The Search-Transfer Problem: The Role of Weak Ties in Sharing Knowledge across Organization Subunits

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This paper combines the concept of weak ties from social network research and the notion of complex knowledge to explain the role of weak ties in sharing knowledge across organization subunits in a multiunit organization. I use a network study of 120 new-product development projects undertaken by 41 divisions in a large electronics company to examine the task of developing new products in the least amount of time. Findings show that weak interunit ties help a project team search for useful knowledge in other subunits but impede the transfer of complex knowledge, which tends to require a strong tie between the two parties to a transfer. Having weak interunit ties speeds up projects when knowledge is not complex but slows them down when the knowledge to be transferred is highly complex. I discuss the implications of these findings for research on social networks and product innovation.•

Why are some subunits in an organization able to share knowledge among themselves whereas others are not? Addressing this question, organization scholars have analyzed factors that inhibit knowledge sharing among subunits, in particular, the lack of direct relationships and extensive communication between people from different subunits (e.g., Lawrence and Lorsch, 1967; Galbraith, 1973; Allen, 1977). More recently, two other lines of research have addressed the topic of knowledge sharing among people in an organization. In the product innovation literature, the argument is often made that close and frequent interactions between research and development (R&D) and other functions, teams, and operational subunits lead to project effectiveness because of the timely integration of knowledge across organizational boundaries (e.g., Clark and Fujimoto, 1991; Leonard-Barton and Sinha, 1993; Henderson and Cockburn, 1994; Eisenhardt and Tabrizi, 1995; Szulanski, 1996). In this literature, efficient knowledge sharing is typically characterized by tight coupling between people from different organization subunits. Some social network scholars, however, provide a different argument. According to the weak-tie theory originally advanced by Granovetter (1973), distant and infrequent relationships (i.e., weak ties) are efficient for knowledge sharing because they provide access to novel information by bridging otherwise disconnected groups and individuals in an organization. Strong ties, in contrast, are likely to lead to redundant information because they tend to occur among a small group of actors in which everyone knows what the others know.

The question thus arises whether it is strong or weak relationships between people in different organizational subunits that lead to efficient knowledge sharing among them. The discrepancy between the different arguments about the effects of relationship strength on knowledge sharing that are proposed in the product innovation literature and the weak tie perspective may be partly due to different foci. Social network research tends to concentrate on the problem of finding relevant information and other resources, a search activity in which weak ties may provide access to new information, while product innovation research tends to focus on the movement of knowledge from various areas in the orga-

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nization to an R&D team in situations in which people know each other beforehand (a transfer activity). I draw on each line of research to consider knowledge sharing among people from different subunits as a dual problem of searching for (looking for and identifying) and transferring (moving and incorporating) knowledge across organization subunits, taking into account the complexity of the knowledge that flows through interunit relationships.

Although several social network scholars have argued that weak ties only provide information benefits under certain conditions and are less beneficial than strong ties in providing socio-emotional support and solving conflict, social network research has largely remained agnostic with respect to the content of what flows through instrumental relations between actors (Nelson, 1989; Wegener, 1991; Krackhardt, 1992; Podolny and Baron, 1997). Whether it is simple information or richer forms of knowledge (e.g., a complex technology) that flows through the ties has not been studied. In contrast, researchers studying product innovation have analyzed the difficulties in transferring complex knowledge, including noncodified or tacit knowledge (Teece, 1977; Zander and Kogut, 1995) and components that are dependent on larger systems (Winter, 1987). When such complex forms of knowledge are considered, the instrumental benefits of weak ties are called into question. Weak ties may lead to search benefits in a social network but they may also cause problems in transferring complex forms of knowledge.

I limit my discussion to one task undertaken by subunits in many multiunit firms—new product development. A product development team situated in an operating unit can use established interunit relations—which exist prior to the start of the project—to search for and transfer to the project various types of knowledge residing in other operating units. For simplicity, I define interunit relations as regularly occurring informal contacts between groups of people from different operating units in an organization. I confine the discussion to relations between operating units, such as divisions, and not functional departments. These informal relations may have an effect on the time it takes to develop a new product from concept development to market introduction by affecting the ease with which project team members search for and transfer knowledge across subunits. Although project completion time is only one dimension of the effectiveness of new product development (Wheelwright and Clark, 1993), it has become an important outcome measure in many industries, notably in the electronics and computing industries (Eisenhardt and Tabrizi, 1995) and is a relevant measure for the empirical study of the electronics and computer company reported in this paper.[1] Product development time captures both the benefits and costs of sharing knowledge across other organization subunits. On one hand, a project team stands to benefit to the extent that it obtains useful knowledge from other subunits, shortening completion time. Knowledge from other subunits can help projects avoid duplication of efforts (e.g., using an existing software module) or provide them with complementary expertise, as when an expert helps solve a technical problem (Teece, 1986). Such knowledge, as defined here, includes product-specific techni-

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Other measures of product development performance that could have been studied include final project costs, product quality, degree of innovation, and market success (e.g., product sales). To limit the analysis I confined the dependent variable to completion time.

cal know-how, knowledge about technologies and markets, as well as knowledge embodied in product components (e.g., in a software module). On the other hand, the project team may expend considerable search time and transfer efforts to be able to use fully the knowledge from other subunits. If search and transfer take a long time, then knowledge sharing is likely to hamper the performance of the tasks, prolonging completion time.

SEARCH AND TRANSFER

Network Search

In a multiunit organization, a product development team situated in an operating unit may want to obtain useful knowledge residing in other operating units, but the team may not know that such knowledge exists in the organization and where it resides. Team members are confronted with the task of looking for and identifying useful knowledge in an organization in which knowledge is dispersed among subunits. Assuming that project team members are boundedly rational, they cannot easily amass and process a large number of opportunities for interunit knowledge sharing, however, and exhaustive intraorganizational searches will be very time-consuming, if not impossible. Multiunit firms, especially large ones with thousands of members, are complex organizations that make the search process difficult and uncertain. Existing relations that span subunits therefore become important because they serve as channels through which both useful knowledge and information about opportunities for knowledge use flow. Through interunit relations, project teams may hear about opportunities for knowledge use, even without having inquired, and have access to other subunits that have valuable knowledge or can point to other sources that do (cf. Burt, 1992: 13).

Search benefits of weak ties. Not all interunit relations are equally valuable in the search process. Following the argument originally advanced by Granovetter (1973), project teams with weak interunit ties—i.e., infrequent and distant relationships—are likely to have a more advantageous search position in the network than teams with strong interunit ties because their contacts are less likely to provide redundant knowledge. Nonredundant knowledge can be of two kinds. The first is new information relayed to a project team about opportunities for interunit knowledge use. Other subunits can point to specific knowledge residing in subunits to which the focal subunit has no direct ties. Here, a project team and its subunit's direct contacts act as bridges. Search is more beneficial to the extent that each direct contact can point to different types of opportunities. Obtaining information about the same opportunity twice is costly if the project team spent time in getting information it already had. A second type of nonredundant knowledge is project-specific knowledge (e.g., a software module) the direct contact itself can provide. Direct interunit contacts are less redundant to the extent that they provide different types of knowledge that can be used by a focal project team. Having two direct contacts that can provide the same software module is less helpful than being directly connected to two subunits that each possesses useful but different knowledge.

This argument rests on the premise that it is costly to maintain direct relations to other subunits. People in a subunit need to spend time cultivating relationships with other subunits and processing the incoming information from direct contacts. Because of these costs, people in a subunit can rarely afford to maintain relations with many other subunits, let alone maintain strong relations, which require more energy than weak ones. There are therefore significant opportunity costs in maintaining interunit relations: instead of having ties to two subunits that provide redundant knowledge, people in a subunit can develop a new relation that provides new knowledge.

Although weak ties may be associated with nonredundancy, however, they do not necessarily result in nonredundant contacts. Burt (1992: 25) argued that tie weakness is a correlate, not a cause, of nonredundancy. The absence of ties among contacts in a focal actor's network is a more direct indicator of nonredundancy. Thus, according to Burt, strong ties can also be nonredundant contacts, although his argument implies that it is more likely that weak ties provide nonredundant contacts (Burt, 1992: 29). The reason is that strong ties that start out as nonredundant contacts are likely to become redundant over time. In this context, a group of engineers in one subunit that works frequently and closely with a group of engineers in another subunit is, over time, likely to be introduced to working relationships held by the other group of engineers, resulting in a circle of engineers who all know one another. Thus, because weak interunit ties are more likely to be associated with nonredundant contacts than strong ones, they serve as indicators of nonredundancy. Nevertheless, at any point in time, some strong interunit ties may also be nonredundant contacts.

Maintaining a strong interunit tie (whether it is redundant or not), however, is significantly more costly than maintaining a weak one (Boorman, 1975). It requires frequent visits to and meetings with people in another subunit on a regular basis. These routine activities are often not directly related to a specific project and hence distract a project team from its task. Assuming that a project team can search reasonably efficiently through weak interunit ties, strong interunit ties can be substituted with weaker ones, freeing up time that can be used to develop a new (weak) interunit tie or be spent on product development tasks inside the subunit. Thus, even if it is possible to have strong nonredundant contacts, weak nonredundant ties across subunit boundaries are more cost-efficient and still provide search benefits.

Network binding. There is another reason why weakly tied project teams are likely to have a more beneficial search position in the interunit network than strongly tied teams. Using the notion of loose coupling, Weick (1976) argued that organizational entities (here subunits and project teams) that are not tightly linked to other entities are more adaptive because they are less constrained by the organization system of which they are part. A weakly tied product development team may have a beneficial search position in the network by being connected to other subunits while, at the same time, escaping the penalties of being strongly enmeshed in a network.

The notion of loose coupling helps to explain the problem of autonomy versus connection in a network. On one hand, organizational autonomy is often considered positive for product innovation because the innovating unit is free of "red tape," bureaucracy, and other responsibilities that disrupt the product innovation task (Burns and Stalker, 1961; Daft, 1982). On the other hand, because project teams stand to benefit from knowledge residing elsewhere, they need connections to the rest of the organization to access that knowledge. Established network ties provide such connections. With increasing degrees of connectedness, however, the risk of losing the autonomy so important for product innovation goes up. The project team begins to take on other responsibilities, is asked to provide help to others, and is confronted with both formal procedures and social obligations. Ties become a constraint, binding the subunit to a greater or lesser extent, depending on the strength of the tie.

Strong interunit ties constrain action more than weak ties, for two reasons. First, strong ties are associated with reciprocal arrangements in which advice and help flow in both directions (Marsden and Campbell, 1984). A focal subunit and its project team members have to provide more help to the subunit to whom they are strongly tied, under the assumption that commitment to help is proportional to the strength of the relationship. In a strong interunit tie, project teams in the focal subunit end up spending a significant proportion of their time helping project teams in other subunits instead of completing their own tasks, slowing down their own projects. Weakly tied subunits, in contrast, escape this binding constraint because their relationships are less likely to be reciprocal. Even if they are reciprocal, they are likely to require less help to partners than is required in strong ties. Weakly tied project teams can use their network connections to search but do not have to provide high levels of help to others in turn.

The second reason strong interunit ties bind more than weak ones concerns network inertia. Search may require going outside established channels, as when a project team is developing a new product that departs from existing technical know-how possessed by the focal subunit and its direct contacts. A strongly tied project team is likely to stay with its existing network relations because they are familiar and close contacts to whom the project team can easily turn. Previous research has shown that product developers come to rely on established communication channels in which they are strongly immersed (Henderson and Clark, 1990). Because of this immersion, strongly tied project teams are less likely than weakly tied teams to search for knowledge outside their existing contacts and forge new ties while conducting searches for useful knowledge.

The Transfer Problem

Once a project team has looked for and identified useful knowledge in another subunit, the knowledge must be moved to the focal subunit and incorporated into the focal project. In product innovation, this transfer can be problematic. In the typical social network argument, it is assumed that knowledge flows from the contact to the focal actor and that it is not necessary to expend extra effort to transfer the knowledge (Granovetter, 1973; Burt, 1992). When ties serve as bridges to other actors, it is further assumed that the knowledge flows through the intermediary to the focal actor. In product innovation, however, useful knowledge (e.g., a product component) often remains in the source unit, even though information about the whereabouts of the knowledge travels through direct contacts and intermediaries. When the knowledge to be used resides in the source unit, the project team has to expend effort in transferring the knowledge from the source unit.

In general, there are two explanations for why there may be a transfer problem in product innovation: willingness and ability. The source unit may be unwilling to share its knowledge, perhaps because of an intraorganizational atmosphere of secrecy and competition. Even if both parties to the transfer are willing to make the effort, however, they may be unable to transfer smoothly because of the inherent difficulty of the task. In this paper, I focus on the ability problem by considering the complexity of the knowledge to be transferred. The transfer is more difficult to the extent that the knowledge involved is complex.

One of the main dimensions of complex knowledge is its level of codification (Winter, 1987; Zander and Kogut, 1995). By codification I mean the degree to which the knowledge is fully documented or expressed in writing at the time of transfer between a subunit and the receiving project team in another subunit. Knowledge with a low level of codification corresponds closely to the concept of tacit knowledge—that is, knowledge that is hard to articulate or can only be acquired through experience (Polanyi, 1966; Nelson and Winter, 1982; Von Hippel, 1988: 76; 1994). Another important dimension of knowledge complexity, especially in product development tasks, is the extent to which the knowledge to be transferred is independent or is an element of a set of interdependent components (Teece, 1986; Winter, 1987). A stand-alone component, a distinct software module, for instance, can be uprooted from its existing use fairly easily, and transfer can take place with the focal team having little or no knowledge of a larger system. In contrast, when the knowledge to be transferred is dependent, the software module functions in conjunction with other components. Uprooting such a piece will require that the project receiving it have some knowledge of the larger system of which it is part. The piece may also need to be modified to function in the new application.

Transferring noncodified and dependent knowledge has been shown to be difficult (Teece, 1977; Zander and Kogut, 1995). Besides this main effect of complex knowledge on transfer difficulty, the strength of the relationship between the two parties to the transfer is likely to interact with the knowledge complexity dimension. Leaving the willingness issue aside, transferring highly codified and independent knowledge across both weak and strong interunit ties should be unproblematic. For example, the source unit can simply share a self-explanatory software by sending it through the mail. When the knowledge being transferred is noncodified and dependent, however, an established strong interunit relationship between the two parties to the transfer is likely to be most beneficial. In a strong interunit tie, the source unit is likely to spend more time articulating the complex knowledge. In evaluating the relative benefits of weak and strong ties, Granovetter (1982: 209) acknowledged this feature of strong ties by pointing out that "strong ties have greater motivation to be of assistance and are typically more easily available." In addition, strong ties often allow for a two-way interaction between the source and the recipient (Leonard-Barton and Sinha, 1993). The focal project team members have the opportunity to try, err, and seek instruction and feedback from the strongly tied source. The two-way interaction afforded by a strong tie is important for assimilating the noncodified knowledge, because the recipient most likely does not acquire the knowledge completely during the first interaction with the recipient but needs multiple opportunities to assimilate it (Polanyi, 1966). Moreover, even if people in the source unit are motivated to assist with the transfer and engage in two-way interactions, transferring noncodified and dependent knowledge is less difficult to the extent that the parties to the transfer understand each other. Two actors that are strongly tied tend to have developed a relationship-specific heuristic for processing noncodified knowledge between them. For example, Uzzi (1997) described the importance of close connections in facilitating the communication of noncodified knowledge about fashion styles between apparel designers and contractors.

In contrast, in weak interunit ties, the necessary interactions for transferring complex knowledge are absent. The interaction between the source unit and the recipient project team is likely to be infrequent. Recipient team members have to interpret and modify the noncodified and dependent knowledge, often in the absence of further explanations, because the source unit is less likely to engage in two-way interactions. When problems occur and questions arise, the source is not immediately available, if available at all. Even if people in the source unit are available, the parties to the transfer have not established a relationship-specific heuristic to communicate knowledge between them, making the transfer effort more difficult. These obstacles take time. They result in statements like "it would have been faster to do it ourselves." The transfer may have become a burden, hampering the progress of the project.

Search and Transfer Combined

The search and transfer arguments developed above lead to opposing effects of weak ties on the benefits of knowledge sharing across subunits. To assess how weak interunit ties affect project completion time through the interunit knowledge sharing process, I use the two knowledge complexity dimensions as boundary conditions to define the search and transfer problem, as shown in figure 1. I contrast weak and strong interunit ties under conditions of low and high levels of knowledge complexity. When project teams end up transferring codified and independent knowledge, weakly tied project teams have an advantageous search position compared with strongly tied teams (lower-right versus lower-left quadrant in figure 1). Furthermore, barring a protective source unit, project teams in this situation (whether weakly or strongly tied) do not incur any significant transfer problems, because the knowledge to be moved across subunit boundaries is not complex. The implication is that the search benefits of weak ties should translate into shorter project completion time because of a more efficient knowledge-sharing process. Project teams in weakly tied subunits are likely to find more useful knowledge per unit of search time, or else they are likely to spend less time searching per unit of useful knowledge obtained through the interunit network:

Hypothesis 1: The weaker the interunit ties, the shorter the completion time when the knowledge to be transferred is highly codified and independent.

Figure 1. Search and transfer effects associated with four combinations of knowledge complexity and tie strength.

KNOWLEDGE	TIE STRENGTH: Strong	TIE STRENGTH: Weak
Noncodified, Dependent	Low search benefits, moderate transfer problems	Search benefits, severe transfer problems
Codified, Independent	Low search benefits, few transfer problems	Search benefits, few transfer problems

A different situation occurs when a weakly tied project team attempts to transfer highly noncodified and dependent knowledge from another subunit (upper-right versus upper-left quadrants in figure 1). Weakly tied project teams still have an advantageous search position compared with strongly tied ones, but, in transferring highly complex knowledge, they are likely to incur severe transfer problems because of a poor interaction with the source unit.[2] Thus, the net effect of weak ties is likely to be an increase in completion time when the level of complex knowledge is very high:

Hypothesis 2: The weaker the interunit ties, the longer the completion time when the knowledge to be transferred is highly noncodified and dependent.

It may be possible to mitigate the transfer problem stated in the second hypothesis if weak interunit ties—which exist before a project begins—can be turned into temporary strong ties between the source and recipient subunits for the duration of the transfer events. Switching from a weak tie (or no tie) to a temporary strong one is problematic, however, because interunit tie creations take time, especially strong ones: Relationships to relevant people in another subunit need to be cultivated, and the source unit's rationale for getting extensively involved in the relationship needs to be established. Even if switching is possible, establishing a temporary, project-specific, and strong interunit tie will take time, slowing down the project.

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Pinpointing where the relative search benefits of weak ties are offset by the transfer problems is left to the statistical analysis.

METHODS

I tested the predictions in a large, multidivisional and multinational electronics and computer company (hereafter called "the company"). The company, which has annual sales of more than $5 billion, is involved in developing, manufacturing, and selling a range of electronics and computing products and systems. It has been profitable for a number of years and has continued to grow in sales. The company is structured into a number of fairly autonomous operating divisions that are responsible for product development, manufacturing, and sales. These divisions, which are organized according to product-market segments, represent the subunits in the analysis.

To define the appropriate set of interunit (i.e., interdivisional) relations, I used the membership criterion used in network research (Marsden, 1990; Wasserman and Faust, 1994: 31). A large proportion of the operating divisions were organized according to a specific sector, which constituted a natural membership boundary. Other subunits, including other operating divisions, the central research lab, and some manufacturing sites were disconnected from this sector of divisions, and I therefore excluded them. Given this boundary specification, I included 41 divisions as subunits in the network of interunit ties. Four divisions were located in Asia and Australia, seven were located in Europe, and the remaining divisions were located in various places in the U.S. All 41 divisions operated within one specific 4-digit Standard Industrial Classification (SIC) code and were therefore fairly comparable units.

I negotiated access to the company through three senior corporate research and development (R&D) managers, who became the main sponsors of the study. Their job in the company was to coordinate the product development efforts undertaken by the 41 divisions in the data set. After I had signed a confidentiality agreement with the company, stating that I would not reveal the identity of the company, I visited 14 divisions and conducted initial open-ended interviews with 50 project engineers and managers to better understand the context and to develop survey instruments that would be valid in this setting.

I used both archival and survey data. There were two surveys: a network survey administered to the R&D managers in the 41 divisions and a survey for the project managers of the product development projects included in this study. I first developed pilot designs of the survey instruments, which I pretested in one-hour face-to-face interviews with two divisional R&D managers and five project managers. Nine managers at corporate headquarters also reviewed the pilot surveys.

The surveys were sent out through intracompany mail from the office of the R&D corporate managers. I chose to send them via internal mail rather than from a university address, partly to obtain higher response rates and partly because people were concerned about sending sensitive data to an outside address. The survey package included a cover letter from the R&D managers introducing the study and advising the respondent that only I would review their responses. After eight weeks, approximately two-thirds of the R&D network surveys and more than half of the project manager surveys had been returned. We then sent out a second round of surveys to those who had not responded. In the end, I achieved 100-percent and 85-percent survey response rates for the R&D managers and project managers, respectively.

Selecting Product Development Projects

I first created a list of all projects that the 41 divisions undertook during the previous three years (1993–1995). I limited the data set to the last three years because it was problematic to collect data further back in time. I then excluded very small projects (i.e., those with less than two project engineers) and proposals that had not yet moved from the investigation to the development phase, which were not considered real and distinct projects yet and were therefore hard to track. I also excluded idiosyncratic projects that had no meaningful start and end (e.g., special on-going customer projects). Because including only successfully completed projects may lead to an overrepresentation of successful projects, biasing the results, I also included both canceled projects and projects still in progress. After having removed too-small, premature, and idiosyncratic projects, I ended up with a list of 147 projects. The project managers of 120 of these projects returned their survey, yielding a response rate of 85 percent. Of the 120 projects, 24 were still in progress at the time of data collection, four had been canceled, and 54 had incurred a transfer event involving another division (i.e., the project managers reported that they had obtained software, hardware, and/or technical and market know-how or information from another division on the survey list).

Interunit Relations

During the preliminary interviews several engineers and managers explained to me how a relationship between two divisions functioned. A group of engineers in a division typically maintained an informal regular contact with a group of engineers in another division, and a project team would use such contacts to access other divisions. Several times people described these relations in terms like "we normally work with those divisions over there," and "there has been a relationship between us and them for a long time." Unlike the relations of an individual gatekeeper, who maintains personal external contacts (Tushman, 1977), these regularly occurring interdivisional contacts did not belong to any one individual but were referred to as divisional-level or group-level contacts. One example of how an interdivisional relation was created and maintained came from an R&D manager, who described to me how, several years earlier, he took the initiative in establishing quarterly meetings with engineers in two other divisions to discuss technology trends. After a couple of years he stopped participating in the meeting. He told me that the engineers who had participated in the beginning were no longer involved but had passed on the relationship to another group of engineers, who had continued the quarterly meetings.

These types of contacts had been institutionalized in that they were regularly occurring patterns of activities between groups of people from different divisions that were enforced by a common belief system among the engineers (cf. Zucker, 1977; DiMaggio and Powell, 1983). The relationships were common knowledge in that most product developers seemed to know about their existence and how to use them, and I was told that a main responsibility of a division's managers was to provide these contacts for his or her project teams, should the need arise. I therefore assumed that at least one member of a project team would know about the divisional-level contacts and that the team members could access these contacts if they wanted to. Because of the importance of these group- or divisional-level contacts in the company, I chose to focus on these types of contacts, as opposed to strictly personal contacts among project engineers. Strictly personal contacts were important in this company, but they seemed to occur between engineers from the same division.

I obtained information on most of the regularly occurring informal contacts between any two divisions through the network survey. I followed several steps in obtaining and cross-validating this information. First, following previous research, I used a key informant to obtain a first cut on the divisional ties (Knoke and Kuklinski, 1982; Marsden, 1990). I considered the divisional R&D managers to be the most appropriate informants because they were "in the thick of things" in the R&D department in their division. The R&D manager in each of the 41 divisions was sent a questionnaire, asking, "Over the past 2 years, are there any divisions from whom your division regularly sought technical and/or market-related input?" The question was followed by a list of the 41divisions included in the study. This approach allows for the construction of asymmetric network data: one division may seek input from another, but the other may not necessarily seek it from the first division. This distinction was important in this company. In the field interviews I learned that search was facilitated by interdivisional ties that people in a focal division had to other divisions but not necessarily by ties other divisions had to the focal division.

The next steps involved several procedures for cross-validating the divisional R&D managers' responses. First, the three corporate R&D managers who sponsored my study went through all reported relations and highlighted those they considered suspect, that is, those they thought were not regular contacts but were likelier ad hoc. I flagged these cases. I next employed the cross-validation method used by Krackhardt (1990). I asked the R&D managers the opposite question, that is, who comes to them for input. An actual tie exists when both divisions agree that one comes to the other for input. As the final procedure, I sent an e-mail to all the R&D managers, asking them about the flagged cases and the ones about which there was no joint agreement. On the basis of their responses, I included some of these suspect ties and excluded others. The problem cases were never strong ties, only very weak ones, a characteristic of problem cases that Marsden (1990) also noted.

In addition to these contacts, there were some other regularly occurring ties between the divisions. I identified two such relations from my initial interviews: licensing agreements between divisions and enduring cross-divisional groups that were focused around a specific technology area. I included these two types of fairly informal relations so as not to bias the network information. Sometimes a regular informal contact between groups of people from two divisions had evolved into a licensing agreement, becoming a taken-for-granted and routinized knowledge-sharing activity. Information on licensing agreements between divisions was furnished by the legal department, and data on ongoing technology groups were provided by the three senior corporate R&D managers. These relations were coded 1 if any two divisions had a licensing agreement or participated together in a technology group, and 0 otherwise. The interunit network by and large comprised informal contacts as captured in the network survey. The network in 1993 consisted of a total of 225 relations, of which 201 were regularly occurring informal contacts.

Merging Project and Network Data

I merged the project data with the divisional network data by assigning a division's network relations to its projects that were included in this study. Thus, interdivisional ties became the equivalent of interdivisional project ties. It is important to record the values on the network variables prior to the start of a project because my theoretical arguments assume that a project team uses established preexisting interunit ties to search for and transfer knowledge. I handled this issue by measuring the interdivisional network relations and other division-level variables over several years. These variables were lagged by one year before they were merged with the project data.

Measuring network data over multiple years was a two-step procedure. First, as described above, I asked the divisional R&D managers about regularly occurring ties. It is common practice in social network research to assume that actors are reasonably likely to recall regularly occurring relations, as opposed to specific ad hoc interactions (Marsden, 1990). Second, following the approach of Burt (1992: 173) and Podolny and Baron (1997), I then asked how many years each of these reported ties had been in existence. Thus, for example, I know whether a particular tie existed for the 1993 network, which I used to construct the network positions for projects that started in 1994. This procedure thus generated time-varying network data for the last four years from information that the respondents could recall.

Dependent and Independent Variables

Project completion time. I measured project completion time, the dependent variable, at the project level. Time to project completion is the number of months from the start of concept development to the time of market introduction for a given project (or time to the end of the study period or cancellation for on-going and canceled projects, respectively). I defined starting time as the month when a dedicated person started working part or full time on the project, which typically coincided with the time an account was opened for the project. I defined the end date as the date on which the product was released to shipment, which is a formal milestone date in this company because it signifies that the product is ready to be manufactured and shipped on a regular basis. These definitions turned out to be very clear and provided few problems in specifying the start and finishing times.

Scholars have proposed two alternative measures of completion time. First, completion time can be measured as the extent to which the project is finished on schedule (e.g., Ancona and Caldwell, 1992). The assumption in this schedule measure is that inherent project differences are accounted for in the original schedule, but also that everybody sets equally ambitious schedules, which was most likely not true in this company, where individual project managers set their own targets. Moreover, it may not be an objective measure: Cyert and March (1992) proposed that targets such as schedules are often adjusted according to expectations and experiences and hence become subjective indicators. A second approach is to group projects according to some similarity measure and then take a project's deviation from the mean completion time of the group (Eisenhardt and Tabrizi, 1995). The problem with this approach is that the mean deviation relies on a clear similarity measure, which was not easy to attain in this setting. Furthermore, the projects included in this study did not span several industries but were confined to one 4-digit SIC code. Thus, their inherent differences were not as large as those in samples comprising multiple industry categories, where the mean-deviation measure has been used (e.g., Eisenhardt and Tabrizi, 1995). Given that these two alternative methods seemed problematic, I chose to use the number of months as the dependent variable and then add project-specific variables to control for inherent differences between the projects.

Interunit tie weakness. Using conventional network measures (e.g., Marsden and Campbell, 1984; Burt, 1992), I measured the weakness of an interdivisional tie as the average of the frequency and closeness scores as reported on 7-point Likert-type scales by the R&D managers in the network survey (see the Appendix for the survey questions). While scholars typically use an affective construct to operationalize closeness between individuals (e.g., Burt, 1992), an affective construct is less meaningful in describing interunit ties that are not strictly between two individuals. I therefore chose to use a work-related meaning of closeness. The correlation between frequency and closeness is very high (.83) in this data set and confirms that these two measures represent the same underlying construct in this context.[3]

A division's tie weakness score is the average weakness of all its ties to other divisions in a given year. I took the average instead of dichotomizing the variable into weak and strong ties to be able to use the fine-grained information created by the 7-point scales. I lagged a division's average tie weakness score by one year before I assigned it to the project teams in that division. For example, if the focal division had an average weakness score of 4.7 in 1993 and the project started in March 1994, then that project would be assigned a weakness score of 4.7.

Noncodified knowledge. I operationalized the degree to which the knowledge was noncodified with a three-item 7-point Likert type scale that measured the extent to which

3
This result differs from that of Marsden and Campbell (1984), who found that frequency and closeness are different dimensions underlying tie strength. This discrepancy is probably due to my using a work-related definition of closeness rather than an affective definition.

the knowledge transferred from the source division to the receiving project team was not fully documented, insufficiently explained in writing, and was mainly personal practical know-how (see the Appendix for specific questions). With a few exceptions (e.g., Zander and Kogut, 1995), empirical research has not employed a direct measure of this variable and, hence, no established scale exists. I therefore chose to develop a scale that was geared toward this particular empirical setting. The Cronbach alpha for this scale is .81. The measure consists of the average of the responses to the three questions.

The scale was designed to capture both knowledge that is very difficult to articulate and self-explanatory knowledge, such as a clearly written market report. The codification level of software and hardware is especially important in this context because many projects teams relied on "ware" from other divisions. Ware is at some level more codified than implicit technical know-how, because the ware is at least represented by drawings, formulas, physical boxes, or lines of code. But ware can also be noncodified, as when an engineer has written a software code that does not make sense to another engineer working in the same technical area. I was told about several cases in which the software lines of code that came from other divisions were illegible and poorly documented. Thus, software and hardware also vary along the codification dimension.

Dependent knowledge. In operationalizing knowledge dependency, I chose to focus on software and hardware by asking, "Could the 'ware' that was leveraged function as 'stand alone,' or was it dependent on other components or products in those divisions?" (anchors being "highly dependent" and "mainly stand-alone"). The question was asked for both software and hardware, and I took the average of the responses to the two questions. Dependency had a straightforward meaning in this company: engineers frequently talked about the extent to which the ware was stand-alone or depended on other components to function. For example, so-called "firmware"—software embedded in hardware—can only function together with certain hardware modules. Information on this variable was missing for seven project teams, so I entered a dummy variable in the analysis to obtain unbiased estimates (*dummy-dependent*). The variable was coded 1 if there was missing information, and 0 otherwise.

Because the project managers were the only respondents for the questions about noncodified and dependent knowledge, it was impossible to test the reliability of the responses by using multiple respondents for each team. But the project manager was most likely the only person who had sufficient information about all the knowledge transferred in a project to answer the questions. Typically, the engineers who worked on a project were involved in different parts of the overall project, and they had only partial knowledge of the project. Thus, their responses would be biased toward their part of the project.

Other explanatory variables. Weak ties may provide a search advantage either because they provide novel knowledge through nonredundant contacts or because they do not bind the project team members to reciprocal helping relations. To attempt to disentangle these two underlying mechanisms, I constructed two additional redundancy variables and a reciprocity variable. Following Burt (1992: 18), I measured redundancy in two ways: by cohesion and structural equivalence. Data on both redundancy measures require that ties beyond a focal division's direct contacts are known. Because I obtained information on all relations among the 41 divisions, the data set is a complete network and includes this information. The first measure—*proportion density*—captures redundancy by cohesion by measuring the presence of ties between a focal division's direct contacts (see Marsden, 1990; Ibarra, 1995; Podolny and Baron, 1997). The premise of this measure is that two direct contacts are redundant if ties exist between them. Relations are asymmetric, so both ties between any pair of direct contacts need to exist for complete redundancy. The measure is the actual number of ties between a focal division's direct contacts divided by the maximum number of ties possible between these direct contacts. This measure ranges from 0 to 1, with 1 indicating that all possible ties between direct contacts exist.

The second redundancy variable measures the extent to which a focal division's *direct contacts* are structurally equivalent to one another (Burt, 1992: 18). The idea is that two direct contacts maintained by the focal division are redundant to the extent that they, in turn, are connected to the same other divisions (apart from ties to the focal division). To compute this version of structural equivalence, I first calculated the Euclidean distance for all pairs of divisions. I did not include ties to the focal division because I wanted to measure the extent to which the focal division's direct contacts had ties to *other* divisions in the company. Thus, the computation was performed on matrices excluding the row and column for the focal division. The Euclidean distance measure between two direct contacts i and j is given by (Wasserman and Faust, 1994: 367):

$$d_{ij} = \sqrt{\sum_{k=1}^{g} (x_{ik} - x_{jk})^2} \text{ for } i \neq k,\ j \neq k,$$

where division k through g are all other divisions in the network apart from divisions i, j, and the focal division, and x_{ik} indicates the presence (1) or absence (0) of a direct relationship from division i to k.[4] If divisions i and j are structurally equivalent, then this measure will be equal to 0. Euclidean distances were computed in UCINET IV (Borgatti, Everett, and Freeman, 1992). To arrive at the redundancy score, I then took the average of the Euclidean distances between those pairs of divisions to which the focal division had a direct contact (*Euclidean distance*).

The two redundancy measures seek to capture redundancy in interdivisional contacts but do not take into account possible redundancy in interpersonal relations that span subunits. It is therefore possible that a project team is connected to two other divisions that do not have any divisional-level contact between them but nevertheless are linked because a few engineers in each division know one another.

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The measure used here excludes relations from k to i because search paths are considered to be directional in this company.

The two redundancy measures used here will not adequately capture the amount of redundancy to the extent that strictly personal relations between subunits exist in areas where divisional-level relations are not present. Because my initial field interviews indicated that interpersonal relations spanning subunits were not as common and as important as divisional-level contacts, I do not expect that this issue leads to a large bias, but it is likely that some redundancy based on interpersonal relations is not captured in this study.

The final alternative variable is *reciprocity,* which is one indication that an interunit network position may be binding by leading project teams to spend efforts helping others rather than working on the focal project. To measure reciprocity, I calculated the proportion of a focal division's direct contacts that were reciprocated by the contact.

Project controls. To make the projects comparable, I controlled for several project-specific factors. I used the log of estimated dollar costs at the start of the project to control for size and scope differences between the projects (*budget*). In my field interviews with project managers, I was also told that estimated costs capture inherent differences in technical complexity among the projects (the more complex the technology, the more engineering hours billed to the project). I used the budget figure to avoid an interaction between final costs and the dependent variable. High final costs may reflect long completion time because of more engineering hours billed to the project. Because information on estimated costs was missing for 19 projects, I imputed the values for these projects through a regression analysis estimating the log of estimated project costs at the start of the project. Predictor variables included number of people on the project and the amounts of new hardware and software coming from other divisions and externally (for which the focal project typically has to pay). The results of this imputation are not reported.

I also controlled for the extent to which the project was able to reuse existing software and hardware within its division and thus save engineering time. I included a measure of the actual proportion of all preexisting software and hardware that the project team reused from its own division (*existing ware*). Project managers were asked to indicate the percentage of all software (and hardware) in the project that they reused from their own divisions. During pretests, project managers thought they could indicate this amount fairly accurately, as many of them kept a record of where the hardware components and software lines of code came from.

Finally, I coded whether a project-specific patent was applied for (*patent*), to measure degree of innovation, and whether the project team developed a product or a system (*product*). More innovative projects presumably take longer to complete. The product-systems distinction was entered as a variable to control for possible differences between these two categories with respect to cross-divisional knowledge use. Each variable was coded as a dummy variable, with a value of 1 indicating a patent and a product, respectively.

Divisional and network controls. To control for the possibility that projects not using the divisional network to gain knowledge obtain it elsewhere, I asked the 41 divisional R&D managers to indicate on a 7-point scale the extent to which their division typically goes outside the company to obtain project-specific knowledge (*external use*). I also controlled for the focal division's sales, because larger divisions tend to have a larger accumulated stock of competencies that a project can draw upon. I obtained divisional sales data from the company's sales data base and used the log of divisional sales in dollars as a proxy for the size of the division's competence base (*divisional sale*).

To control for the possibility that project teams may use divisional relations not to search for and transfer information but to ensure cooperation from contributing divisions, I used one centrality measure, *indegree,* which is typically used by network researchers to indicate a division's power or status in a network (Wasserman and Faust, 1994). Indegree refers to the number of divisions that nominate a focal division as a source of advice. The more nominations, the higher the status in the system (Podolny, 1994). Indegree serves as an indicator of the source division's willingness to help the transfer. A source division should feel more obliged to put effort into the transfer to the extent that the requesting division is a high-status unit in the company. I also included the number of direct relations that the focal division has to other divisions (*outdegree*) to control for the possibility that tie weakness is not simply associated with the number of divisions that the focal division goes to for advice.

Transfer controls. I included two variables to control for the magnitude of the knowledge transferred from other divisions to the focal project team. These variables control for the possibility that the knowledge complexity variables are not simply indicators of large transfers. The project manager was asked to indicate the percentage of a project's total hardware and software that came from other divisions, broken down by the percentage of ware developed specifically for the focal project by another division (*transferred ware-new*) and the percentage of ware that was reused by the focal project team and that resided in another division (*transferred ware-old*).

Statistical Approach

Because project teams need to have reported a transfer event involving another division to be able to report knowledge complexity scores for the transferred knowledge (otherwise the knowledge complexity variables are undefined), I only included in the main analysis projects that reported such an event. The main sample therefore includes the 54 projects that reported a transfer of knowledge from one or more divisions. This sample was not selected based on the dependent variable (completion time) but rather on whether an interdivisional transfer occurred at any point during a project's lifetime. In this approach I do not assume that a transfer event in and of itself is necessarily beneficial for completion time.

The potential bias in this approach is that the tie weakness variable may affect completion time for those project teams that did not report that they obtained knowledge from other divisions. For example, some strongly tied project teams may have attempted to find useful knowledge through the interdivisional network but failed to do so because of a limited search position caused by strong ties. Strong ties should therefore negatively affect completion time among these projects because of the wasted search effort. It could also be the case that some weakly tied project teams did not attempt to search for useful knowledge through the interdivisional network in the first place but nevertheless benefited from the weak tie position, which provided the team with more autonomy and fewer reciprocal relationships that required helping others. Weak ties should therefore positively affect completion time among these projects because of the non-binding network position offered by weak ties. Because of these possibilities, I conducted a separate analysis of the 66 projects that did not incur any transfer events to check whether tie weakness explained completion time (this analysis is reported at the end of the results section).[5]

The statistical analysis was complicated by the fact that 24 of the 120 projects were still ongoing at the time of data collection and represented right-censored cases (Tuma and Hannan, 1984). Furthermore, four projects were canceled. I included ongoing and canceled projects so as not to bias the results toward successfully completed projects, but because the data set contained right-censored data, I could not use ordinary least square regression analysis (Tuma and Hannan, 1984). Instead, I used a hazard rate model. In this approach, a project enters the risk set at the time it was started and leaves the risk set when it is completed or canceled. The instantaneous transition rate is a measure of the likelihood of a project either completing or terminating at time t, conditional on it not having completed or terminated before t. The higher the transition rate, the more likely the project will be completed faster. The hazard rate model takes the following form:

$$r(t)_j = r(t)_j^* \exp[aW_j + bWC_j],$$

where $r(t)_j$ is the completion rate of project j, t is project time in the risk set, and $r(t)_j^*$ is the completion rate including the effects of all the control variables in the model. The effects of the independent variables are specified in the exponential bracket. W_j is the tie weakness variable for project j, and WC_j is the interaction term for tie weakness and complex knowledge (noncodified and dependent knowledge, respectively). I expected to find that $a > 0$ and $b < 0$. To evaluate the hypotheses, the main effect of tie weakness and the interaction term need to be combined. Hypotheses 1 and 2 are supported if $(aW_j + bWC_j) > 0$ when the knowledge to be transferred is codified or stand-alone and if $(aW_j + bWC_j) < 0$ when the knowledge to be transferred is noncodified or dependent.

I used maximum likelihood estimation as implemented in the statistical program TDA (Blossfeld and Rohwer, 1995). I used the piecewise exponential specification because I did not want to make any assumption about duration dependence that would require a specific parametric distribution. The piecewise exponential model was suitable here because it estimates completion rates without making strong parametric assumptions. To control for duration dependence, the

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There is no significant difference between the average tie weakness in the two subsamples. Average tie weakness is 2.8 (s.d. = 1.20) in the first sample (*N* = 54) and 3.0 (s.d. = 1.33) in the second (*N* = 66).

model included six time periods that reflect the time-distribution of events (the interval marks are 300, 350, 450, 550, and 650 days).[6] The transition rate is assumed to be constant within these periods, and covariates are assumed not to vary across time periods (Blossfeld and Rohwer, 1995: 114).

RESULTS

Descriptive statistics are reported in table 1. The models estimating the interaction of knowledge complexity and tie weakness for projects incurring a transfer event are depicted in table 2. Control variables are included in model 1 in table 2, and the main effect of tie weakness is reported in model 2 and is not significant. Model 3 includes the tie weakness and the knowledge complexity variables as well as two interaction terms, one for noncodified knowledge and tie weakness and one for dependent knowledge and tie weakness. The main effect of tie weakness reported in model 3 can be interpreted in isolation when the noncodified and dependent knowledge variables are set to zero (i.e., the knowledge to be transferred is highly codified and mainly stand-alone), which sets the interaction terms to zero. The main effect of tie weakness is significant and positive in model 3. This result confirms the first hypothesis, that weak ties shorten completion time when the knowledge to be transferred is highly codified and stand-alone.

The positive net effect of having weak ties only holds as long as the knowledge to be transferred is codified and stand-alone. The results from model 3 in table 2 reveal two negative interaction terms for knowledge complexity and tie weakness.[7] When the noncodified and dependent knowledge variables are above zero, the negative interaction effects set in, as follows:

$$rate = \exp[1.329*Weakness + Weakness*(-0.343*Noncodified - 0.193*Dependent)].$$

The magnitude of this rate is depicted in figure 2 for three levels of noncodified and dependent knowledge. A multiplier of the rate that is above one indicates a positive effect of tie weakness on project completion time. As figure 2 reveals, the net effect of tie weakness is still positive for low and medium-high levels of noncodified and dependent knowledge. When the noncodified knowledge variable takes on a value of 1.3 (one standard deviation below the mean) and the dependent variable takes on its mean value of 2.3, the multiplier of the rate is above one and rising with weaker ties. Thus, there is still a net benefit of having weak ties in this situation. The positive main effect of tie weakness dampens, however, as the knowledge to be transferred becomes more noncodified and dependent. When both the noncodified and dependent knowledge variables are at their mean value (2.8 and 2.6, respectively), the net effect of tie weakness is negative (the multiplier of the rate is below one). The weaker the ties, the more negative the rate and, hence, the worse the transfer problem. This result supports hypothesis 2.

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I reran several of the models with somewhat different time periods, in particular, with small (200 days) and large (750 and 850 days) periods to check whether projects with extreme values on the dependent variable affect the results, but the results were unchanged.

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Because the main effects for noncodified and dependent knowledge are positive and significant in model 3 in table 2, I reran the model with a mean-deviated tie weakness variable to reduce the correlations between the variables and the interaction terms. The effects for tie weakness and the interaction terms stayed the same, but the main effect for complex knowledge was no longer significant.

Table 1

Descriptive Statistics and Correlations for Project Variables (N = 120)

Variable	Mean	S.D.	Min.	Max.	1	2	3	4	5	6	7
1. Budget (log)	6.74	1.06	4.50	10.72							
2. Existing ware	.45	.31	.00	1.00	−.26						
3. Patent	.20	.40	.00	1.00	.28	.14					
4. Product	.75	.43	.00	1.00	−.04	.11	−.10				
5. External use	3.49	1.88	.00	7.00	.19	−.08	−.05	.06			
6. Divisional sale (log)	3.94	.78	1.10	5.30	.09	.37	.16	.16	−.06		
7. Indegree	6.28	3.70	1.00	15.00	.09	.16	−.01	.14	−.39	.51	
8. Outdegree	5.61	2.97	1.00	14.00	.37	.08	.40	−.07	.21	.32	.02
9. Transferred ware-new*	.02	.04	.00	.25	.24	−.28	.16	−.01	.02	−.04	−.08
10. Transferred ware-old*	.07	.15	.00	.90	−.05	−.37	−.08	−.10	.07	−.15	−.04
11. Tie weakness	2.90	1.26	.00	4.82	.05	.35	.20	−.12	.04	.36	.42
12. Noncodified knowledge*	2.84	1.47	.00	6.00	.02	.12	−.12	−.06	.08	.20	.09
13. Dependent knowledge*	2.56	2.16	.00	6.00	.04	.18	.13	−.05	.03	.16	.12
14. Dummy-dependent*	.13	.34	.00	1.00	−.05	.10	−.10	.04	.10	.08	−.11
15. Noncodified × weakness*	7.88	5.35	.00	20.77	.07	.47	.01	−.32	.13	.39	−.36
16. Dependent × weakness*	7.65	7.89	.00	28.50	.00	.41	.12	−.16	.05	.28	.33
17. Euclidean distance	2.65	.37	1.62	3.33	−.04	.11	.12	−.05	.09	−.21	−.03
18. Prop. density	.32	.30	.00	1.00	.13	−.26	.03	−.04	−.11	−.22	−.10
19. Reciprocity	.53	.29	.00	1.00	.24	.05	.02	−.08	−.23	.00	.16

Variable	8	9	10	11	12	13	14	15	16	17	18
1. Budget (log)											
2. Existing ware											
3. Patent											
4. Product											
5. External use											
6. Divisional sale (log)											
7. Indegree											
8. Outdegree											
9. Transferred ware-new*	.14										
10. Transferred ware-old*	.18	.09									
11. Tie weakness	.25	−.12	−.11								
12. Noncodified knowldge*	−.10	−.16	−.07	−.05							
13. Dependent knowledge*	.05	.17	−.12	.13	.27						
14. Dummy-dependent*	−.08	−.14	−.21	−.09	.39						
15. Noncodified × weakness*	.21	−.20	−.11	.62	.66	.31	.17				
16. Dependent × weakness*	.16	.05	−.13	.56	.27	.83	.	.60			
17. Euclidean distance	.24	−.03	.11	.33	.12	.11	.06	.27	.30		
18. Prop. density	−.10	−.01	.07	−.59	−.13	−.09	−.05	−.41	−.27	−.42	
19. Reciprocity	−.15	.12	−.13	−.17	−.03	.02	.04	−.16	−.06	−.31	.30

* N = 54.

The results reported in model 3 in table 2 thus support both hypotheses.[8] Tie weakness has a positive effect on the completion rate when the knowledge to be transferred is not complex, whereas tie weakness has a negative impact on the rate when complex knowledge is involved.

I conducted a supplementary analysis to check whether the interaction effects of tie weakness and knowledge complexity varied by project type. As suggested by an anonymous reviewer, I checked whether more innovative projects (as measured by the patent variable) obtained a net benefit from having weak interunit ties, even when the knowledge to be transferred was complex. Teams pursuing innovative projects may find weak interunit ties especially useful because they are more likely than strong ones to point the team to existing knowledge (e.g., a software module) that they did not know about but that they could use to create innovative combinations of previously unconnected knowledge. This

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I also ran models in which the interaction terms were entered separately and obtained the same results. The same results were also obtained when tie weakness was broken down by both infrequency and distance.

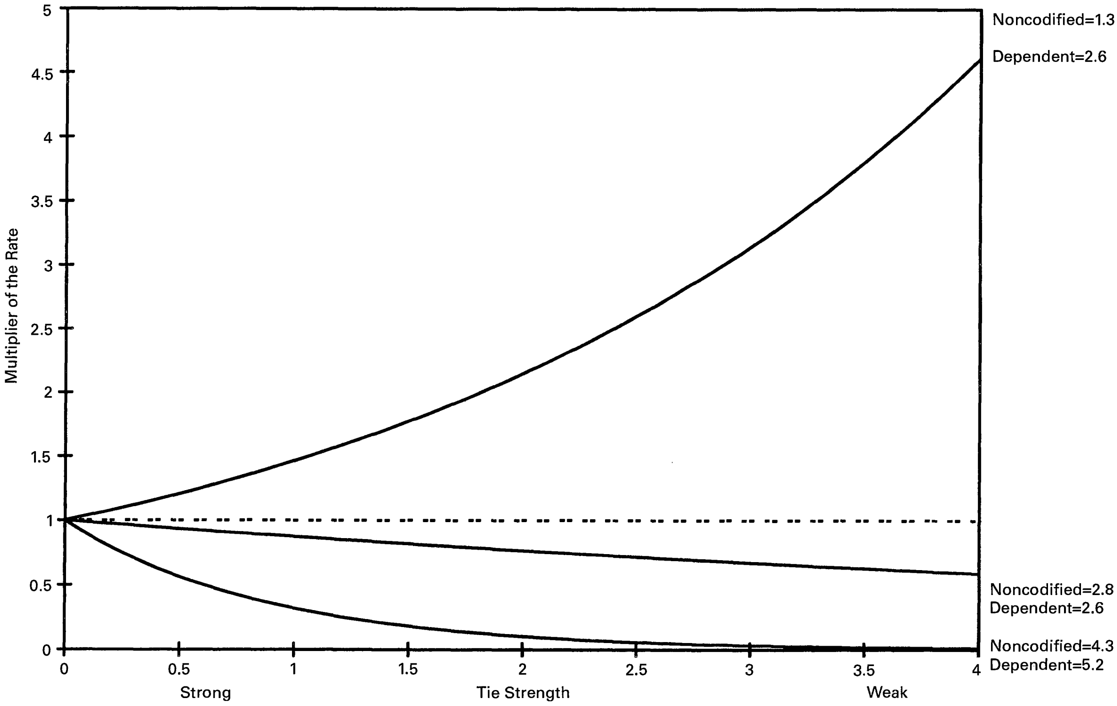
Table 2

Results from Hazard Rate Analysis of Project Completion Time for Projects That Incurred a Transfer Event (*N* = 54)*

Variable	Model 1	Model 2	Model 3	Model 4	Model 5
Period effects					
Period-1	−4.322•••	−4.078••	−7.045•••	−9.037•••	−8.356•••
	(1.702)	(1.783)	(2.079)	(2.679)	(2.969)
Period-2	−1.926	−1.697	−4.479••	−6.403••	−5.717•
	(1.696)	(1.770)	(2.040)	(2.651)	(2.953)
Period-3	−1.617	−1.378	−4.067••	−5.838••	−5.110•
	(1.687)	(1.765)	(2.001)	(2.576)	(2.924)
Period-4	−1.100	−0.860	−3.513•	−5.197••	−4.467
	(1.715)	(1.792)	(2.018)	(2.553)	(2.909)
Period-5	−0.635	−0.418	−2.860	−4.481•	−3.732
	(1.775)	(1.840)	(2.048)	(2.550)	(2.927)
Period-6	0.166	0.399	−1.668	−3.089	−2.347
	(1.843)	(1.918)	(2.096)	(2.598)	(2.970)
Project controls					
Budget (log)	−0.837•••	−0.835•••	−1.061•••	−1.347•••	−1.332•••
	(0.223)	(0.223)	(0.270)	(0.296)	(0.300)
Existing ware	1.294	1.531	2.448••	2.954••	3.195••
	(0.983)	(1.090)	(1.164)	(1.206)	(1.299)
Patent	−0.532	−0.509	−1.170•	−1.713••	−1.749••
	(0.504)	(0.512)	(0.645)	(0.728)	(0.730)
Product	−0.324	−0.423	−0.823	−0.867	−1.019
	(0.411)	(0.459)	(0.533)	(0.565)	(0.637)
Divisional and network controls					
External use	−0.044	−0.028	−0.014	0.112	0.076
	(0.106)	(0.111)	(0.122)	(0.143)	(0.158)
Divisional sale (log)	0.468	0.430	0.642•	0.772••	0.774••
	(0.299)	(0.311)	(0.337)	(0.365)	(0.361)
Indegree	−0.136•	−0.122	−0.087	−0.144	−0.124
	(0.075)	(0.080)	(0.090)	(0.094)	(0.102)
Outdegree	0.029	0.048	0.035	0.115	0.095
	(0.085)	(0.095)	(0.106)	(0.143)	(0.146)
Transfer controls					
Transferred ware-new	0.996	0.923	3.041	5.581	6.013
	(3.246)	(3.264)	(3.536)	(3.771)	(3.845)
Transferred ware-old	1.289	1.213	1.529	1.253	1.229
	(1.049)	(1.059)	(1.104)	(1.120)	(1.116)
Independent variables					
Tie weakness		−0.130	1.329••	1.528•••	1.560•••
		(0.263)	(0.543)	(0.563)	(0.567)
Noncodified knowledge			0.645•	0.758••	0.780••
			(0.354)	(0.337)	(0.339)
Dependent knowledge			0.511•	0.550••	0.559••
			(0.285)	(0.272)	(0.273)
Dummy-dependent			0.702	0.634	0.674
			(0.633)	(0.644)	(0.653)
Noncodified × weakness			−0.343••	−0.379•••	−0.397•••
			(0.138)	(0.139)	(0.143)
Dependent × weakness			−0.193•	−0.251••	−0.247••
			(0.107)	(0.109)	(0.109)
Euclidean distance				0.420	0.289
				(0.431)	(0.500)
Prop. density				3.271••	3.089••
				(1.319)	(1.335)
Reciprocity					−0.574
					(1.101)
Log-likelihood	−298.375	−298.253	−292.728	−289.516	−289.381
Chi-square (d.f.)†		0.24 (1)	11.05 (6)••	17.72 (8)••	18.00 (9)••

• *p* < .10; ••*p* < .05; •••*p* < .01; two-tailed tests.
* Standard errors are in parentheses.
† Compared with model 1.

Figure 2. Effects of tie strength and knowledge complexity on completion rate.



benefit may outweigh the transfer problem caused by complex knowledge. In results not reported here, I added a new interaction term to model 3 in table 2 (patent*knowledge complexity*weakness), but this variable was not significant, and the previous results remained the same. The interaction effects of tie weakness and knowledge complexity therefore seem to hold for both innovative and less innovative new-product development efforts in this sample of projects.

Nonredundancy or Less Binding?

To assess whether the results can be explained by weak interunit ties being advantageous because they are associated with nonredundant contacts, I added the alternative redundancy measures (Euclidean distance and proportion density, respectively) in model 4 in table 2. If the addition of these direct redundancy measures causes the main effect of tie weakness to evaporate, then tie weakness is likely to capture redundancy. If the tie weakness effect still holds, however, then the network binding argument may be more plausible, because the redundancy explanation has to some extent been controlled for by the addition of the two new nonredundancy variables. As model 4 reveals, the additions of the two direct redundancy measures do not remove the main effect of tie weakness. The size of the coefficient for tie weakness also remains about the same. Thus, controlling for the extent to which direct contacts are structurally equivalent among one another and the proportion of ties between the focal division's direct contacts, there is still a positive main effect of having weak ties. This result implies that weak interunit ties are not primarily beneficial because they are associated with nonredundant contacts.[9]

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The results also reveal that the effect of proportion density is positive and significant, whereas the effect for structural equivalence is not. This result suggests that when the effect of weak ties is controlled for, there is a positive effect on completion time of having contacts that are connected among themselves (proportion density).

I also added the reciprocity variable in model 5 in table 2 to assess whether the main effect of tie weakness would become nonsignificant when the proportion of a focal division's direct contacts that are reciprocated is controlled for. The reciprocity variable is not significant, and the main effect of tie weakness remains positive and significant. This result implies that the positive effect of tie weakness is not primarily explained by weakly tied project teams having fewer reciprocal relationships and hence having to spend less time helping other divisions.

There are a few other significant results in table 2. The effect for the budget variable—estimated costs at the start of a project—is negative and significant throughout the models. Larger projects take more time to complete. The two variables that measure the use of existing knowledge in the focal division are also significant and positive. The coefficients for existing ware (i.e., the proportion of software and hardware that was reused from the focal division) and divisional sales (which indicates the size of the focal division's competence base) are both positive and significant in models 3–5. A project is completed faster to the extent that it is able to reuse existing ware in the division and takes place in a large division. Finally, more innovative projects—as measured by whether a patent was applied for—take longer to complete, as revealed in models 3–5.

Tie Weakness Effect without Transfer

The final part of the analysis involved projects in which the project manager did not report any transfer event from an-

Table 3

Results from Hazard Rate Analysis of Project Completion Time for Projects That Did Not Incur a Transfer Event (*N* = 66)*

Variable	Model 1		Model 2		Model 3	
Period effects						
Period-1	−4.127••	(1.784)	−5.635••	(2.317)	6.509•••	(2.452)
Period-2	−2.133	(1.810)	−3.589	(2.312)	−4.475•	(2.452)
Period-3	−2.051	(1.815)	−3.483	(2.303)	−4.335•	(2.429)
Period-4	−0.677	(1.825)	−2.127	(2.322)	−2.915	(2.435)
Period-5	−1.861	(2.004)	−3.351	(2.481)	−4.185	(2.587)
Period-6	−0.904	(2.092)	−2.427	(2.549)	3.292	(2.651)
Project controls						
Budget (log)	−0.748•••	(0.240)	−0.752•••	(0.250)	−0.855•••	(2.720)
Existing ware	1.439••	(0.642)	1.555••	(0.651)	1.276•	(0.725)
Patent	0.439	(0.500)	0.420	(0.506)	0.546	(0.527)
Product	0.727	(0.458)	0.863•	(0.492)	0.913•	(0.493)
Divisional and network controls						
External use	−0.048	(0.130)	−0.064	(0.139)	−0.031	(0.144)
Divisional sale (log)	0.133	(0.379)	0.288	(0.395)	0.517	(0.468)
Indegree	−0.121	(0.082)	−0.172•	(0.098)	−0.201•	(0.105)
Outdegree	−0.058	(0.075)	−0.102	(0.087)	−0.122	(0.090)
Tie weakness	0.109	(0.165)	0.218	(0.232)	0.255	(0.235)
Euclidean distance			0.284	(0.312)	0.412	(0.343)
Prop. density			0.818	(0.865)	0.850	(0.856)
Reciprocity					0.777	(0.849)
Log-likelihood	−335.69		−335.109		−334.687	
Chi-square (d.f.)†			1.16 (2)		2.00 (3)	

• $p < .10$; •• $p < .05$; ••• $p < .01$; two-tailed tests.
* Standard errors are in parentheses.
† Compared with model 1.

other division. I included this analysis to control for the possibility that tie weakness may explain project completion time among this subset of projects. Table 3 displays the models estimating the effect of tie weakness on completion time for this sample of 66 projects. As revealed in model 1, tie weakness has no significant impact on completion time for these projects. There is no apparent benefit of having weak ties in this situation. The results obtained in the main analysis and reported in table 2 are therefore not likely to be biased by excluding projects that did not incur a transfer event.

I also added the two direct redundancy measures and the reciprocity variable in models 2 and 3 in table 3. None of these variables is significant. Among the control variables, the coefficient for budget is still significant and negative. The analysis also reveals that the existing-ware variable is significant and positive in this sample of projects. Projects that did not incur a transfer event seemed to rely on their own division's preexisting software and hardware components to complete projects more quickly.

DISCUSSION AND CONCLUSIONS

The main finding of this study is that neither weak nor strong relationships between operating units lead to efficient sharing of knowledge among them. Weak and strong interunit ties have their respective strengths and weaknesses in facilitating search for and transfer of useful knowledge across organization subunits. The net effect on project completion time of having either weak or strong interunit ties is contingent on the complexity of the knowledge to be transferred across subunits. Strong interunit ties provide the highest relative net effect (or least negative effect on completion time) when the knowledge is highly complex, whereas weak interunit ties have the strongest positive effect on completion time when the knowledge is not complex.

Another finding from this study is that weak interunit ties are not primarily beneficial because they are associated with nonredundant contacts. The main positive effect of weak interunit ties remained significant when redundancy measures were added to the model. Another explanation for this effect is that weak interunit ties are advantageous because they are less costly to maintain than strong ones. Project engineers in this company may well obtain the same information about opportunities for knowledge use from weak interdivisional ties than from strong ones, but they obtain this information at lower search costs and can therefore dedicate more time and energy to completing the focal project. This cost argument for the benefits of weak ties provides an alternative explanation to the predominant claim that weak ties are beneficial because they provide access to nonredundant information.

Limitations

Overall, these results lend considerable support to the argument that weak ties facilitate search but impede the transfer of complex knowledge. There are, however, a few important limitations of these empirical results. The focus has been on product development time, which was an appropriate variable to study given that it captures both costs (search and transfer efforts) and benefits (work saved) in using knowledge from other subunits. The findings may not hold, however, for other outcome variables, such as final project costs, product quality, and degree of innovation, although some of these performance dimensions have been implicitly controlled for here. The company that I studied has certain rules for what is acceptable quality. Products cannot be shipped before they have met these requirements. Software projects need to follow procedures for debugging before they are released, for instance. Other objectives, such as low manufacturing costs, are also emphasized in the company, limiting the extent to which other project outcomes can be traded off for shorter completion time.

This study was limited to interdivisional relationships—regularly occurring informal contacts between groups of people from different divisions—but project teams may have used other channels of communication to search for knowledge, in particular, their own strictly personal relations. Although my field interviews indicated that few engineers in this company had many personal relations spanning subunits, some relations nevertheless did exist. This possibility brings up the more general issue of conducting network analysis at two different levels of analysis—interunit and interpersonal, respectively. Relations at the interpersonal level may substitute for or complement relations at the interunit level (and vice versa). This possibility complicates the analysis, and further research is needed to study the interaction between personal and interunit-level relations.

Project teams in this sample may also have used other sources for information, by relying on electronic means of communication, searching through data bases and using e-mail. These other channels may have overlapped or complemented interdivisional relations. Furthermore, I did not include the role of headquarters in facilitating the search for and transfer of knowledge across subunits. Corporate managers may sometimes have intervened by helping a subunit find knowledge elsewhere or by deciding that two or more subunits should work together. Because this study did not address these other linking mechanisms, I cannot conclude that knowledge sharing through interdivisional ties is more beneficial than sharing through other means.

Finally, the findings reported here are confined to one company, which may affect the generalizability of the results. The company that I studied is probably more networked than are many multiunit firms, especially when it is compared with holding-type companies in which business units tend to operate independently of one another, but this bias may, however, be in a conservative direction. It is likely that both search and transfer will be more difficult in a network with fewer interunit relations: search is likely to be more difficult to the extent that there are fewer interunit connections to rely on, whereas transfer is more likely to occur between parties without prior relationships and will thus be more difficult. If the search-transfer problem occurs even in a relatively dense interunit network, then it is also likely to occur in a company with a less dense network.

Implications

This research was motivated by an apparent discrepancy between two lines of research in extant organization theory. Whereas researchers studying product innovation have found that a tight coupling and extensive communication between two departments or business units is most effective, some social network researchers have argued that a loose coupling—weak ties—is most beneficial. Part of this discrepancy exists because these two lines of research examine either search or transfer but not both activities. I sought to combine arguments about interunit search and transfer because these two processes may be intertwined. If either the search or transfer arguments were considered alone, the dual effect of weak ties on project completion time would not have been elucidated. The implication is that organization research that concentrates on either search or transfer, but not both, is likely to be incomplete when task outcomes are being studied.

The finding in this study that tie weakness and knowledge complexity interact to explain project completion time provides some evidence for the contention that social network research that considers task outcomes could benefit from a richer conceptualization of knowledge. Most social network research has remained agnostic with respect to the content that flows through network ties, but even those researchers who have considered the content of what flows through the ties have not taken into account knowledge complexity. Some network scholars have argued that sparse networks characterized by nonredundant and weak contacts are most beneficial for instrumental tasks such as obtaining advice, whereas dense (i.e., more cohesive) networks are more advantageous for conveying normative expectations, identity, and affect (e.g., Krackhardt, 1992; Podolny and Baron, 1997). The findings in this study introduce a boundary condition on the assertion that sparse networks (i.e., those with many weak and nonredundant contacts) are most advantageous for instrumental tasks. Even when network relations are used for instrumental purposes, strong ties may be beneficial in some situations, as when the knowledge to be transferred is highly complex. The implication is that social network research could provide a more complete account of the role of instrumental network ties in organizations by considering search and transfer as well as various forms of knowledge that flow through network relations.

Whereas network scholars tend to neglect the transfer aspect, scholars studying cross-functional integration and knowledge transfer in product innovation tend to neglect the search aspect.[10] For example, a central finding in this line of research is that product development is most effective to the extent that R&D and other functions (marketing and manufacturing in particular) communicate frequently and work closely together in cross-functional teams (e.g., Eisenhardt and Tabrizi, 1995). But this result came from compar-

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For an exception, see Ancona and Caldwell (1992), who studied external scouting activities, a process similar to search.

ing R&D departments that communicate frequently with a few other functions and those that do not. The analysis does not include a larger search process that includes multiple sources of information beyond neighboring marketing and manufacturing departments. Following the argument developed in this paper, it is quite possible that R&D departments that are tightly linked to local marketing and manufacturing functions may, under some conditions, perform poorly in finding and transferring useful knowledge because the strength of these ties precludes or limits searches for useful knowledge beyond a few functional subunits.

This problem with tight linking to a few subunits is likely to be accentuated for project teams that face uncertain environments, as is the case when project teams need to broaden their horizon to keep abreast of rapidly changing technologies and market developments. Although extant research posits that tight cross-functional integration is more important in situations with high environmental uncertainty (Lawrence and Lorsch, 1967; Henderson and Cockburn, 1994), this argument does not consider the possibility that tight coupling may constrain the inflow of new knowledge and inhibit the search for new knowledge outside established channels, an activity that is likely to be more important in changing environments (cf. Henderson and Clark, 1990). The implication is that studies of cross-functional integration and knowledge transfers in product innovation could provide a more complete account of knowledge sharing between various sources by considering the larger search process, in addition to direct relationships between a few subunits.

Finally, my analysis of the effects of interunit network variables on product development effectiveness complements much prior research on project-specific determinants of product development success. Whereas I have emphasized the larger interunit network within which project teams are situated, extant research on new-product development has uncovered many project team and organization attributes that explain effective new-product development. Studies have demonstrated the importance of communicating across functions (as discussed above), having a heavyweight project leader, using overlapping development phases, engaging actively in predevelopment activities, testing designs frequently, communicating frequently within the team, and buffering the team from outside pressure (see Brown and Eisenhardt, 1995, for a review). Although I did not include any of these factors in my analysis, the interunit network variables I analyzed may interact with some of the factors that have been studied previously. For example, studies have shown the importance of having a heavyweight team leader who coordinates team work, gains resources for the team, and works across functional boundaries (Clark and Fujimoto, 1991). Part of the positive aspect of having heavyweight team leaders may have to do with the use of the interunit network. Such effective team leaders may know how to initialize and use interunit relations to the team's advantage. The general category of "effective team leader" may therefore include interunit networking skills in addition to other managerial competencies. Subsequent research could try to disentangle the interunit network effects from other managerial aspects by including both sets of variables in the analysis.

Previous research on product development has also found that teams with high internal communication and coordination are more effective (Brown and Eisenhardt, 1995). The extent to which external communication, or interunit networking more specifically, varies with internal communication is unclear (Ancona and Caldwell, 1992). Frequent within-team communication may lead to effective coordination of work but may also make the team overly inward focused, causing the team to neglect using interunit relations to search for and transfer useful knowledge from other subunits. Active interunit networking may, in contrast, interfere with internal team coordination, in part because the introduction of external and diverse knowledge may upset the team's consensus on important product design choices that are needed to move the project forward. Teams may partly resolve these tensions by engaging in interunit networking and internal coordination at different times, attending to interunit search and transfer at certain times during the project when the team is open to input from the environment (cf. Gersick, 1988). Future research could analyze the various relationships between internal communication and interunit networking to detect combinations and contingencies that explain effective product development.

Although organization scholars from different areas such as social network and product innovation research have analyzed how knowledge flows through relationships, they have remained focused on different parts of the process of sharing knowledge among actors in an organization, arguing for different benefits and costs of weak and strong relationships. Even when these various arguments are considered together, however, the effect of the strength of relationships between subunits still implies a puzzle. The findings reported in this paper imply that if a project team does not know ex ante what type of knowledge it will end up transferring, a certain strength of relationships in the interunit network (strong or weak) is likely to cause some problems. A strong tie will constrain search, whereas a weak tie will hamper the transfer of complex knowledge. Thus, there appears to be no obvious organization design solution to the search-transfer problem, to the extent that organizational actors cannot determine ex ante what types of knowledge are likely to flow across which types of relations. One possible solution to this puzzle is to organize operating subunits in a multiunit organization into separate sectors according to whether they need complex or simple knowledge and then develop the appropriate type of interunit relations in each sector. Another design solution is to develop a pure organization form by only keeping and acquiring operating subunits that need a certain type of knowledge (whether complex or simple) and then develop the appropriate type of interunit relations. Experimenting with such design solutions could provide firms in knowledge-intensive industries with a competitive advantage in solving the search-transfer problem.

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APPENDIX: Survey Questions for Independent Variables

Respondents answered the questions below on a 7-point scale, ranging from 0 to 6.

Interunit Tie Weakness

1. How frequently do (did) people in your division interact with this division (on average over the past two years)?

[0 = once a day, 1 = twice a week, 2 = once a week, 3 = twice a month, 4 = once a month, 5 = once every 2nd month, 6 = once every 3 months.]

2. How close is (was) the working relationship between your division and this division?

[0 = "Very close, practically like being in the same work group," 3 = "Somewhat close, like discussing and solving issues together," 6 = "Distant, like an arm's-length delivery of the input".]

Noncodified Knowledge

1. How well documented was the knowledge that your team leveraged from this division? Consider all the knowledge.

[0 = It was very well documented, 3 = It was somewhat well documented, 6 = It was not well documented.]

2. Was all this knowledge sufficiently explained to your team in writing (in code comments, written reports, manuals, e-mails, faxes, etc.)?

[0 = All of it was, 3 = Half of it was, 6 = None of it was.]

3. What type of knowledge came from this division?

[0 = Mainly reports, manuals, documents, self-explanatory software, etc., 3 = Half know-how and half reports/documents, 6 = Mainly personal practical know-how, tricks of the trade.]