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Can Informal Communication Networks Disrupt Coordination in New Product Development Projects?

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This paper investigates how the structure of the informal communication network that results from efforts to coordinate task interdependence between design teams in complex product development projects moderates the effect of task interdependence on interteam communication. Drawing on theoretical mechanisms from the social network and knowledge transfer literature, as well as on recent empirical advances in exponential random graphs models of social networks, we examine how the presence of a common third party in the communication network affects the likelihood of technical communication between interdependent teams designing the components of a large commercial aircraft engine. Although task interdependence has a strong and significant effect on the likelihood of communication between teams, this effect is moderated by the presence of common third parties. The nature of this moderation depends on the position of the common third party within the triadic communication structure. When the common third party seats in the middle of a communication chain between the potential source and the potential recipient of technical communication, its presence increases the likelihood of communication between these two teams. However, when the communication between the source and recipient can trigger cyclic exchanges between the three teams, the presence of the third party reduces the likelihood of communication between the two interdependent teams, increasing the risk of coordination disruptions. We discuss the implications of our findings on the literature of intraorganizational networks in new product development.

Keywords: interteam communication; new product development; social networks; triads; closure; exponential random graph models (ERGMs)

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1. Introduction

Since the pioneering work by Allen (1977), organizational scholars have highlighted the crucial role of informal communication networks in new product development organizations. Because task-related (informal) interteam communication can help teams coordinate interdependent tasks, a proper understanding of such communication patterns has been recognized as a key element in improving the performance of new product development organizations (Tushman 1977, Tushman and Katz 1980, Ancona and Caldwell 1992, Brown and Eisenhardt 1995, Reagans and Zuckerman 2001, Reagans et al. 2004, Lomi and Pattison 2006). The importance of understanding informal communication between teams in new product development organizations became even more apparent once Henderson and Clark (1990, p. 15) stated that both formal and informal communication channels are “the relationships around which the organization builds [product] architectural knowledge” and elaborated on the consequences of a poor understanding of such channels for incumbent organizations developing complex products while facing architectural innovation.

Researchers have documented well the effect of task interdependence on predicting interteam communication patterns in new product development organizations. This line of research has shown that the network of informal communication between teams aligns closely with the network of task interdependence (e.g., see Morelli et al. 1995, Terwiesch et al. 2002, Sosa et al. 2004, Cataldo et al. 2006, Sosa 2008, Gokpinar et al. 2010). Yet the *alignment* of task interdependence and informal communication networks is not perfect, and this might have important consequences for organizations’ capability to achieve their goals in their new product development efforts (Gargiulo and Benassi 2000, Sosa et al. 2004, Gokpinar et al. 2010). Scholars have shown that the alignment between the two networks can be moderated by spatial arrangements (Allen 1977, 2004; Van den Bulte and Moenaert 1998) and by the formal organization structure (Nadler and Tushman 1997, Sosa et al. 2004). Yet less attention has been paid to the possibility that the alignment could be moderated by the very structure of the informal communication network (McEvily et al. 2014). This possibility, however, is fully

consistent with the fact that the presence or absence of a given tie in a communication network may depend on the presence or absence of other ties in the same network (Contractor et al. 2006). In particular, we are interested in understanding how the presence of common third parties in the communication network may moderate the effect of task interdependence on predicting communication between teams in new product development efforts. Studying such a moderating effect is important because they may prompt “mismatches” between interteam communication and task interdependence in ways that are both theoretically interesting and practically relevant for the managers involved.

Mismatches between the network of task interdependencies and the network of interteam communication occur when teams communicate in the absence of task interdependence or when interdependent teams do not communicate (Sosa et al. 2004). Although both types of mismatch are likely to occur, their effect on the product development process is likely to be different. Communication ties in the absence of task interdependence may result in a suboptimal allocation of resources by the teams, in the sense that members could be spending time exchanging information with other teams without an apparent reason to do so. Yet this “excess” in communication is unlikely to be directly harmful to the design process; moreover, there may be unobserved but important reasons for which teams feel compelled to communicate (Gokpinar et al. 2010). The second type of mismatch is potentially more consequential. A lack of communication between two interdependent teams may result in an inadequate exchange of information, which in turn can create coordination disruptions in the design process. Empirical evidence supports this claim. In a study of the vehicle development process in a major automaker, Gokpinar et al. (2010) found that subsystems with abnormally high warranty claims were designed by teams that did not communicate sufficiently with teams in charge of other interdependent subsystems. We are especially interested in understanding how the presence of common third parties in the interteam communication network affects the probability of this latter type of mismatch to occur.

From a theoretical viewpoint, our interest on the effects of common third parties on the likelihood of communication between two interdependent teams puts triads at the center of this study (Simmel 1950). Research on triadic closure suggests that the presence of a common third party should increase the likelihood of communication between two interdependent focal teams (Granovetter 1973, Coleman 1990, Raub and Weesie 1990). This general prediction, however, does not take into consideration the specific triadic configurations defined by the direction of the communication between the focal teams and the common third party. We argue that a close examination of such configurations allows

for a better understanding of how the local communication structure may shape the behavior of the parties involved. Whereas in some cases the presence of a common third party does increase the likelihood of direct communication between the two interdependent focal teams, as predicted by the tendency toward triadic closure in communication networks, in others it may actually inhibit the formation of such a tie, increasing the likelihood that the communication triad would remain open. To develop our arguments, we analyze the different possible directed triadic structures of two interdependent focal teams communicating with a common third-party team and specify the conditions in which the presence of the common third party may increase or decrease the likelihood of communication between the two focal teams.

We test our predictions analyzing communication ties between interdependent teams responsible for designing the components of the Pratt & Whitney PW4098 commercial engine that powers the Boeing 777 twin-engine aircraft (Sosa et al. 2004). Each team was in charge of designing a specific component of the engine, whereas technical interfaces between components determined the structure of task interdependencies between the teams. To conduct our analysis, we relied on recent methodological advances in exponential random graph models (ERGMs) that make it possible to model the endogenous effects of the interteam communication network (Wasserman and Pattison 1996, Snijders et al. 2006, Hunter et al. 2008, Robins et al. 2009; see Lusher et al. 2013 for a review). Our findings support our core arguments. We find that when the common third party falls in the middle of a communication chain between the potential source and the potential recipient of technical communication, its presence *increases* the likelihood of communication between these two teams, creating a classic *transitive* structure. However, the situation is significantly different when the communication between the source and recipient can trigger cyclic exchanges between the three teams. In such a *cyclic* triad, the presence of the common third party actually *reduces* the likelihood of the two teams communicating, despite their task interdependence.

By enhancing our understanding of how common third parties in communication networks may affect the alignment between interteam communication and task interdependence in product development efforts, our paper has implications for organization theory and practicing managers. From a theoretical viewpoint, our results call the attention on the paradox that the same communication network that emerges to help teams coordinate their task interdependence may lead some teams to neglect exchanging information about some of those interdependencies. In doing so, our findings also open venues for a more systematic analysis of how the endogenous dynamics of informal communication networks may influence the effectiveness of such networks in facilitating

coordination between interdependent intraorganizational actors. From a practical standpoint, our findings highlight the importance of attending to situations where, contrary to what is often assumed by managers and engineering scholars (Cataldo et al. 2006, Olson et al. 2009), task interdependence may not trigger the informal communication patterns necessary to coordinate these tasks.

2. Coordination Mechanisms in New Product Development Organizations

Formal organizations seek to structure tasks in ways that minimize coordination requirements and put in place a number of formal mechanisms to meet these requirements (Thompson 1967, Galbraith 1973). In the specific case of engineering organizations developing complex products, efforts to reduce coordination requirements focus on minimizing the number and complexity of the interdependencies between product components without compromising product functionality (Baldwin and Clark 2000). Formal coordination mechanisms involve decisions such as assigning the responsibility for designing product components to design teams, grouping these teams into subsystem groups led by a manager, and introducing special teams to facilitate horizontal coordination across teams designing related components.

Yet formal mechanisms are seldom sufficient to adequately coordinate interdependent tasks. This insufficiency prompts the emergence of informal communication between interdependent teams, which exchange task-related information that helps them coordinate their work (Nadler and Tushman 1997, McEvily et al. 2014). This communication is particularly important in the development of new and complex products. The very novelty and complexity of such products makes it harder to anticipate the nature and the intensity of task interdependencies between the teams, which limits the effectiveness of formal mechanisms in coordinating interdependencies and strengthens the role of informal interteam communication (Henderson and Clark 1990, Sosa et al. 2004, Gokpinar et al. 2010).

Despite the importance of informal communication in helping teams coordinate task interdependencies, our knowledge of the factors that shape the emergence of such communication remains vague. The basic tenet is that the informal communication network between teams should mirror the structure of task interdependencies between these teams (Henderson and Clark 1990). This mirroring results from a process through which a team whose task is affected by the task of another team typically seeks to acquire the relevant information from the second team, which normally provides such information to the first (Sosa et al. 2004, Gokpinar et al. 2010, McCord and Eppinger 1993, Morelli et al. 1995,

Terwiesch et al. 2002). The result is a network of directed communication ties between teams that largely matches the network of task interdependencies between those teams.

Although the relationship between the task interdependence and the communication networks has been documented in a number of occasions (see Colfer and Baldwin 2010 for a review), research has also shown that this relationship is not perfect (Gargiulo and Benassi 2000). In other words, not all interdependence ties are “matched” with communication ties. The mismatches can result from communication between teams in the absence of task interdependence or from lack of communication between interdependent teams (Sosa et al. 2004). These two types of mismatches are not equally important. Communication in the absence of interdependence may result in inefficient allocation of team resources, but it is unlikely to be detrimental in its own right. Failure to exchange information between interdependent teams may be also inconsequential, but the missing exchanges can have disruptive effects on the new product development effort (Gokpinar et al. 2010). From an analytical viewpoint, if the missing communication ties were randomly distributed, their occurrence would not be a fruitful place for theorizing, although they would still be a source of concern for managers. Yet existing organizational and network theories suggest that the absence of communication between interdependent teams may not be random.

Previous research has shown that spatial arrangements, the formal organizational structure, and the strength of the task interdependence affect the likelihood of communication between interdependent teams (Sosa et al. 2004). Physically distant teams are significantly less likely to exchange information than proximate teams are, even in the presence of task interdependence (Allen 2004, Sosa et al. 2002). Members of a formal unit may communicate well with one another, but they are also likely to neglect establishing communication ties across units, generating a “silo effect” that undermines cross-unit coordination (Gulati 2010). The strength of task interdependence also plays an important role in explaining missing communication ties. These missing ties are more likely to correspond to weak task interdependencies (Sosa et al. 2004). Yet scholars have not examined the possibility that the very structure of the informal communication network that is supposed to help organizations coordinate interdependence between teams may itself induce teams to neglect establishing communication ties with other interdependent teams. In particular, if the presence of common third parties prevents the creation of communication ties between interdependent teams, we would be confronted with an interesting paradox: the same communication network that emerges to help teams coordinate their technical interdependencies may be leading some teams to neglect exchanging

information about some of those interdependencies. To understand where and how this may happen, we turn our attention to how the common third-party teams in the communication network may help or hinder the alignment between task interdependence and interteam communication.

3. Mismatched Interdependencies and Common Third Parties

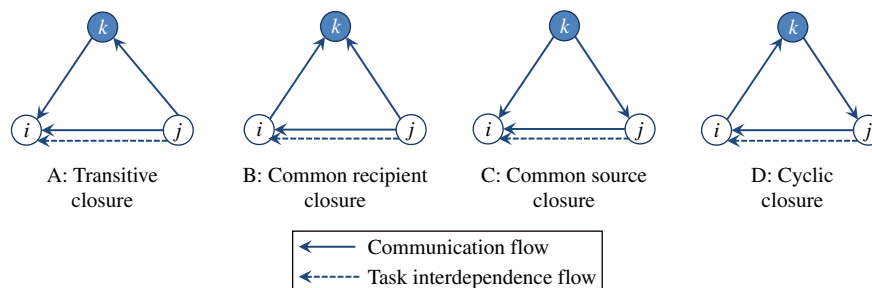
The possibility that the communication network that emerges to coordinate task interdependence between teams could itself affect the likelihood of communication between those teams is consistent with our knowledge of the endogenous mechanisms that shape communication networks—in particular, the effect of common third parties in such networks (Contractor et al. 2006, Robins et al. 2009). The central idea behind these mechanisms is that the communication between the third party and each of the two interdependent teams can affect the propensity of the latter ones to exchange information regarding their own task interdependence. To clarify how these mechanisms operate, we need to examine the different triadic configurations involving the three actors.

Figure 1 depicts the four possible triadic structures with directed communication ties between two interdependent teams i and j and a common third party k . The dashed arrows represent exogenous task interdependence, and the solid lines represent informal (task-related) communication between teams. The direction of the arrows indicates task-dependence flows (e.g., the task of team j affects the task of team i) or flows of task-related information between the respective teams. We focus solely on directed ties to simplify the discussion and to remove the potentially confounding effects of reciprocal ties, although these are controlled for in our empirical analyses. In addition, in our analysis we control for the possibility that the communication ties with the common third party k may (or may not) be accompanied by task interdependence flow. Yet, for the purpose of our argument, we assume that if communication flow occurs it is because the recipient used such information to carry out its design tasks.

Insofar as communication ties help coordinate existing task interdependence, the presence of the interdependence x_{ij} should trigger an informal communication tie y_{ij} through which team j sends relevant information to team i . This communication tie would “match” the exogenous interdependence between these two teams. Yet the presence of the common third party k in the local communication structure may affect the likelihood of the communication tie y_{ij} . In principle, the mechanisms typically associated with triadic closure should increase the baseline tendency to form a communication tie y_{ij} that results from the underlying interdependence tie x_{ij} , irrespective of the direction of the communication ties with the common third party. In other words, the common relationship with k should make it easier for i to seek information from j and compel j to respond favorably to such a request, or even proactively sending this information in some cases. The mechanisms typically invoked include the role of the common third party k in facilitating mutual awareness and trust between i and j (Simmel 1950; Granovetter 1973, 1985; Burt 2005), as well as j 's reputational concerns in the event that k becomes aware of its noncooperative behavior toward i (Coleman 1990, Raub and Weesie 1990). These considerations are supported by empirical evidence. Research on knowledge transfer confirms that the presence of common third parties facilitates the source transferring knowledge to the recipient (Reagans and McEvily 2003) and the recipient acquiring knowledge, even when the knowledge exchange occurs across organizational boundaries (Tortoriello et al. 2012).

Yet the tendency toward triadic closure, and hence the effect of the common third party on the likelihood of a communication tie between the two focal teams, may vary depending on the position this party occupies in the local communication structure, as defined by the specific information flows between the focal teams and the common third party. Specifically, we argue that in some cases the position that the common third party occupies in the local structure may create incentives to discourage the communication between the two focal teams, despite their interdependence. This could prevent the closure of the triad in the communication network, leaving the interdependence x_{ij} without the corresponding

Figure 1 (Color online) Triadic Structures with Two Interdependent Teams and One Common Communication Third Party



communication tie y_{ij} and generating a “mismatched” interdependence, which may disrupt interteam coordination. To understand how this may be the case, we need to focus on how the structural differences across the four triads shown in Figure 1 may affect the role that the third party plays in inducing or inhibiting the communication between the two other interdependent parties. We argue that such differences are rooted in the directionality of the communication flows between the third party k and the two other members of the triad (Robins et al. 2009).

Triad A is a classic transitive triad (Robins et al. 2009). In this triad, the third party k receives information from j and sends information to i . The transitivity logic that operates in most communication networks suggests that this local structure should facilitate the emergence of trust and awareness between i and j , making j more likely to send information to i . That j provides information to k and k provides to i should also make k more aware of i 's need for information from j . In knowledge transfer terms, a common third party that understands the information provided by the source (team j) and also understands the needs of the recipient of information (team i) is likely to facilitate the transfer of information between i and j because it can help the source framing its outputs and the recipient acquiring the knowledge it receives (Reagans and McEvily 2003, Tortoriello et al. 2012). Thus, this local structure allows k to reduce any friction that might exist against information being sent from j to i , which should encourage i and j to communicate, further increasing the trust-enhancing properties of the triad. The mechanism operating here is similar to Burt's (2001) argument on the effect of common third parties on trust and reputation, whereby the common third party “amplifies” the strength of the relationship between the other two members of the triad (see also Burt and Knez 1995). Although it is possible that k might also act as intermediary between i and j , this indirect information is unlikely to completely substitute for firsthand information obtained directly from the source in complex product design projects such as the one studied in this paper. In sum, both the trust-enhancing properties of transitive triads and the ability of the third party, based on its exchanges of information with both i and j , to facilitate conditions for the ease transfer of information from j to i increase the likelihood that j would send technical information to i , closing the communication triad.

Whereas triad A is a classic transitive triad, triads B and C represent other types of transitive triads in which the common third party either receives or sends information to the other two interdependent teams in the triad (Robins et al. 2009). In triad B, the common third party k receives information from both i and j , but it does not send information to either. In triad C, the common third party k sends information to both i and j , but it does not receive information from either. This local structure does not create incentives for k to either encourage or

discourage the communication between the two interdependent teams i and j because the communication between i and j is less likely to affect k 's work in any discernible way. In triad B, team k is downstream of the decisions of both i and j , so once k receives information from them, it can carry on with its task without worrying about what i and j do. Analogously, in triad C, k likely occupies an upstream position in the design chain, so the decisions k makes cascade down to i and j , which would need to adjust their work accordingly, but such adjustments should not impact the work of k . Hence, the presence of a common third party in the communication network is less likely to significantly modify the baseline tendency for the two interdependent teams i and j to communicate in triads B and C.

In triad D, the directionality of the information flows with the common third party is the exact opposite of the flows in triad A. Team j receives information from k , which in turn receives information from i . If team j sends information to i , they would then form a communication pattern characterized by cyclic triadic closure, which is fundamentally different from the other three triads shown in Figure 1. If i makes changes in its design to align it with j 's design, these changes may end up forcing modifications to k 's design, which could in turn cause j to further adjust its design. Such a cyclic pattern may cause the three teams to become involved in an endless chain of information exchanges such as the one depicted in triad D. Although cyclic interdependence patterns are not infrequent in new product development efforts (Smith and Eppinger 1997, Mihm et al. 2003), they are difficult to manage and increase the likelihood of errors (Sosa et al. 2013). Given the difficulties associated with cyclic communication in triads, the third party k is unlikely to induce j to send information to i , because this information may end up forcing k to make further adjustments to its own design. On the contrary, once k has received information from i and understands how i 's design can affect its own, k has an incentive to encourage i and j to “freeze” (or even neglect) their task interdependence to prevent design changes that may lead to subsequent rework in k 's design. Because the cycle would also affect i and j , these teams may also prefer to freeze their interface to avoid triggering the cyclic communication involving k . This approach to managing iterative problem solving has been recognized in the new product development literature (Eppinger et al. 1994, Mihm et al. 2003). When a set of tasks are related to each other in a cyclic manner, the teams involved may decide to “cut” the communication cycle by removing, freezing, or making assumptions about one of the interdependencies in the cycle, which allows them to carry out their activities in a sequential rather than iterative way (Mihm et al. 2003). In this structure, the presence of the common third party k should reduce the likelihood of communication between teams j and i .

The previous discussion suggests that we should expect the influence of a common third party on the baseline tendency for two interdependent focal teams to communicate to vary with the position it occupies in its triadic structure. When the third party falls in the middle of a communication chain whose closure would result in a transitive triad, the third party's presence is likely to amplify the awareness of the interdependence between the two focal teams and reduce any friction that may prevent the information exchange to take place, thus inducing the exchange of technical information about their interdependence. Conversely, when the third party falls in the middle of a communication cycle whose closure is likely to be detrimental to this third party, the third party may have an incentive to encourage "freezing" the interdependence between the two focal teams to avoid changes that may cycle back and affect the third party's work. Hence, the presence of a common third party may end up hindering the communication between the two focal teams when this communication would result in a cyclic triad.

Finding empirical evidence to test the predicted effects of common third parties on the likelihood of communication between interdependent teams is not straightforward, however. The very nature of the endogenous mechanisms discussed in this paper makes standard statistical techniques inappropriate for testing for the presence of these effects. Fortunately, recent advances in the use of ERGMs allows for testing whether the observed frequency of a given structural configuration in a network is significantly different from what one would expect had this configuration occurred randomly, after controlling for appropriate endogenous and exogenous effects. In the context of this paper, the configurations of interest are the four triadic structures depicted in Figure 1. If our reasoning is correct, we should observe that the frequency of triad A is significantly higher than expected, indicating a tendency for communication closure in this triad. We should also observe that the frequency of triad D is significantly lower than expected, indicating a tendency for cyclic triads to remain "open." Finally, the observed frequencies for triads B and C should not depart significantly from randomness, as the effect of the common third party is not clearly discernible in these triads. We now elaborate on how we test these predictions.

4. Data and Methods

We test our predictions by studying the detailed design phase in the development of a large commercial aircraft engine. Figure 2 shows the product architecture and formal organizational structure of the PW4098 engine. Panel (a) is a cross-sectional diagram of the engine that shows the eight subsystems into which the 54 engine components were configured. Panel (b) shows the (flat)

formal organizational structure by which design teams were grouped into subsystems of teams, quasi-mirroring the engine architecture.

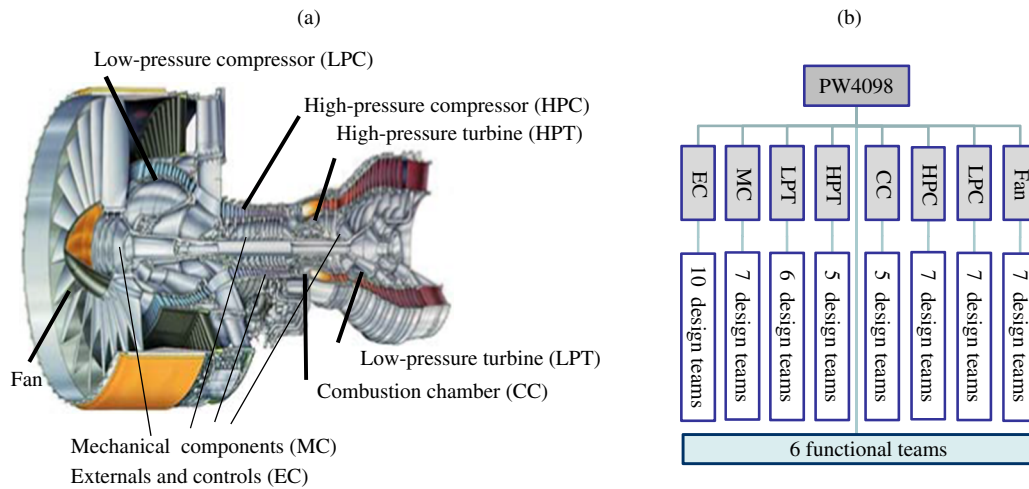
We also captured network data associated with both the organization and the product. We captured the *interteam communication* network of the 60 teams (54 design teams plus 6 functional teams) that designed the engine components and evaluated the overall engine performance as well as the *technical interface* network of the 54 components comprising the engine (Sosa et al. 2004, 2007). We collected data from multiple sources. Data on interteam communications were gathered by interviewing and surveying key members of the teams (Marsden 1990). Product network data were constructed by interviewing several experienced engine architects.

4.1. Interteam Communication Network Data

The informal communication network between the teams is defined by the presence or absence of task-related technical communication between any 2 of the 60 teams (i.e., 54 core design teams plus 6 functional teams) involved in the 10-month detailed design phase of the development process. Our focus on technical task-related interactions is akin to what Allen (1977) and Morelli et al. (1995) defined as "coordination-type communication." The fact that the design of each engine component depends in complex ways on the design of some other components as well as the stringent functional requirements of a product that needs to operate faultlessly in extreme conditions highlights the importance of direct communication between teams to adequately understand the effects that design choices might have on product performance. Although we acknowledge that various types of interteam technical information flows are likely to exist during the design of complex systems, we did not try to distinguish between specific types of technical exchanges and focused instead on an overarching measure that captures all these possible technical exchanges in a single indicator. Doing so was both consistent with previous research studying technical communication in engineering organizations (Allen 1977, McCord and Eppinger 1993, Morelli et al. 1995) and important to avoid posing insurmountable cognitive hurdles to our respondents that could jeopardize the quality of the data.

We measured the presence of technical communication between teams through a questionnaire addressed to team leaders and validated (or revised, when necessary) their responses by interviewing at least one other key member of each team. Presentations describing the terminology and overall objective of the data collection were made in two sessions to more than two-thirds of the respondents; the others were later briefed individually. Respondents were presented with the roster of the 54 design and 6 functional teams and asked to report if they had received nontrivial technical information from each of the other teams during the design phase of the project.

Figure 2 (Color online) The (a) Aircraft Engine Studied and (b) Formal Organizational Structure of the Project



Respondents were encouraged to focus on technical information exchanges that actually took place (i.e., “how it was,” not “how it should have been”) and that contributed to “fulfil[ing] the functional requirement of their component design or program goals” (Rowles 1999, p. 51). We were able to obtain responses from 57 of the 60 teams. The three teams whose direct responses were missing were the interface team at Boeing (one of the six functional teams), one team in the high-pressure compressor subsystem group, and one team in the externals and controls subsystem group. Yet because these teams were identified as information providers by other teams in the development process, we did not exclude them from the network. We estimated all our models excluding the three missing teams, and the results were consistent with the ones reported here.

Consistent with previous research on technical communication (e.g., Allen 1977, Morelli et al. 1995, Lomi and Pattison 2006, Rank et al. 2010), we used a dichotomous definition of interteam communication and assumed that relevant communication did take place insofar as team i (the recipient) acknowledged receiving some technical information from team j (the source). Based on these data, we reconstructed the informal technical communication network $\{y\}$ among the 60 teams involved in the project, where each element y_{ij} of $\{y\}$ captures the transfer of technical communication from team j (the source) to team i (the recipient). The resulting communication network contains 680 directed nonzero interteam communication ties ($y_{ij} = 1$) among the 60 teams—that is, 19% of all possible interteam communication ties.

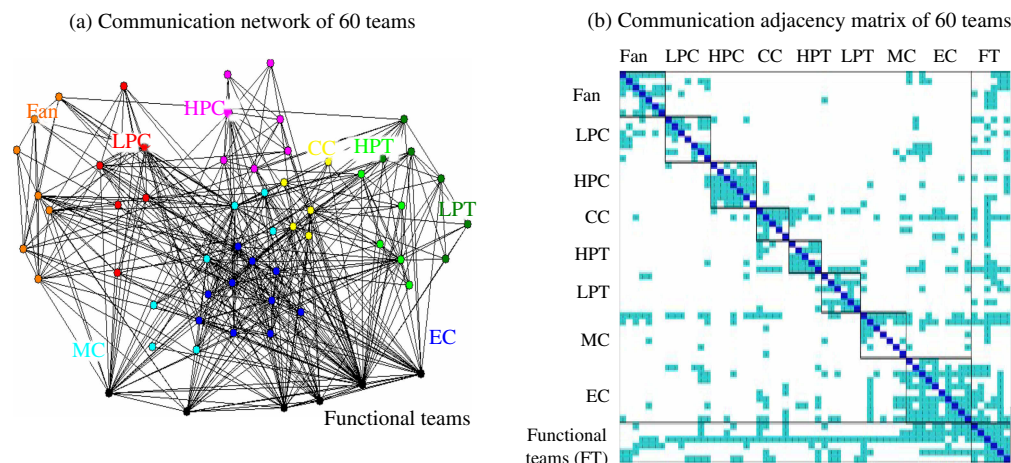
Figure 3, panels (a) and (b) exhibit the team communication network and its corresponding adjacency matrix. In panel (a), each node of the network is shaded according to subsystem membership, and each link indicates technical communication between two teams. In

panel (b), a nonzero cell of the adjacency matrix captures a directed interteam technical communication.

4.2. Product Network Data

Our product data capture the breakdown of the engine structure into 8 subsystems and 54 components, as well as the five types of design dependencies among those components: spatial constraint, structural constraint as a result of transfer of loads, exchange of material, exchange of energy, and exchange of information, as identified by the system engineers. Even though such a detailed map of the product architecture was not available at the project’s onset, design teams shared a common understanding of (i) the engine’s division into subsystems and components and (ii) the relevant technical interfaces between their own components and the components designed by other teams. Each technical interface x_{ij} is a function of a vector of the five design dependencies that capture the various types of technical linkages going from component j to component i (see Sosa et al. 2007 for details). In our analysis, we are concerned with the presence or absence of a technical interface; therefore, $x_{ij} = 1$ if the design of component i depends on the design of component j ; otherwise, $x_{ij} = 0$. There were 569 technical interfaces between the 54 components identified by system architects. This means that 20% of the theoretically possible interfaces between components were actually present in the project.

Figure 4, panels (a) and (b) exhibit the component interface network and its corresponding technical interface matrix. In panel (a), each node of the 54-node network is shaded according to subsystem membership, with each link representing a technical interface between two components. In panel (b), a nonzero cell in the technical interface matrix represent a directed technical interface between two engine components. The technical interface matrix shown in panel (b) quasi-mirrors the adjacency matrix shown in Figure 3, panel (b) because

Figure 3 (Color online) Inter-team Technical Communication Network

their elements are identically sequenced so that the first 54 elements of the adjacency matrix (the 54 design teams in the organization) mirror the 54 elements in the technical interface matrix (the 54 engine components designed by each of the 54 design teams).

4.3. Variables

We model the observed network of interteam technical communication $\{y\}$ between the 54 design teams (which is the dependent variable in the analysis) as a function of both exogenous and endogenous variables. The key exogenous variables comprise the *technical interface network*, which captures the presence of a directed technical interface x_{ij} between each pair of components in the product and therefore indicates the existence of task interdependence between two teams. In addition, there are a number of exogenous controls described below. The endogenous variables are the patterns of interteam communications related to any dyad in the interteam communication network. Because the phenomenon of interest—the moderating role that common third parties may have on the effect of task interdependence in predicting interteam communication—involves both the exogenous technical interface network and the endogenous interteam communication network, we must describe the variables that test our predictions along with the statistical network modeling approach described in the next section.

4.3.1. Exogenous Nodal Variables.

- *Component redesign*: An important factor that affects both a team's workload and the need to communicate with other interdependent teams is the novelty of the team's component. The more novel a component with respect to the prior generation, the more likely it will involve extra work for the team, and the more likely it will affect interfaces with adjacent components. By contrast, components that carry over a significant portion of design content from previous engine models decrease

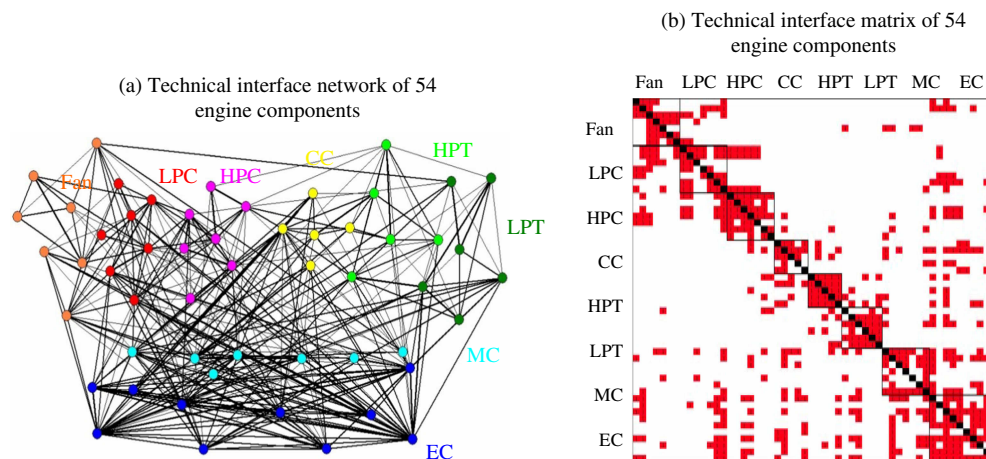
the demand for attention to associated interfaces. We capture this factor by measuring component redesign as the percentage of novel design content in a component relative to its design in the product's previous version. Because it is impossible to determine the exact amount of redesign in a component, we relied on estimates provided by the team leader responsible for the design of each component.

- *Component complexity*: Another component attribute that can affect the team's workload is its internal complexity. We measure a component's complexity in terms of its estimated number of distinct parts. For this estimate we relied on the experience of one of the authors, who is a design expert with substantial experience in similar engine programs and who also reviewed the design work for this particular project.

- *Component connectivity*: The component connectivity is simply the number of incoming and outgoing technical interfaces of each component in a dyad, irrespective of their strength. For each component, this measure counts the number of components with which it shares at least one design dependency, and it is thus equivalent to the "degree" of the component in the technical interface network.

- *Team size*: The team's capacity to communicate with others might well be affected by the resources available to the team. Because managers, when allocating resources to design teams, may take into account the workload entailed by component characteristics and by its interfaces with other engine components, the effects the communication network structures may be confounded by the effects of the resources available to the team. To control for this possibility, we include a four-point ordinal variable that accounts for the manpower resources allocated to teams. Although we were unable to collect precise data on team size (which, in any case, varied throughout different stages of the process), we did obtain a qualitative assessment of team size based on one author's direct experience in the project.

Figure 4 (Color online) Technical Interface Network of 54 Engine Components



- *Subsystem group membership*: Because each design team is formally assigned to a subsystem-level group, teams in the same group might share some characteristics that affect their ability to attend to technical interfaces. These teams will be also part of the same formal coordination structure, with their leaders reporting to the manager responsible for the subsystem. For instance, the seven teams that formed the fan group share technical expertise and experience relevant to the design of fan components, which is different from that of design teams responsible for components of the low-pressure compressor or high-pressure turbine subsystems. On the organizational side, teams in the same subsystem group share a subsystem manager who is responsible for planning and control of resources. All these factors create “silo” effects that foster communications between teams within a subsystem while hindering communications between design teams that belong to different subsystems (Allen 1977, Sosa et al. 2004). To account for this, we created a categorical nodal variable that when entered in our statistical model allows us to control for whether or not any pair of design teams belong to the same subsystem group.

Table 1 shows descriptive statistics and correlation coefficients of the continuous nodal variables used in our analysis.

Table 1 Descriptive Statistics and Pairwise Correlations of Exogenous Nodal Variables

Variable	Mean	S.D.	1	2	3
1. <i>Component redesign</i>	0.487	0.333	1.000		
2. <i>Component complexity</i>	41.593	66.189	−0.334*	1.000	
3. <i>Component connectivity</i>	13.074	6.434	−0.217*	0.577*	1.000
4. <i>Team size</i>	2.444	0.925	0.142	0.308*	0.533*

Note. $N = 54$.

* $p < 0.05$.

4.3.2. Exogenous Dyadic Variables.

- *Technical interface strength*: Our statistical modeling approach takes directly into account the effect of task interdependence as captured by the presence or absence of a technical interface going from component i to component j . In addition, we include a dyadic control for the strength of the technical interface that is equal to the sum of the nonzero directional dependencies from component j to i .

- *Functional third parties*: As mentioned previously, the project studied included the participation of six functional teams that were not responsible for the design of any engine component. Hence, for the purpose of our analysis, we consider these teams to be exogenous to the core network of 54 design teams. Nonetheless, to account for the possible influence of these functional teams on the interteam communication patterns of the 54 design teams, we count the number of functional teams that act as common third-party teams between any pair of design teams i and j .

5. Statistical Network Analysis

A standard tenet in network analysis is that the presence or absence of a relationship between two actors in a network is not independent of the structure of that same network. This endogenous nature of the statistical relationship between the network structure and the presence or absence of specific ties within this same network makes traditional statistical techniques inappropriate to test our hypotheses. Hence, we resort to ERGMs, also known as p^* models (refer to Lusher et al. 2013 for a comprehensive review). In essence, ERGMs allow for modeling an observed network—in our case, the binary network of technical communication among the 54 design teams—as a function of both exogenous parameters (i.e., the attributes of both teams and components) and endogenous parameters (e.g., the number of ties, the number of reciprocated ties, the number of transitive triads in the communication network).

This approach allows us to obtain reliable estimates of the effect of task interdependence on the probability of observing an interteam communication tie as well as to examine how the presence of common third parties moderates such an effect, net of the effect of other endogenous and exogenous factors that might also affect that probability (Contractor et al. 2006).

To estimate the effects of interest associated with each triad shown in Figure 1, we estimate a probabilistic model of the bivariate network formed by the interteam communication network of design teams and the exogenous technical interface network of engine components. As in any bivariate ERGM, our model specification can be divided into within-network effects, based on ties from one network, and cross-network effects, based on ties from both networks (Lusher et al. 2013, Chapter 10). In our case, the within-network effects correspond to configurations of the communication network. The cross-network effects correspond to the “entrainment” (or co-occurrence in the same direction) of an interteam communication and a technical interface (which captures the effect of task interdependence on the probability of observing an interteam communication), as well as triadic configurations such as the ones shown in Figure 1. Because the technical interface network is exogenous (or *fixed*), its “within-network parameters” are not estimated. For estimation purposes, we use XPNNet (Wang et al. 2009).

Our model considers interteam communication as a random variable. Hence, for i and j (which are distinct teams of the network of 54 design teams), we consider a random variable Y_{ij} where $Y_{ij} = 1$ if design team i (the recipient) receives technical information from team j (the source) and where $Y_{ij} = 0$ otherwise. We specify y_{ij} as the observed value of Y_{ij} , where Y is the matrix of all Y_{ij} variables and y is the matrix of observed ties (i.e., the binary adjacency matrix corresponding to the interteam technical communication network of 54 design teams). Intuitively, our model predicts the probability of team i receiving technical information from team j as a function of (i) within-communication-network configurations; (ii) cross-network configurations that capture certain types of associations between the communication network and the technical interface network, including the triadic cross-network configurations of interest (shown in Figure 1); (iii) certain attributes of the design teams (nodal effects); and (iv) and certain attributes of the dyads (dyadic effects). Formally, the model we estimate takes the following form:

$$\begin{aligned} \Pr(Y = y \mid X = x, W = w, D = d) \\ &= \frac{1}{\kappa} \exp(\text{WithinCommEffects} + \text{CrossNetworkEffects} \\ &\quad + \text{NodalEffects} + \text{DyadicEffects}) \\ &= \frac{1}{\kappa} \exp\left(\sum_k \theta_k Z_k(y, x, w, d)\right), \end{aligned} \quad (1)$$

where (i) Y is a random network of size 54 with possible ties Y_{ij} and y being a realization of Y ; (ii) X is the 54×54 binary matrix of technical interfaces with realization x ; (iii) W is a $54 \times p$ array of nodal attributes (e.g., component redesign, component complexity, team size) with realization w ; (iv) D is a $54 \times 54 \times p$ array of dyadic attributes (i.e., strength of technical interfaces, number of common functional third parties) with realization d ; (v) $Z_k(y, x, w, d)$ is a network statistic that can be computed for a particular y that may also depend on the matrix x of technical interfaces, the array w of nodal attributes, and the array d of dyadic attributes; and (vi) κ is a normalizing quantity to ensure that Equation (1) is a proper probability distribution.



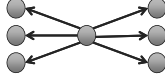
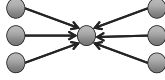
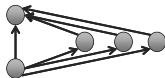
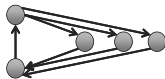
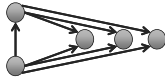
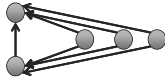
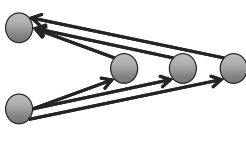
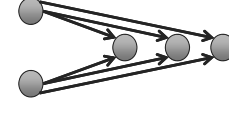
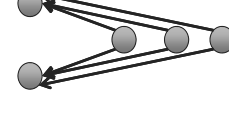

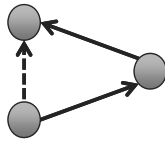
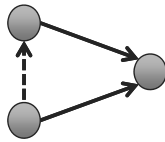
As mentioned above, our model includes four types of parameters, which define the family of probability distributions that can generate the observed interteam communication network. The coefficient parameters (θ_k) in the model are estimated to maximize the fit between the random networks and the observed data. Table 2 describes qualitatively each parameter included in the model and the tendency that it accounts for. Given the novelty of the cross-network triadic effects included in our models, we describe the network statistics of such parameters in the table.

Table 2 describes 11 interteam within-communication-network parameters that capture network configurations in a typical intraorganizational network (Contractor et al. 2006, Rank et al. 2010, Lomi et al. 2014). To this end, we follow Robins et al. (2009) in specifying the various configurations in which both closure and two-path communications can occur because they capture the various ways in which common third-party teams may influence the communication between a focal pair of design teams.

Table 2 also describes the cross-network effects included in our model. First, we include the effect of entrainment of interteam communication and technical interface between any pair of teams to test for the effect of task interdependence. Then, we describe two sets of cross-network triadic effects. The first set captures the overall tendency of a technical interface to be surrounded by common third parties in the communication network. Because our network data are directed, there are four possible ways in which a common third party can communicate with interdependent teams i and j whose components share a technical interface (Robins et al. 2009). As specified by the parameters' network statistics, this set of cross-network triads consists merely of controls in our models because they count the number of occurrences of such configurations in our data *without* capturing whether a communication between i and j takes place.

To account for the moderating effect of common third parties on the effect of task interdependence, we must define a second set of cross-network triadic statistics that accounts precisely for the four triadic configurations

Table 2 Summary of Within-Network and Cross-Network Effects Included in Our ERGMs

Parameter	Visual description	What it accounts for
Within-communication-network effects		
<i>Arc</i>		Baseline tendency for interteam communication to occur
<i>Reciprocity</i>		Tendency to reciprocate communication
<i>Source spread</i>		Tendency for variation in the degree to which a team sends technical information to others
<i>Recipient spread</i>		Tendency for variation in the degree to which a team receives technical information from others
<i>Transitive path closure in communication network (AT-T)</i>		Tendency for transitive path closure to occur in the interteam communication network
<i>Cyclic closure in communication network (AT-C)</i>		Tendency for multiple cyclic structures to occur in the interteam communication network
<i>Activity closure in communication network (AT-D)</i>		Tendency for shared activity closure (teams <i>i</i> and <i>j</i> providing information to a <i>common recipient</i>) to occur in the interteam communication network
<i>Popularity closure in communication network (AT-U)</i>		Tendency for shared popularity closure (teams <i>i</i> and <i>j</i> receiving information from a <i>common source</i>) to occur in the interteam communication network
<i>Multiple two-path in communication network (A2P-T)</i>		Tendency for multiple two-path communications to occur in the interteam communication network
<i>Two-path activity in communication network (A2P-D)</i>		Tendency for shared activity (with a <i>common recipient</i>) to occur in the interteam communication network
<i>Two-path popularity in communication network (A2P-U)</i>		Tendency for shared popularity (with a <i>common source</i>) to occur in the interteam communication network
Cross-network effects		
(Interteam communication (Network A) \longrightarrow Technical interface (Network B) \dashrightarrow)		
<i>Entrainment of interteam communication and technical interface (Arc AB)</i>		Tendency for interteam communication and technical interface to co-occur in the same direction; this tests for the baseline effect of task interdependence
Cross-network triadic effects between a focal interface and communications with a common third party		
<i>Cross-network transitive triad (T-ABA)</i>		Overall tendency for cross-network transitivity to occur; the network statistic for this network configuration is $\sum_i^{54} \sum_j^{54} (\sum_k^{54} Y_{ik} Y_{kj}) X_{ij}$
<i>Cross-network common recipient triad (T-AAB)</i>		Overall tendency for a cross-network common recipient triad to occur; the network statistic for this network configuration is $\sum_i^{54} \sum_j^{54} (\sum_k^{54} Y'_{ik} Y_{kj}) X_{ij}$

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Table 2 (cont'd)

Parameter	Visual description	What it accounts for
Cross-network common-source triad (T-BAA)		Overall tendency for a cross-network common source triad to occur; the network statistic for this network configuration is $\sum_i^{54} \sum_j^{54} (\sum_k^{54} y_{ik} y'_{kj}) x_{ij}$
Cross-network cyclic triad (C-AAB)		Overall tendency for a cross-network cycle to occur; the network statistic for this network configuration is $\sum_i^{54} \sum_j^{54} (\sum_k^{54} y'_{ik} y_{kj}) x_{ij}$
Moderating effects of a common third party on the effect of task interdependence		
Cross-network transitive closure (triad A in Figure 1)		Tendency for triad A (shown in Figure 1) to occur; the network statistic for this network configuration is $\sum_i^{54} \sum_j^{54} (\sum_k^N y_{ik} y_{kj}) x_{ij} y_{ij}$
Cross-network common recipient closure (triad B in Figure 1)		Tendency for triad B (shown in Figure 1) to occur; the network statistic for this network configuration is $\sum_i^{54} \sum_j^{54} (\sum_k^N y'_{ik} y_{kj}) x_{ij} y_{ij}$
Cross-network common source closure (triad C in Figure 1)		Tendency for triad C (shown in Figure 1) to occur; the network statistic for this network configuration is $\sum_i^{54} \sum_j^{54} (\sum_k^N y_{ik} y'_{kj}) x_{ij} y_{ij}$
Cross-network cyclic closure (triad D in Figure 1)		Tendency for triad D (shown in Figure 1) to occur; the network statistic for this network configuration is $\sum_i^{54} \sum_j^{54} (\sum_k^N y'_{ik} y_{kj}) x_{ij} y_{ij}$
Categorical nodal effects		
Communication within subsystem group		Tendency for communication to occur between teams in the same subsystem group
Entrainment within subsystem group		Tendency for co-occurrence to occur between teams in the same subsystem group
Continuous nodal effects		
Communication with sum of attributes		Tendency for communication to occur between teams with higher values of a specific continuous attribute
Entrainment with sum of attributes		Tendency for co-occurrence to occur between teams with higher values of a specific continuous attribute
Dyadic effects (Dyadic covariate =)		
Communication with dyadic attributes		Tendency for communication to occur between teams with higher values of a specific dyadic attribute
Entrainment with dyadic attributes		Tendency for co-occurrence to occur between teams with higher values of a specific dyadic attribute

shown in Figure 1. The network statistics of these triadic configurations are also included in Table 2. Contrary to the network statistics of the cross-network triadic parameters described above, this second set of network statistics only accounts for the technical interface

between *i* and *j* when *matched* by the corresponding interteam communication between *i* and *j*.¹ Estimating the coefficients for this latter set of triadic parameters allows us to test our key predictions.² Specifically, we expect to observe a positive coefficient for the effect

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of cross-network transitive closure (triad A in Figure 1) and a negative coefficient for the effect of cross-network cyclic closure (triad D in Figure 1).

Finally, Table 2 includes categorical and continuous node- and dyadic-level effects to capture whether exogenous factors such as the membership of a design team in one of the subsystem groups (a categorical nodal attribute), the complexity of the component a team is designing (a continuous nodal attribute), and the number of common functional third parties between a pair of design teams (a dyadic attribute) influence the likelihood of a communication tie and of an entrainment tie.

6. Results

Table 3 presents ERGMs estimating the probability of observing a directed technical communication tie between two design teams in the project studied. The estimates were obtained using the Markov chain Monte Carlo maximum likelihood estimation (MCMCMLE) procedure implemented in XPNNet (Wang et al. 2009). Although the model of interest is Model 4 (the full model), we also present partial models to introduce sequentially the various effects that our models account for. After describing the results, we also discuss how we assessed their robustness and the models' goodness of fit to the data.

Model 1 in Table 3 includes within-network effects that capture the basic endogenous tendencies (within the communication network) to form ties. To that end, this model suggests that the interteam communication network exhibits a positive tendency to form reciprocated ties, to form (short-path) transitive closure, and to form two-path communications resulting from common third parties that receive information from two teams that do not communicate with each other. Other effects are either nonsignificant or become nonsignificant in subsequent models that include cross-network triadic effects. Most importantly, Model 1 includes a dyadic cross-network effect that captures the baseline effect of task interdependence. The positive and significant coefficient for the entrainment of interteam communication and technical interface provides empirical evidence for the effect of task interdependence on communication: teams designing interdependent components are more likely to communicate. Holding other variables constant (in Model 1), the baseline probability of observing a directed communication tie between two design teams is 12 times higher if their components are connected by a technical interface ($e^{2.505} = 12.2$); this probability is 17 times higher in the full model.

Model 2 includes various exogenous nodal and dyadic effects. As described in Table 2, for each of these exogenous effects, two parameters are estimated. One parameter captures how the exogenous attribute influences the

tendency of team i receiving information from team j , whereas the other parameter captures how the exogenous attribute moderates the tendency for entrainment of interteam communication and the technical interface to occur along interface ij . For instance, the effects of *formal* organizational subsystem group boundaries (a categorical nodal effect) are captured by first showing a positive and significant (1.667, $p < 0.001$) greater tendency for teams that were part of the same subsystem organizational group to communicate than for those who belonged to different subsystem groups, independent of whether or not their components shared a technical interface.

The moderating effect that organizational boundaries have on the entrainment of the technical interface and interteam communication (Sosa et al. 2004) is captured by the negative and significant coefficient for the communication/interface entrainment (-1.106 , $p < 0.001$), which suggests that the predictive power of technical interfaces diminishes within subsystem group boundaries, where other forces associated with the formal organizational structure play an important role in triggering interteam communication. This is consistent with the fact that teams that belong to the same subsystem group are much more likely to communicate in the absence of a technical interface than those from different subsystems do (Lessard and Zaheer 1996). Within subsystems, 20% of the potential communication ties between teams whose components do not share an interface are actually realized; the corresponding figure for teams across subsystems is only 2%.

Model 2 also includes various (continuous) nodal effects to control for the possibility that both interteam communication and communication/interface entrainment may be explained by the properties of the engine components designed by teams i and j or by the properties of the teams. These controls, however, do not have much influence on the patterns of interteam communication, nor do they moderate the effect of task interdependence. Only team size seems to have a significant effect on interteam communication: bigger teams are more likely to communicate. Of the two dyadic effects, the number of functional teams that act as a common third party between teams i and j shows a positive effect on the communication between these teams. The more two teams communicate with any of the six functional teams, the more likely they are to communicate with each other. However, communication with functional teams does not seem to influence the effect of task interdependence on interteam communication.

Model 3 includes a set of controls that capture cross-network triadic effects. These effects account for the tendency for a technical interface to be surrounded by common third-party teams in the communication network (see Table 2 for a visual description of these effects). Model 3 shows that there is a negative tendency

Table 3 Maximum Likelihood Estimates of ERGMs for Interteam Communication

Variable	Model 1	Model 2	Model 3	Model 4
Within-communication-network effects				
<i>Arc</i>	−2.905** (1.213)	−4.054** (1.860)	−3.740* (1.979)	−4.089** (2.036)
<i>Reciprocity</i>	2.505*** (0.284)	2.229*** (0.301)	2.505*** (0.319)	2.629*** (0.338)
<i>Source spread</i>	0.001 (0.644)	−0.176 (0.770)	−0.455 (0.953)	−0.349 (0.954)
<i>Recipient spread</i>	−0.944* (0.529)	−0.916 (0.664)	−0.784 (0.573)	−0.775 (0.59)
<i>AT-T</i>	0.728*** (0.227)	0.620** (0.246)	0.472** (0.238)	0.560** (0.242)
<i>AT-C</i>	−0.422*** (0.093)	−0.424*** (0.113)	−0.116 (0.139)	−0.125 (0.149)
<i>AT-D</i>	0.099 (0.143)	0.048 (0.165)	−0.088 (0.154)	−0.137 (0.158)
<i>AT-U</i>	0.318* (0.174)	0.289 (0.198)	0.194 (0.173)	0.216 (0.176)
<i>A2P-T</i>	−0.086*** (0.026)	−0.077*** (0.029)	−0.020 (0.032)	−0.012 (0.031)
<i>A2P-D</i>	0.117*** (0.014)	0.136*** (0.020)	0.092*** (0.021)	0.105*** (0.025)
<i>A2P-U</i>	−0.039 (0.053)	−0.006 (0.053)	−0.012 (0.056)	−0.015 (0.058)
Task interdependence effect				
<i>Arc AB</i>	2.505*** (0.152)	2.901*** (0.844)	2.823*** (0.885)	2.842*** (0.924)
Nodal categorical effects				
<i>Communication within subsystem group</i>		1.697*** (0.343)	1.727*** (0.350)	1.708*** (0.327)
<i>Entrainment within subsystem group</i>		−1.106*** (0.387)	−1.136*** (0.391)	−1.231*** (0.413)
Nodal continuous effects				
<i>Communication with sum of component redesign</i>		−0.208 (0.295)	−0.177 (0.284)	−0.180 (0.285)
<i>Entrainment with sum of component redesign</i>		0.190 (0.374)	0.176 (0.378)	0.200 (0.382)
<i>Communication with sum of component complexity</i>		−0.002 (0.002)	−0.001 (0.002)	−0.001 (0.002)
<i>Entrainment with sum of component complexity</i>		0.000 (0.002)	0.000 (0.002)	0.001 (0.002)
<i>Communication with sum of component complexity</i>		−0.015 (0.019)	−0.028 (0.022)	−0.028 (0.022)
<i>Entrainment with sum of component complexity</i>		0.024 (0.023)	0.026 (0.025)	0.016 (0.024)
<i>Communication with sum of team size</i>		0.329*** (0.126)	0.331*** (0.127)	0.331*** (0.128)
<i>Entrainment with sum of team size</i>		−0.219 (0.159)	−0.260* (0.156)	−0.272* (0.162)
Dyadic effects				
<i>Communication with functional third parties</i>		0.224** (0.108)	0.162 (0.111)	0.157 (0.124)
<i>Entrainment with functional third parties</i>		0.021 (0.143)	0.042 (0.041)	−0.011 (0.162)
<i>Communication with technical interface strength</i>		0.023 (0.040)	0.085 (0.154)	0.036 (0.043)
Cross-network triadic effects between a focal interface and communications with a common third party				
<i>T-ABA</i>			−0.075 (0.067)	−0.090 (0.083)
<i>T-AAB</i>			0.182*** (0.033)	0.151*** (0.041)
<i>T-BAA</i>			0.069 (0.044)	0.037 (0.056)
<i>C-AAB</i>			−0.144*** (0.053)	−0.087 (0.061)
Moderating effects of a common third party on the effect of task interdependence				
<i>Cross-network transitive closure (triad A)</i>				0.223** (0.102)
<i>Cross-network common recipient closure (triad B)</i>				0.097 (0.091)
<i>Cross-network common source closure (triad C)</i>				0.085 (0.095)
<i>Cross-network cyclic closure (triad D)</i>				−0.235** (0.100)

Note. Standard errors are given in parentheses.

* $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$ (two-tailed).

for third-party teams to surround technical interfaces in a cyclic triad (C-AAB). Yet this negative tendency becomes nonsignificant in the full model (Model 4). Model 3 also shows that there is a positive tendency for third-party teams to act as a common receiver of information from the other two interdependent teams in the triad (T-AAB). These basic tendencies are important controls because they account for the overall tendencies for these four cross-network triadic configurations to form, but they do *not* test our predictions because they do not account for whether the focal interface is matched by its corresponding interteam communication.

Model 4 tests how the local structure in which the common third-party team is embedded influences the effect of task interdependence on interteam communication. To do so, the model includes four triadic effects that account for the four possible ways in which a common third-party team may interact with a pair of interdependent teams that exchange information in the same direction as their task interdependence (as shown in Figure 1). The coefficients associated with the tendency for triads B and C to form are not significant. This suggests that the presence of a common third party does not significantly moderate the effect of task interdependence on

interteam communication when this party is a common recipient or a common source of information for the interdependent teams, which is consistent with our theorizing. As predicted, there is a *positive* and significant tendency for cross-network transitive closure (triad A in Figure 1) to form (0.223, $p < 0.05$). When the information flowing through the common third-party teams flows in the direction of the focal interface, the third party can facilitate the knowledge transfer between the interdependent teams, which reinforces the effect of task interdependence on the likelihood of communication. Also, as predicted, Model 4 shows that there is a *negative* and significant tendency for cross-network cyclic closure (triad D in Figure 1) to form (-0.235 , $p < 0.05$). This suggests that when a common third party is involved in a potentially cyclic triadic communication structure with two interdependent teams, the presence of this common third party may actually hinder the exchange of information between the interdependent teams, effectively freezing their interdependence.

6.1. Robustness

We test the robustness of our results in several ways. First, our results are robust to the exclusion of any of the exogenous nodal and dyadic effects, as well as to the exclusion of the four cross-network triadic effects that act as controls. Second, we estimated alternative models in which our key variables of interest (i.e., the cross-network closure variables) are calculated taking into account the communications with the six functional teams, and the results are consistent with the ones presented in Table 3. Third, we also estimated the cross-network closure variables considering only communications with the third-party team that were matched by the corresponding technical interface with the common third-party team. The results obtained with this alternative specification were also consistent with the ones presented here. Fourth, we also tested the robustness of our results with alternative specifications of the within-network effects. Our results are robust to the inclusion of Markov parameters for transitive and cyclic triads, as well as to the inclusion of social circuit effects with higher values of the λ parameter (we use $\lambda = 2$ in the models reported here). Finally, our results are also fully robust to the inclusion of a cross-network reciprocity effect (which is not significant in our models), as well as to the inclusion of four additional cross-network triadic effects that account for a focal pair of communicating teams and common third parties in the technical interface network.

6.2. Goodness-of-Fit Evaluation

We examined the goodness of fit of our ERGMs by comparing the structural statistics of the observed network with the corresponding statistics on a sample of networks simulated from the fitted model (Hunter et al. 2008,

Robins et al. 2009). We built our sample out of 10 million simulated networks. Using t -ratios³ from such a sample, we estimated whether the observed graph feature is extreme compared with the simulated distribution. As indicated by Robins et al. (2009, p. 112), “For effects explicitly [included] in the model, good convergence of the estimation algorithm is represented by [t -ratio] values close to zero (less than 0.1 is desirable). For an observed graph feature not included in the model, we decided that a t -ratio less than two in absolute value indicates that the observed feature is not unusual in the estimated graph distribution.” Overall, all our models seem to provide a good fit to our data as indicated not only by t -ratios below 0.1 for all the estimated parameters included in the models but also by t -ratios below 1.0 for all additional structural parameters available in XPNet that were not included in our models. We also verified that the t -ratio of additional nodal and dyadic parameters that were *not* included in our models but were available in XPNet were not unusual in the estimated graph distribution. For Model 4, all such t -ratios were below 2.0.

Our models also seem to replicate well features that are not typically modeled, such as the degree distribution and clustering coefficient (Hunter et al. 2008, Robins et al. 2009). For instance, in the full model (Model 4), the magnitudes of t -ratios for the standard deviations of both in- and out-degree distributions were less than 0.4, whereas the magnitudes of the t -ratios for the skewedness of both in- and out-degree distributions were less than 1.0. For global and alternating clustering coefficients, the magnitudes of the t -ratios were less than 0.3. Overall, our models (and, in particular, Model 4) seem to be consistent with the observed data for the graph properties examined. All goodness-of-fit diagnostics carried out after extensive simulations are available from the authors upon request.

7. Discussion and Conclusions

This paper considers whether the local structure of the informal interteam communication networks in new product development organizations might affect the communication patterns between interdependent teams. Although our findings show that task interdependence is a strong exogenous determinant of the communication network among design teams, we show that this effect can be moderated by the presence of common third parties in this network. Our analysis of task interdependence and informal communication among the teams in charge of designing a major aircraft engine shows that the presence of a common third party in the informal communication network can affect the likelihood of communication between interdependent teams in different ways. Whereas task interdependence creates incentives for two teams to exchange information, their

communication with a common third party affects the likelihood that they will actually do so. The direction of the effect, however, is contingent on the position the common third party occupies in the local communication structure. When the common third party is positioned in the middle of a transitive triad so that it gets information from the potential source and also sends information to the potential recipient, then the local structure enables the third party to be a facilitator of the information exchanged between the source and the receiver in the focal dyad. In such triads, the common third party may alleviate any friction associated with the exchange of knowledge between the source and the recipient (Reagans and McEvily 2003, Tortoriello et al. 2012). In these local structures, the presence of the common third party increases the likelihood of communication between the two focal interdependent teams. However, when the common third party team sits in the middle of a triad that can become cyclic if the two interdependent teams exchanged information, then the presence of the common third party hinders the communication between the two interdependent teams, preventing the formation of the cyclic communication structure. In this case, the presence of the common third party decreases the likelihood of communication between the two interdependent teams, which can increase the risk of coordination disruptions in the product development process.

Our findings highlight an interesting paradox of informal communication networks between interdependent actors. This communication typically results from the actor's efforts to coordinate their interdependence, but we show that, in some circumstances, the emerging local structure of the communication network may affect the likelihood of actors actually engaging in such efforts. In exploring the mechanisms behind these effects, we argue that the position occupied by the common third party in the local structure can make this party a catalyst or an inhibitor of communication between two focal interdependent teams. When the communication between the two interdependent teams results in a typical transitive triad, the local structure is more likely to turn the third party into a catalyst of communication between the interdependent teams. Conversely, when the communication between the two interdependent teams would put the third party in the middle of a communication cycle that can result in an endless iteration in the design chain, the presence of the common third party may actually inhibit the communication between the interdependent teams. It is important, however, to highlight that these mechanisms do not necessarily assume intentionality or even active agency from the parties involved; rather, they are rooted in how the structure of the local communication network shapes the role of the common third party in ways that makes it more or less likely to promote or

inhibit the communication between the two interdependent focal teams.

Our study is based on comprehensive fieldwork that enabled us to collect rich quantitative and qualitative data on the technical interfaces between components of an extremely complex product as well as on the technical communication network among teams responsible for designing the components of that product. The independent measurement of task interdependence between teams—based on the observed technical interfaces between their respective components—provides a unique setting to investigate how the structure of the communication network that emerges to address those technical interfaces may itself moderate the effect of task interdependence in predicting interteam communication. Despite these advantages, the study has three limitations that result from the nature of our data.

First, our data on communication among teams capture only those exchanges that were explicitly related to technical matters. Hence, our communication network may fail to capture informal social interactions between members of different teams—that is, a social network that might exist in addition to the observed technical communication network. However, we note that unobserved social exchanges could pose a problem for our study only if they are largely unrelated to the observed exchanges of technical communication. Such a possibility is not consistent with our qualitative observations of the communication patterns between teams, which suggest that it was rare for social exchanges to occur between teams that did not also communicate for technical reasons. This dynamic is consistent with the idea that teams are preoccupied with their work and hence that social interactions in organized settings will usually stem from encounters triggered by exogenous factors (in this case, interdependencies caused by shared interfaces). In sum, these considerations suggest that the lack of information on purely social exchanges between teams is unlikely to have biased our results. Also related to our measure of technical communication, our data do not allow us to make fine-grained distinctions among various types of technical communication. Unfortunately, given the complexity of the project studied, collecting the interteam communication data at a more granular level was impossible at our research site. Nonetheless, it is important to acknowledge that distinguishing technical communication at a more granular level could have allowed us to test further whether there are some types of technical flows more likely to be responsible for the moderating effects of local structures with a common third party observed in our study.

Second, our measure of interteam technical communication is based on a team's acknowledgment of having received technical information from the source team. Strictly speaking, failure to observe communication between the teams sharing a technical interface

might have resulted from failure of the recipient team to request information or of the source team to supply information, or both. By the same token, observed communication might have resulted from proactive behavior by the source that is acknowledged by the recipient, even in the absence of a specific request. Although our data cannot conclusively discriminate among these situations, our theory does not depend on this discrimination. This is particularly important in the case of the cyclic local structure. Although we argue that the presence of the common third party in this structure hinders the communication between the interdependent focal teams to prevent the emergence of cyclic problem-solving dynamics, we do not stipulate whether this outcome results from a less proactive recipient or from a less compliant source, or both. More generally, our reasoning focuses on how the local communication structure shapes the behaviors of the involved parties in ways that facilitate or hinder their communication, without making assumptions about the specific roles of the source and the recipient in generating these patterns.

Another limitation associated with the way we measure interteam communication is its directionality. In reality, interteam communications are not *purely* directional. For instance, if A talks to B, then B listens to A; this means they are communicating even if they play two different roles. Fortunately, our empirical setting allows us to capture in a reliable and meaningful way the directionality implicit in interteam communications (and intercomponent technical interfaces). The directionality of interteam communication is determined by the impact that the information exchanged had “on the design tasks” of the recipient team. Although this way of establishing directionality in communication is meaningful in our context (and probably meaningful in most contexts where the value of the knowledge transferred is largely valued by the recipient), it is also true that such a directionality does not capture whether the communicating parties were engaged in more or less bidirectional information exchanges. Having said this, and given the strong tendencies for reciprocation in the communication network featured in this study, it is possible that many of the communications were indeed two-way communications. Fortunately, we were able to control for the underlying tendency to reciprocate communication ties in our analysis.

Third, our findings show how the structure of the communication network might affect the behaviors of design teams involved in a complex new product development project, but we cannot say anything regarding the desirability or undesirability of such behaviors. A possible interpretation of our findings is that, given the complexity of the technical interfaces in the PW4098 engine, some teams might have consciously neglected to attend to some interdependencies (in cyclic triads) to focus on other, more critical ones as a way to

allocate team resources more efficiently. Two elements raise doubts about this interpretation, however. First, an additional post hoc analysis (not reported here) did not reveal a significant association between mismatched interfaces in the presence of a common third party and the strength of the mismatched technical interface. Second, anecdotal evidence from our research site suggests that some mismatched interfaces did cause significant rework in subsequent stages of the process. Although we lack systematic data in this respect, these qualitative observations are fully consistent with the results of Gokpinar et al. (2010), who found a significant association between a lack of (or insufficient) communication about technical interfaces and quality issues in the automobile industry.

Despite this evidence, we cannot say that teams were “talking too little” with other teams, as it is indeed possible that omissions to establish a direct communication between two interdependent teams could have sometimes been an efficient way to use scarce team resources. Nor can we say that they were “talking too much.” Although our data do show instances of communication in the absence of technical interfaces, which are disproportionately present within subsystem group boundaries in the formal organizational structure, such communication cannot be dismissed as superfluous because it might have addressed unobserved technical interfaces that were uncovered during the design process or other types of task-related interdependencies not directly traceable to physical interfaces between components. What our results do show is that although the technical interface network largely determines the presence or absence of communication between design teams, deviations from this overall tendency are systematically associated with specific triadic configurations in the structure of the communication network among the teams.

Despite their limitations, our findings have important practical implications for managers seeking to improve the coordination between design teams in complex product development projects. Whereas our study confirms the salience of task interdependence in prompting informal exchanges of technical communication between teams, we also identify situations that can significantly alter this association. This is important because managers (and engineering scholars) often assume that technical interdependence should automatically trigger the communication necessary to coordinate design tasks (Cataldo et al. 2006, Olson et al. 2009). Managers are aware of the unintended effect of formal organizational boundaries in hindering communication between actors that sit across such boundaries. However, the possibility that informal communication networks—often touted as a remedy to the failure of formal organization—would also have unintended consequences that may increase the risk of coordination disruptions in product development

projects has not been considered. In particular, the possibility that the presence of a common third party that participates in potentially cyclic communication patterns can reduce the likelihood of other teams communicating to coordinate their interdependence should prompt managers to pay special attention to identify and manage actors that are likely involved in cycles in the communication network (Sosa et al. 2013). The consequences of not doing so may be significant. Even minor disruptions in coordination may lead to design inadequacies that, although not critical, could affect the performance or durability of the affected components and subsystems, causing significant warranty or service expenses over the life of the product. For example, if a critical component of an aircraft engine (e.g., a turbine airfoil) fails to reach its life expectancy, this will cause additional engine removals for maintenance. For an engine such as the PW4098, a single such removal could cost the customer as much as \$150,000, in addition to the loss of revenues associated with a grounded plane.

In conclusion, we refer to Simon (1996), who suggested that a complex system is difficult to understand because the behavior of the whole depends in nontrivial ways on how its elements interact. In studying the determinants of interteam communications when designing a complex system, we have learned that common third-party teams have a significant moderating influence on the predictive power of the patterns of task interdependence. We have shown that our results have important implications for both theory and practice. They also raise a number of interesting questions. How does the presence of common third parties to a focal technical interface influence the ability of interdependent teams to discover and attend to other relevant interfaces that may also require interteam communication? How do component connectivity and team network structure relate to such important design decisions as component outsourcing and component redesign? With the uprise in open innovation projects, how does the relationship between task interdependence and interteam communication change when development projects are carried out across firm boundaries? In this paper we have described a path that can lead organizational scholars in answering these important questions.

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Endnotes

¹The internal summation of these network statistics is defined up to N , where $N = 54$ so that the triadic configurations considers all 54 design teams as possible common third parties between i and j . However, we can also set $N = 60$ to account for the six functional teams as common third parties. Our results are robust to both specifications.

²To estimate these effects, we consider the two-path statistic associated with these triadic configurations (i.e., the internal summation of these network statistics) as an exogenous dyadic predictor. We then allow XPNET to estimate the interaction of such a dyadic predictor with the term "ArcAB." Considering the two-path statistic to be exogenous is a necessary approximation due to the limitations of all existing software packages to estimate our full model. This is a good approximation, however, to the extent that all lower-order effects are included in our model.

³"These t -ratios are calculated in the traditional way as the difference between the observed value of a particular graph statistic and the mean from the sample of simulated graphs, as a ratio of the standard deviation from the simulated sample" (Robins et al. 2009, p. 112).

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