring knowledge is proportional to the type of knowledge transferred. Easily transferred knowledge is widely dispersed at a low cost (Boisot 1998), thus the likelihood that explicit knowledge contains novel elements that would lead to innovation is lower. On the other hand, when knowledge is very “sticky” (von Hippel 1998) and contains a large tacit component, the degree of difficulty and the costs of transfer are high. Consequently, the expected gains realized from this information are uncertain, as the cost of obtaining information may exceed its value. This suggests that when knowledge involves a moderate level of complexity, the benefits derived from transfer may be greatest. Figure 3.4 suggests a hypothetical inverted

U-shaped relationship between innovation and codification. Here we assume that there is variability in the cost of information transfer, and that the greatest value may be derived when novel ideas are transmitted without too much difficulty.

Szulanski's (1996) analysis of the transfer of internal benchmarking efforts in eight companies suggests key
p. 77 dimensions along which knowledge transfer can be ↳ distinguished. He demonstrates that relationships between sender and receiver are important, in that both parties need mutual awareness of state-of-the-art practices. Obviously, communication is critical to information exchange. But even when relationships function well, some knowledge is causally ambiguous, or sticky, and thus not easily transferred. Moreover, information exchange is hindered when the parties have differential levels of absorptive capacity, that is, the ability to recognize the value of new information, assimilate it, and apply it to commercial ends (Cohen and Levinthal 1990). This capacity is essential to innovative capability. For example, internal success with R&D and R&D expenditures positively affect a firm's ability to exploit the opportunities presented in external relations (Cohen and Levinthal 1990; Powell et al. 1996).

Fig. 3.4



Knowledge codification and innovation

The productive transfer of knowledge is also essential when two or more organizations are able to combine their different capabilities, and create a product or service that they would not be able to construct on their own. A good illustration is the Italian motorcycle industry where the locus of innovation is broadly dispersed, and through cooperation, the participants benefit from specialization and variety generation (Lipparini, Lorenzoni, and Zollo 2001). Because all the participants provide valuable inputs, there is a high commitment to knowledge generation. The lead firms develop relational capacities aimed at pooling the skills of specialized participants, helping the overall flow of information and resources in the network. A parallel analysis of the Italian packaging machinery industry stresses the creation of a supplier network in which specialized roles are highly complementary (Lorenzoni and Lipparini 1999). Over time, managers of the core companies developed a specialized supplier network and each participant focused on a narrow, but highly competitive set of core competencies. This network structure enabled every step of the supply chain to specialize in improvements of their specific component, thereby increasing the responsiveness of the participants to market conditions.

3.6 Governance and Incentive Issues

Many studies of interfirm networks draw data from a single point in time and thus do not examine how collaborations unfold over time. Even studies that do look at dynamics tend to do so from the perspective of a dyad. Initially, the choice by a young firm of whom to partner with is often driven by resource needs. As both firms and the network mature, various dyadic choices increasingly reflect structural properties of the network. Thus, the existing network structure shapes search p. 78 ↳ behavior. Consequently, networks both enable information to become knowledge and determine the nature of knowledge (Kogut 2000). But we do not, as yet, have a parallel understanding of the management and governance of networks to accompany analyses of structure and topology. Concerns with how the parties in a relationship adapt to changing circumstances, or attend to the incentives to adjust the relationship to make improvements remain largely unexamined.

Not surprisingly, then, many studies assume that as long as a relationship persists, the participants are achieving their goals, and view termination as a sign of failure. Such a view misses the point that the relationship may have completed its goal or outlived its usefulness. Inkpen and Ross (2001) find evidence that the termination of alliances might not signify failure, but simply be a sign of the conclusion of collaborative activity (for example, a new product is launched). Nevertheless, some collaborations seem to persist even though they have stagnated or outlived their usefulness. Inkpen and Ross suggest several reasons why interfirm alliances may persist beyond their optimal duration.[4] Alliances can be difficult and expensive to form; thus, once established, there may be reluctance to disband them. Moreover, as more firms pursue alliances, a bandwagon effect is created and many firms jump on it out of fear of being left without a partner. There are also challenges and costs associated with managing a partnership. If the relationship is poorly coordinated, the costs can outweigh the benefits. Alliances can also become synonymous with a firm's values, making them difficult to discontinue. Finally, there may be costs associated with closing an alliance. All of these factors may contribute to alliances existing beyond the period when they create value for a firm.

Several studies have pointed to problems of stagnation that can occur in some long-term associations. Although this work does not deal directly with rates of innovation, focusing instead on viability and survival, the general point is apt. When the participants in a network become too tightly knit and information circulates only among a small group, networks can become restrictive and ossified. Information that cycles back and forth only among the same participants can lead to lock-in or sclerosis. When networks turn inward and become restricted in terms of access to new members, the possibility of “group think” increases. Grabher's (1993) study of steelmaking in the Ruhr illustrates how a highly cohesive, homogeneous region became so over-embedded that no producers opted for alternative strategies. This cognitive lock-in eventually led to the decline of steelmaking in Germany. Powell (1985) shows how the failure of editors to renew and update their networks leads to a decline in the quality of a book publisher's list and reputation. Portes and Sensenbrenner (1993) illustrate how ethnic community networks can become restrictive and subject successful entrepreneurs to ostracism when they deviate too much from community standards. In sum, the ties that bind economic actors together can become the ties that blind, thwarting recognition of preferable alternatives.

p. 79

3.7 Summary

Interorganizational networks have grown considerably in importance over recent decades. Networks contribute significantly to the innovative capabilities of firms by exposing them to novel sources of ideas, enabling fast access to resources, and enhancing the transfer of knowledge. Formal collaborations may also allow a division of innovative labor that makes it possible for firms to accomplish goals they could not pursue alone. Research on alliances documents that investments in mutual learning and a portfolio of diverse collaborations are associated with increased patenting. While patenting is only an input to the innovation process, the strength of these empirical results highlights the importance of access to heterogeneous contacts.

We have argued that the nature of knowledge, conceptualized in terms of tacitness or explicitness, is an important factor in determining whether members of a network can effectively share information and skills. Networks that are rooted in a division of innovative labor logic may find it easier to transfer tacit knowledge in the form of finished inputs, while networks involved in the co-creation of novel ideas may succeed or fail on the basis of their ability to convey and transfer ideas that are not easily codified.

Another central challenge to networks of innovators is developing the capacity to simultaneously enhance the flow of information among current participants and be open to new entrants. The twin tests of increasing cohesion within the network and recognizing promising sources of new ideas are difficult to surmount. Some research suggests that a mixture of strong and weak ties affords the proper blend of reliability and novelty.

Much more research is needed, however, to ascertain how mixtures of thick, reliable affiliations can be combined with novel linkages to newcomers. Moreover, since some affiliations are essentially person to person ties, a greater understanding is needed of how relations among individuals are aggregated to productive relations between corporate actors. Or, in cases where this issue is neglected, as in studies of contractual relations between firms where the informal relational underpinnings are not analyzed, the opportunity to examine the intertwining of the careers of individuals and the strategies of firms is missed. Equally important, the network literature has not focused explicitly on different measures of innovative output, whether it is new products or services, new modes of organizing production, or more rapid response to competitive demands. The standard measures are based on either patents, an input to the innovation process, or problem solving, without sufficient attention to either the timeliness or the optimality of the solution. The network literature is still relatively young, however, so it may be premature to expect such sophisticated answers. We look forward to future research that offers a more compelling analysis of the specific ways in which networks shape innovative outputs.

p. 80

Notes

1. The five that formed the core of the human sequencing component were the Whitehead Institute, Washington University, Baylor College of Medicine, the Joint Genome Institute (a cluster of three national laboratories at the Department of Energy), and the Sanger Institute in England.

2. Notable exceptions include Ahuja 2000*a*, Rowley et al. 2000, Powell et al. 2005.

3. Owen-Smith and Powell (2003) found that US universities with strong ties to a limited set of commercial partners had “fertile” patent portfolios, with fertility measured by the impact of patent citations. Those universities with few ties also had les fertile patents and patented much less. The optimal strategy for research universities, with respect to patent volume and impact, appears to be one of diverse ties to a wide array of industrial partners. Diversity mitigates possible capture from too close relations with commercial firms.

4. Inkpen and Ross (2001) do not specify how to measure the appropriate duration of relationships. Instead, they assume that some relationships become stale and dutiful over time, and no longer generate benefits that outweigh the costs of sustaining them.

References

* AHUJA, G. (2000*a*), “Collaboration Networks, Structural Holes, and Innovation: A Longitudinal Study,” *Administrative Science Quarterly* 45: 425–55. 10.2307/2667105
WorldCat Crossref

—— (2000*b*), “The Duality of Collaboration: Inducements and Opportunities in the Formation of Interfirm Linkages,” *Strategic Management Journal* 21: 317–43. 10.1002/(SICI)1097-0266(200003)21:3<317::AID-SMJ90>3.0.CO;2-B
WorldCat Crossref

AKERA, A. (2001), “The IBM User Group, Share,” *Technology and Culture* 42: 710–36. 10.1353/tech.2001.0146
WorldCat Crossref

BAUM, J. A. C., CALABRESE, T., and SILVERMAN, B. S. (2000), “Don't Go It Alone: Alliance Network Composition and Startups' Performance in Canadian Biotechnology,” *Strategic Management Journal* 21: 267–94. 10.1002/(SICI)1097-0266(200003)21:3<267::AID-SMJ89>3.0.CO;2-8
WorldCat Crossref

BECKMAN, C., and HAUNSCHILD, P. (2002), “Network Learning: The Effects of Partner's Heterogeneity of Experience on Corporate Acquisitions,” *Administrative Science Quarterly* 47: 92–1724. 10.2307/3094892
WorldCat Crossref

BLAU, P. M. (1963), “Consultation Among Colleagues,” in*Dynamics of Bureaucracy*, Chicago: University of Chicago Press, 157–69.
Google Scholar Google Preview WorldCat COPAC

BOISOT, M. H. (1998), *Knowledge Assets: Securing Competitive Advantage in the Information Economy*, Oxford: Oxford University Press.
Google Scholar Google Preview WorldCat COPAC

BROWN, J. S., and DUGUID, P. (2001), “Knowledge and Organization: A Social Practice Perspective,” *Organization Science* 12(2): 198–213.
WorldCat

BRUSCO, S. (1982), “The Emilian Model: Productive Decentralization and Social Integration,” *Cambridge Journal of Economics* 6: 167–84.
WorldCat

* BURT, R. S. (1992), *Structural Holes*, Cambridge, Mass.: Harvard University Press.
Google Scholar Google Preview WorldCat COPAC

CALLON, M. (1998), “Actor-Network Theory—The Market Test,” in J. Law and J. Hassard (eds.), *Actor Network Theory and After*, Cambridge, Mass.: Blackwell, 186–96.
Google Scholar Google Preview WorldCat COPAC

p. 81 —— (2002), “From Science as an Economic Activity to Socioeconomics of Scientific Research,” in P. Mirowski and E. M. Sent (eds.), *Science Bought and Sold*, Chicago: University of Chicago Press.
Google Scholar Google Preview WorldCat COPAC

CHESBROUGH, H. (2003), *The Era of Open Innovation*, Boston: Harvard Business School Press.
Google Scholar Google Preview WorldCat COPAC

COHEN, S., and FIELDS, G. (1999), “Social Capital and Capital Gains in Silicon Valley,” *California Management Review* 41(2): 108–30.
WorldCat

COHEN, W., and LEVINTHAL, D. (1990), “Absorptive Capacity: A New Perspective on Learning and Innovation,” *Administrative Science Quarterly* 35: 128–52. 10.2307/2393553
WorldCat Crossref

COWAN, R., DAVID, P. A., and FORAY, D. (2000), “The Explicit Economics of Knowledge Codification and Tacitness,” *Industrial and Corporate Change* 9: 211–53. 10.1093/icc/9.2.211
WorldCat Crossref

CRANE, D. (1972), *Invisible Colleges: Diffusion of Knowledge and Scientific Communities*, Chicago: University of Chicago Press.
Google Scholar Google Preview WorldCat COPAC

CROSS, R., BORGATTI, S., and PARKER, A. (2002), “Making Invisible Work Visible,” *California Management Review* 44(2): 25–46.
WorldCat

CUSUMANO, M., MYLONADIS, Y., and ROSENBLOOM, R. (1992), “Strategic Maneuvering and Mass-Market Dynamics: The Triumph of VHS over Beta,” *Business History Review* 66: 51–94. 10.2307/3117053
WorldCat Crossref

DALTON, M. (1959), “Power Struggles in the Line,” in *Men Who Manage*, New York: Wiley, 71–109.
Google Scholar Google Preview WorldCat COPAC

DAVID, P. A. (2001), “Cooperation, Creativity, and Closure in Scientific Research Networks: Modeling the Simpler Dynamics of Epistemic Communities,” Conference at Centre Saint- Gobain, Paris.

* DYER, J. H. (1996), “Specialized Supplier Networks as a Source of Competitive Advantage: Evidence from the Auto Industry,” *Strategic Management Journal* 17(4): 271–91. 10.1002/(SICI)1097-0266(199604)17:4<271::AID-SMJ807>3.0.CO;2-Y
WorldCat Crossref

—— and NOBEOKA, K. (2000), “Creating and Managing a High-Performance Knowledge- Sharing Network: The Toyota Case,” *Strategic Management Journal* 21: 345–67. 10.1002/(SICI)1097-0266(200003)21:3<345::AID-SMJ96>3.0.CO;2-N
WorldCat Crossref

ECCLES, R. (1981), “The Quasifirm in the Construction Industry,” *Journal of Economic Behavior and Organization* 2: 335–57. 10.1016/0167-2681(81)90013-5
WorldCat Crossref

EISENHARDT, K. M., and SCHOONHOVEN, C. B. (1996), “Resource-based View of Strategic Alliance Formation: Strategic and Social Effects in Entrepreneurial Firms,” *Organization Science* 7: 136–50. 10.1287/orsc.7.2.136
WorldCat Crossref

FARRELL, J., and SALOMER, G. (1988), “Coordination through Committees and Markets,” *RAND Journal of Economics* 19(2): 235–52. 10.2307/2555702
WorldCat Crossref

FLEMING, L., and SORENSON, O. (2001), “Technology as a Complex Adaptive System: Evidence from Patent Data,” *Research Policy* 30: 1019–39. 10.1016/S0048-7333(00)00135-9
WorldCat Crossref

* FREEMAN, C. (1991), “Networks of Innovators: A Synthesis of Research Issues,” *Research Policy* 20: 499–514. 10.1016/0048-7333(91)90072-X
WorldCat Crossref

GALUNIC, D. C., and RODAN, S. (1998), “Resource Recombinations in the Firm: Knowledge Structures and the Potential for Schumpeterian Innovation,” *Strategic Management Journal* 19: 1193–201. 10.1002/(SICI)1097-0266(1998120)19:12<1193::AID-

SMJ5>3.0.CO;2-F
WorldCat Crossref

GHOSHAL, S., and BARTLETT, C. (1990), “The Multinational Corporation as an Interorganizational Network,” *Academy of Management Review* 15: 561–85.
WorldCat

GODOE, H. (2000), “Innovation Regimes, R&D and Radical Innovations in Telecommunications,” *Research Policy* 29: 1033–46. 10.1016/S0048-7333(99)00051-7
WorldCat Crossref

GOMES-CASSERES, B. (1996), *The Alliance Revolution: The New Shape of Business Rivalry*, Cambridge, Mass.: Harvard University Press.
Google Scholar Google Preview WorldCat COPAC

p. 82 GRABHER, G. (1993), “The Weakness of Strong Ties: The Lock-in of Regional Development in the Ruhr Area,” in G. Grabher (ed.), *The Embedded Firm*, London: Routledge.
Google Scholar Google Preview WorldCat COPAC

—— and POWELL, W. W. (2004), “Introduction,” in *Critical Studies in Economic Institutions: Networks*, London: Edward Elgar.
Google Scholar Google Preview WorldCat COPAC

* GRANOVETTER, M. (1973), “The Strength of Weak Ties,” *American Journal of Sociology* 78: 1360–80. 10.1086/225469
WorldCat Crossref

—— (1985), “Economic Action and Social Structure: The Problem of Embeddedness,” *American Journal of Sociology* 91: 481–510. 10.1086/228311
WorldCat Crossref

GRILICHES, Z. (1990), “Patent Statistics as Economic Indicators: A Survey,” *Journal of Economic Literature* 28: 1661–707.
WorldCat

GULATI, R. (1995), “Does Familiarity Breed Trust? The Implications of Repeated Ties for Contractual Choice in Alliances,” *Academy of Management Journal* 38: 85–112. 10.2307/256729
WorldCat Crossref

HAGEDOORN, J. (1995), “Strategic Technology Partnering During the 1980s: Trends, Networks, and Corporate Patterns in Non-Core Technologies,” *Research Policy* 24: 207–31. 10.1016/0048-7333(94)00763-W
WorldCat Crossref

—— (1996), “Trends and Patterns in Strategic Technology Partnering since the Early Seventies,” *Review of Industrial Organization* 11: 601–16. 10.1007/BF00214825
WorldCat Crossref

—— (2002), “Inter-Firm R&D Partnerships: An Overview of Major Trends and Patterns since 1960,” *Research Policy* 31: 477–92. 10.1016/S0048-7333(01)00120-2
WorldCat Crossref

——, and DUYSTERS, G. (2002), “External Sources of Innovative Capabilities: The Preference for Strategic Alliances or Mergers and Acquisitions,” *Journal of Management Studies* 39(2): 167–88. 10.1111/1467-6486.00287
WorldCat Crossref

HÅKANSSON, H., and SNEHOTA, I. (1995), *Developing Relationships in Business Networks*, London: Routledge.
Google Scholar Google Preview WorldCat COPAC

HANSEN, M. T. (1999), “The Search–Transfer Problem: The Role of Weak Ties in Sharing Knowledge across Organization Subunits,” *Administrative Science Quarterly* 44: 82–111. 10.2307/2667032
WorldCat Crossref

HELPER, S., MACDUFFIE, J. P., and SABEL, C. (2000), “Pragmatic Collaborations: Advancing Knowledge While Controlling Opportunism,” *Industrial and Corporate Change* 9(3): 443–89. 10.1093/icc/9.3.443
WorldCat Crossref

HICKS, D. M., and KATZ, J. S. (1996), “Where is Science Going?” *Science, Technology and Human Values* 21(4): 379–406. 10.1177/016224399602100401
WorldCat Crossref

INKPEN, A. C., and ROSS, J. (2001), “Why do Some Strategic Alliances Persist beyond their Useful Life?” *California Management Review* 44: 132–48.
WorldCat

KOGUT, B. (2000), “The Network as Knowledge: Generative Rules and the Emergence of Structure,” *Strategic Management Journal* 21: 405–25. 10.1002/(SICI)1097-0266(200003)21:3<405::AID-SMJ103>3.0.CO;2-5
WorldCat Crossref

KREINER, K., and SCHULTZ, M. (1993), “Informal Collaboration in R&D. The Formation of Networks across Organizations,” *Organization Studies* 14: 189–209. 10.1177/017084069301400202
WorldCat Crossref

LAMBRIGHT, W. H. (2002), “*Managing ‘Big Science’: A Case Study of the Human Genome Project,*” Washington, DC: Pricewaterhouse Coopers Endowment for the Business of Government.
Google Scholar Google Preview WorldCat COPAC

LARSON, A. (1992), “Network Dyads in Entrepreneurial Settings: A Study of the Governance of Exchange Processes,” *Administrative Science Quarterly* 37: 76–104. 10.2307/2393534
WorldCat Crossref

LATOUR, B. (1987), *Science in Action*, Cambridge, Mass.: Harvard University Press.
Google Scholar Google Preview WorldCat COPAC

LEONARD-BARTON, D. (1995), *Wellsprings of Knowledge: Building and Sustaining the Sources of Innovation*, Boston: HBS Press.
Google Scholar Google Preview WorldCat COPAC

LINK, A. (1996), “Research Joint Ventures: Patterns from Federal Register Filings,” *Review of Industrial Organization II* (October): 617–28. 10.1007/BF00214826
WorldCat Crossref

p. 83 —— (1999), “Public/Private Partnerships in the United States,” *Industry and Innovation* 6(2): 191–217. 10.1080/13662719900000011
WorldCat Crossref

LIPPARINI, A., LORENZONI, G., and ZOLLO, M. (2001), “*Dual Network Strategies: Managing Knowledge-based and Efficiency-based Networks in the Italian Motorcycle Industry,*” Working paper.
Google Scholar Google Preview WorldCat COPAC

LORENZONI, G., and LIPPARINI, A. (1999), “The Leveraging of Interfirm Relationships as a Distinctive Organizational Capability,” *Strategic Management Journal* 20: 317–38. 10.1002/(SICI)1097-0266(199904)20:4<317::AID-SMJ28>3.0.CO;2-3
WorldCat Crossref

MCKENDRICK, D. G., DONNER, R. F., and HAGGARD, S. (2000), *From Silicon Valley to Singapore: Competitive Advantage in the Hard Disk Drive Industry*, Stanford, Calif.: Stanford University Press.
Google Scholar Google Preview WorldCat COPAC

MERRILL, S. A., and COOPER, R. S. (1999), “Trends in Industrial Research and Development: Evidence from National Data Sources,” in *Securing America's Industrial Strength*, Washington, DC: National Academy Press, 99–116.
Google Scholar Google Preview WorldCat COPAC

MERTON, R. K. (1957), “The Role-Set: Problems in Sociological Theory,” *British Journal of Sociology* 8: 110–20.
WorldCat

MOWERY, D. C. (ed.) (1988), *International Collaborative Ventures in US Manufacturing*, Cambridge, Mass.: Ballinger.
Google Scholar Google Preview WorldCat COPAC

—— (1999), “America's Industrial Resurgence? An Overview,” in *U.S. Industry in 2000: Studies in Competitive Performance*. Washington, DC: National Academy Press, 1–16.
Google Scholar Google Preview WorldCat COPAC

—— OXLEY, J. E., and SILVERMAN, B. S. (1996), “Strategic Alliances and Interfirm Knowledge Transfer,” *Strategic Management Journal* 17: 77–91.
WorldCat

MURRAY, F. (2002), “Innovation as Co-evolution of Scientific and Technological Networks: Exploring Tissue Engineering,” *Research Policy* 31: 1389–403. 10.1016/S0048-7333(02)00070-7
WorldCat Crossref

National Science Board (1998), *Science and Engineering Indicators—1998*. Arlington, Va.: National Science Foundation.
Google Scholar Google Preview WorldCat COPAC

NELSON, R., and WINTER, S. (1982), *An Evolutionary Theory of Economic Change*, Cambridge, Mass.: Harvard University Press.
Google Scholar Google Preview WorldCat COPAC

NEWMAN, M. (2003), “The Structure and Function of Complex Networks,” *SIAM Review* 45: 167–256. 10.1137/S003614450342480
WorldCat Crossref

NONAKA, I., and TAKEUCHI, N. (1995), *The Knowledge-Creating Company*, New York: Oxford University Press.
Google Scholar Google Preview WorldCat COPAC

NOTEBOOM, B. (1999), *Inter-Firm Alliances: Analysis and Design*, London: Routledge.
Google Scholar Google Preview WorldCat COPAC

O'MAHONY, S. (2002), *The Emergence of a New Commercial Actor: Community Managed Software Projects*, Ph.D. dissertation, Department of Management Science and Engineering, Stanford University.

OWEN-SMITH, J. (2003), “From Separate Systems to a Hybrid Order: Accumulative Advantage Across Public and Private Science at Research One Universities,” *Research Policy* 32(6): 1081–104. 10.1016/S0048-7333(02)00111-7
WorldCat Crossref

—— and POWELL, W. W. (2003), “The Expanding Role of University Patenting in the Life Sciences,” *Research Policy* 32(9): 1695–711. 10.1016/S0048-7333(03)00045-3
WorldCat Crossref

PIORE, M., and SABEL, C. (1984), *The Second Industrial Divide*, New York: Basic Books.
Google Scholar Google Preview WorldCat COPAC

POLANYI, M. (1956), *Personal Knowledge—Towards a Post-Critical Philosophy*, Chicago: University of Chicago Press.
Google Scholar Google Preview WorldCat COPAC

PORTES, A., and SENSENBRENNER, J. (1993), “Embeddedness and Immigration: Notes on the Social Determinants of Economic Action,” *American Journal of Sociology* 98: 1320–50. 10.1086/230191
WorldCat Crossref

POWELL, W. W. (1985), *Getting Into Print: The Decision-Making Process in Scholarly Publishing*, Chicago: University of Chicago Press.
Google Scholar Google Preview WorldCat COPAC

p. 84 POWELL, W. W. (1990), “Neither Market Nor Hierarchy: Network Forms of Organization,” in B. M. Straw and L. L. Cummings (eds.), *Research in Organizational Behavior*, Greenwich, Conn.: JAI Press, 12: 295–336.
Google Scholar Google Preview WorldCat COPAC

—— (1996), “Inter-Organizational Collaboration in the Biotechnology Industry,” *Journal of Institutional and Theoretical Economics* 120(1): 197–215.
WorldCat

—— (1998), “Learning from Collaboration: Knowledge and Networks in the Biotechnology and Pharmaceutical Industries,” *California Management Review* 40(3): 228–40.
WorldCat

—— and BRANTLEY, P. (1992), “Competitive Cooperation in Biotechnology: Learning Through Networks?” in R. Eccles and N. Nohria (eds.), *Networks and Organizations*, Boston: Harvard University Press.
Google Scholar Google Preview WorldCat COPAC

*—— KOPUT, K. W., and SMITH-DOERR, L. (1996), “Interorganizational Collaboration and the Locus of Innovation in Biotechnology,” *Administrative Science Quarterly* 41(1): 116–45. 10.2307/2393988
WorldCat Crossref

—— —— and OWEN-SMITH, J. (1999), “Network Position and Firm Performance,” in S. Andrews and D. Knoke (eds.), *Research in the Sociology of Organizations* Greenwich, Conn.: JAI Press, 16: 129–59.
Google Scholar Google Preview WorldCat COPAC

—— and OWEN-SMITH, J. (1998), “Commercialism in Universities: Life Sciences Research and Its Linkage with Industry,” *Journal of Policy Analysis and Management* 17(2): 253–77.
WorldCat

——, WHITE, D. R., KOPUT, K., and OWEN-SMITH, J. (2005), “Network Dynamics and Field Evolution: The Growth of Interorganizational Collaboration in the Life Sciences,” *American Journal of Sociology*. 10.1086/421508
WorldCat Crossref

ROBERTS, E. B., and LIU, W. K. (2001), “Ally or Acquire? How Technology Leaders Decide,” *Sloan Management Review* 43: 26–34.
WorldCat

ROSENBLOOM, R. S., and SPENCER, W. J. (1996), “The Transformation of Industrial Research,” *Issues in Science and Technology* 12(3): 68–74.
WorldCat

* ROSENKOPF, L., and TUSHMAN, M. (1998), “The Coevolution of Community Networks and Technology: Lessons from the Flight Simulation Industry,” *Industrial and Corporate Change* 7: 311–46.
WorldCat

—— METIU, A., and GEORGE, V. P. (2001), "From the Bottom Up? Technical Committee Activity and Alliance Formation," *Administrative Science Quarterly* 46: 748–72. 10.2307/3094830
WorldCat Crossref

ROWLEY, T., BEHRENS, D., and KRACKHARDT, D. (2000), "Redundant Governance Structures: An Analysis of Structural and Relational Embeddedness in the Steel and Semiconductor Industries," *Strategic Management Journal* 21: 369–86. 10.1002/(SICI)1097-0266(200003)21:3<369::AID-SMJ93>3.0.CO;2-M
WorldCat Crossref

RUEF, M. (2002), "Strong Ties, Weak Ties and Islands: Structural and Cultural Predictors of Organizational Innovation," *Industrial and Corporate Change* 11: 427–49. 10.1093/icc/11.3.427
WorldCat Crossref

SABEL, C. F. (1994), "Learning by Monitoring: The Institutions of Economic Development," in N. Smelser and R. Swedberg (eds.), *Handbook of Economic Sociology*, Princeton: Princeton University Press, 137–65.
Google Scholar Google Preview WorldCat COPAC

SARKAR, K. B., ECHAMBADI, R., and HARRISON, J. S. (2001), "Alliance Entrepreneurship and Firm Market Performance," *Strategic Management Journal* 21: 369–86.
WorldCat

* SAXENIAN, A. (1994), *Regional Advantage: Culture and Competition in Silicon Valley and Route* 128. Cambridge, Mass.: Harvard University Press.
Google Scholar Google Preview WorldCat COPAC

SHAN, W., WALKER, G., and KOGUT, B. (1994), "Interfirm Cooperation and Startup Innovation in the Biotechnology Industry," *Strategic Management Journal* 15: 387–94. 10.1002/smj.4250150505
WorldCat Crossref

SIMMEL, G. (1954), *Conflict and the Web of Group Affliations*, Glencoe, Ill.: The Free Press.
Google Scholar Google Preview WorldCat COPAC

p. 85 SIMONIN, B. L. (1999), "Ambiguity and the Process of Knowledge Transfer in Strategic Alliances," *Strategic Management Journal* 20: 595–623. 10.1002/(SICI)1097-0266(199907)20:7<595::AID-SMJ47>3.0.CO;2-5
WorldCat Crossref

STUART, T. E. (1998), "Network Positions and Propensities to Collaborate," *Administrative Science Quarterly* 43: 668–98.
WorldCat

—— (2000), "Interorganizational Alliances and the Performance of Firms: A Study of Growth and Innovation Rates in a High-technology Industry," *Strategic Management Journal* 21: 791–811. 10.1002/1097-0266(200008)21:8<791::AID-SMJ121>3.0.CO;2-K
WorldCat Crossref

SZULANSKI, G. (1996), "Exploring Internal Stickiness: Impediments to the Transfer of Best Practice with the Firm," *Strategic Management Journal* 17: 27–43.
WorldCat

TSAI, W., and GHOSHAL, S. (1998), "Social Capital and Value Creation: The Role of Intrafirm Networks," *Academy of Management Journal* 41: 464–76. 10.2307/257085
WorldCat Crossref

* UZZI, B. (1997), "Social Structure and Competition in Interfirm Networks: The Paradox of Embeddedness," *Administrative Science Quarterly* 42: 464–76.
WorldCat

Van Wijk, R., VAN DEN BOSCH, F. A. J., and VOLBERDA, H. W. (2003), "Knowledge and Networks," in M. Easterby-Smith and M. A. Lyles (eds.), *Handbook of Organizational Learning and Knowledge Management*, Oxford: Blackwell.
Google Scholar Google Preview WorldCat COPAC

VINDING, A. L. (2002), "Interorganizational Diffusion and Transformation of Knowledge in the Process of Product Innovation," Ph.D. Thesis, Aalborg University.

Von Hippel, E. (1987), "Cooperation between Rivals: Informal Know-how Trading," *Research Policy* 16: 291–302. 10.1016/0048-7333(87)90015-1
WorldCat Crossref

—— (1998), "Economics of Product Development by Users: The Impact of 'Sticky' Local Information," *Management Science* 44: 629–44. 10.1287/mnsc.44.5.629
WorldCat Crossref

* WALKER, G. B., KOGUT, B., and SHAN, W. (1997), "Social Capital, Structural Holes and the Formation of an Industry Network," *Organization Science* 8: 109–25. 10.1287/orsc.8.2.109
WorldCat Crossref

WALUSZEWSKI, A. (1995), "Glulam," in H. Håkansson and I. Snethota (eds.), *Developing Relationships in Business Networks*, London: Routledge.
Google Scholar Google Preview WorldCat COPAC

WEBER, S. (2003), *The Success of Open Source*, Cambridge, Mass.: Harvard University Press.
Google Scholar Google Preview WorldCat COPAC

WENGER, E. (1998), *Communities of Practice*, New York: Cambridge University Press.
Google Scholar Google Preview WorldCat COPAC

WOMACK, J. P., JONES, D. T., and ROOS, D. (1990), *The Machine That Changed the World: The Story of Lean Production*, New York: Harper & Row.
Google Scholar Google Preview WorldCat COPAC