JOHNSON
Cornell University

Administrative Science Quarterly
56 (2)159–201

DOI: 10.1177/0001839211428131
asq.sagepub.com
SAGE

Rotating Leadership and Collaborative Innovation: Recombination Processes in Symbiotic Relationships

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Abstract

Using a multiple-case, inductive study of eight technology collaborations between ten organizations in the global computing and communications industries between 2001 and 2006 this paper examines why some interorganizational relationships produce technological innovations while others do not. Comparisons of more and less innovative collaborations show that high-performing collaborative innovation involves more than possessing the appropriate structural antecedents (e.g., R&D capabilities, social embeddedness) suggested by prior alliance studies. Rather, it also involves dynamic organizational processes associated with collaboration partners' leadership roles that solve critical innovation problems related to recombination across boundaries. While dominating and consensus leadership processes are associated with less innovation, a rotating leadership process is associated with more innovation. It involves alternating decision control that accesses the complementary capabilities of both partner organizations, zig-zagging objectives that engender deep and broad technological search for potential innovations, and fluctuating network cascades that mobilize different participants who bring variable inputs to recombination. The paper also discusses recombination mechanisms in the organization of collaborative innovation, variations in the performance of dynamic interorganizational ties, and how organizations develop symbiotic relationships that overcome the tendency of long-lived relationships toward inertia.

Keywords: technology collaboration, alliance process, interorganizational relationships, recombination, innovation

Technological innovation is central to how organizations create value for themselves, unleash gales of creative destruction on competitors, and enable progress for society. Product development and acquisition have long been

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significant strategies for innovation (Brown and Eisenhardt, 1997; Ahuja and Katila, 2001). But in increasingly open and dynamic industries in which resources are highly distributed and frequently changing, it is unlikely that single organizations can consistently develop or acquire the best innovations. Instead, technology collaboration has become an essential innovation strategy (Teece, 1986; Mowery, Oxley, and Silverman, 1998).

Technology collaborations are interorganizational relationships focused on the joint development of technological innovations (Powell, Koput, and Smith-Doerr, 1996; Ahuja, 2000; Stuart, 2000). These relationships use a collaborative approach to innovation that involves combining knowledge, technologies, and other resources across organizational boundaries. Examples are prominent, ranging from Intel and Microsoft's many collaborations (Bresnahan and Greenstein, 1999; Casadesus-Masanell and Yoffie, 2007) to Apple and Google's recent collaborations (Rosmarin, 2007). When successful, these collaborations allow partners to reap the benefits of both an open innovation approach that utilizes new external resources (Chesbrough, 2003; O'Mahony and Ferraro, 2007) and a closed innovation approach that ensures some proprietary protection of innovations through the use of contracts (Gans, Hsu, and Stern, 2001; Mayer and Argyres, 2004). The innovation-related outcomes of these collaborations include intellectual property, commercial products and platforms, and, ultimately, market success and firm performance. Yet despite their importance, many technology collaborations fail to achieve their technical and commercial objectives.

Previous research about alliances offers some insights into the performance of technology collaborations, focusing primarily on the structural antecedents of innovation. For instance, studies have shown that technology collaborations between organizations with strong R&D capabilities and relevant complementary technologies are likely to be high performing (Hagedoorn, 1993; Ahuja, 2000; Stuart, 2000). The broader alliance literature suggests that collaborations with efficient governance forms and between partners with extensive collaboration experience, dedicated alliance functions, and trusting relationships are also likely to be high performing (Gulati, 1995a; Uzzi, 1996; Anand and Khanna, 2000; Kale, Dyer, and Singh, 2002). Overall, this literature makes a strong case for the importance of structural antecedents of innovative technology collaborations.

Although existing alliance research is instructive, several outstanding issues remain. First, its performance measures are often limited. Most studies of technology collaborations rely on patent-based measures of innovation. Yet many collaborating organizations use other forms of intellectual property protection, such as trade secrets (Katila, Rosenberger, and Eisenhardt, 2008), and pursue other outcomes, such as novel products (Katila, 2002). Studies of alliances often use performance measures like duration or subsequent alliance formation (Doz, 1996). But these outcomes are not directly linked to innovation and may even be misleading. For instance, duration is a problematic measure because partners often dissolve technology collaborations when their innovation objectives are achieved (i.e., success) (Arino and de la Torre, 1998). These measurement limitations suggest that our understanding of innovative technology collaborations may be less than it initially appears.

Second, and more significant, this research strikingly neglects the collaborative process. Yet as a handful of process studies indicate, the interactions between partners in intensely participative alliances such as technology collaborations seem likely to influence performance (Doz, 1996; Arino and de la Torre, 1998). The classic technology collaborations between Intel and Microsoft suggest the importance of process. This seemingly straightforward relationship involved repeated confusion and conflict about technological development, placing future technology collaborations in doubt (Casadesus-Masanell and Yoffie, 2007). Yet these two organizations overcame these problems in a series of collaborations that led to the lengthy dominance of the Wintel platform technologies (Bresnahan and Greenstein, 1999). As Intel's CEO Andy Grove once described, these collaborations led to a ''symbiotic relationship'' that enabled both partners to mutually adapt to the changing demands of the computer industry (Burgelman, 2002: 341).

A central challenge in managing technology collaborations and organizing symbiotic relationships more broadly is that both partners have their own well-established processes for innovation, which may conflict. They are likely to have different decision rules for managing R&D, pursue distinct product-market objectives, and have individuals with very different expertise (Allen, 1977; Clark and Fujimoto, 1991; Brown and Eisenhardt, 1997). Reconciling these differences requires recombining aspects of both organizations without excessively constraining innovation with too much structure (Davis, Eisenhardt, and Bingham, 2009). Though the appropriate antecedent conditions may be germane, this reconciliation of decision making, objectives, and participants primarily occurs during the collaborative process. Despite its importance, the literature lacks such an in-depth account of how partners create high-performing technology collaborations.

The purpose of this paper is to better understand the processes by which some technology collaborations generate innovations while others do not. Given limited prior theory and empirical research, we used inductive, comparative case methods to examine eight technology collaborations among ten firms in the global computing and communications industries. By selecting cases that share the structural antecedents recommended by the literature, we control for rival explanations in order to focus on the less-explored collaborative process. In what follows, we identify three primary mechanisms that underlie successful innovation in collaborative contexts: marshalling complementary capabilities from partners, conducting deep and broad search for innovations with a common technological trajectory, and mobilizing diverse participants from the boundary-spanning network linking both organizations. What is lacking is an account of how these mechanisms are actually achieved, especially in the collaborative processes of technology collaborations. Identifying such processes would be a major step forward in our understanding of the collaboration innovation mode that is central to organizational adaptation in dynamic and interdependent environments like the computer industry.

COLLABORATIVE INNOVATION

The literature suggests three primary mechanisms underlying successful innovation through collaboration. The first mechanism is the activation of relevant capabilities. As suggested by resource dependence theory, technology collaborations often form between partners that are mutually interdependent (Casciaro and Piskorski, 2005; Gulati and Sytch, 2007; Katila, Rosenberger, and Eisenhardt, 2008). Examples include firms like Intel and Microsoft, which produce different products (i.e., microprocessors and software) that are both needed for a complete solution (i.e., the personal computer). To develop innovations together, these partners need to access their complementary capabilities.

The alliance process literature offers several insights into how partners might activate their relevant capabilities (Hamel, 1991; Larson, 1992; Doz, 1996; Uzzi, 1997; Arino and de la Torre, 1998). This work suggests that mutual learning, frequent interaction, and trusting relationships are likely to do so. To illustrate, Doz's (1996) study of three technology collaborations in minicomputers, jet engines, and drug delivery systems showed that reinforcing cycles of learning, evaluation, and adjustment allow both partners to use their capabilities. By contrast, when partners fail to learn, they dissolve the relationship prior to achieving their objectives (Doz, 1996). The implication is that learning from each other probably makes activating relevant capabilities more likely. In a study of relationships between garment firms, Uzzi (1997) found that when partners have trusting, prior interactions, they are more likely to exchange fine-grained information and engage in complex problem solving that may activate their distinct capabilities.

Other alliance studies suggest that when competitive tensions are reduced, partners are more likely to activate their relevant capabilities (Hamel, 1991; Khanna, Gulati, and Nohria, 1998; Katila, Rosenberger, and Eisenhardt, 2008). For example, in Hamel's (1991) study of two partnerships between European and Japanese firms, partners who competitively raced to learn their partner's technologies often failed to deploy their own capabilities. An implication is that competition between partners limits the activation of capabilities. Taken together, the literature suggests that mutual learning, trust, interaction, and limited competition are helpful preconditions for accessing relevant capabilities. But because this literature addresses neither innovation outcomes nor activation of capabilities directly, it remains unclear how exactly partners activate their relevant complementary capabilities during the collaborative innovation process.

The second mechanism underlying successful innovation is a deep and broad innovation search trajectory. In the innovation literature, a search trajectory is defined as a series of "recombinations" of existing knowledge, technologies, and other resources (Nelson and Winter, 1982; Helfat, 1994; Podolny and Stuart, 1995; Galunic and Rodan, 1998). This research suggests that pursuing deep search trajectories is conducive to innovation (Dosi, 1982; Fleming, 2001; Katila and Ahuja, 2002). Deep trajectories are composed of a series of elements that build on prior elements in the series. The argument is that deep trajectories allow organizations to efficiently avoid useless or unvalued innovations because some familiar elements are reused during each recombination step. But excessive pursuit of deep trajectories eventually reaches diminishing returns. Fleming's (2001) research on inventors' search trajectories using a sample 17,264 patents offers empirical support. He found that patents that cite familiar patent subclasses tend to be cited more often but that the value of this trajectory can be exhausted if too many of the combinations are used (Fleming, 2001).

Research has also found that broad search trajectories are conducive to innovation (Rosenkopf and Nerkar, 2001; Katila and Ahuja, 2002; Ahuja and Katila, 2004). Broad search trajectories are created when recombination includes novel elements and makes use of few (or no) prior elements. Broad search is conducive to innovation because it enhances novelty. For instance, in a study of U.S. chemical firms, Ahuja and Katila (2004) found that firms often respond to search exhaustion in deep trajectories by developing broad trajectories that include new elements such as those from basic science. Rosenkopf and Nerkar (2001) found that the most innovative technologies come from a broad search that spans technological categories and organizational boundaries. The most innovative optical disk technologies use knowledge from distant technologies and from multiple organizations. For example, Sony combined error correction techniques with Philips' digital storage techniques to create the compact disk standard (Rosenkopf and Nerkar, 2001). Taken together, the innovation search literature suggests that both deep and broad search trajectories are necessary for innovation. Deep trajectories stimulate innovation at least until the limit of useful combinations is reached, while broad trajectories stimulate innovation by introducing novelty. But because this literature typically only tracks patent citations and product outcomes, and typically only in single organizations, the process through which partners might actually blend deep and broad search trajectories collaboratively remains unclear.

A third mechanism underlying successful innovation is the mobilization of diverse participants over time. Diverse participation is linked to innovation and firm performance in multiple contexts (Reagans and Zuckerman, 2001; Beckman, 2006; Mors, 2009). Maurer and Ebers' (2006) study of six new biotechnology firms makes the further point that this mobilization is particularly relevant over time. They found that the highest-performing firms mobilized different individuals over time to make ties to new types of partners as new strategic imperatives emerged (Maurer and Ebers, 2006). But this research does not examine how that mobilization actually occurs.

Research on project teams that engage in creative actions, however, does offer insights into how mobilization might occur (Edmondson and Bohmer, 2001; Obstfeld, 2005, 2011; Bechky, 2006; Klein et al., 2006).[1] An exemplar is Edmondson and Bohmer's (2001) research on 16 hospitals that implemented new minimally invasive cardiac surgery technologies. They found that successful implementation involved an active enrollment process by which new team members were motivated to join by leaders and then subsequently engaged in practice sessions. A key lesson is that the mobilization of diverse participants requires leaders to recruit and instruct employees. Mobilization is not automatic. A related study by Klein and colleagues (2006) in a trauma unit further emphasizes the role of leaders in the mobilization of diverse participants. By observing the treatment of 175 patients, they found that senior leaders repeatedly delegated leadership to and took it back from junior leaders to generate reliable performance as well as to build the skills of novice team members.

While the above research describes the role of leadership in generating the mobilization of diverse participants over time, other research on creative project teams emphasizes the complementary role of stable structures in dynamic participation (Human and Provan, 2000; Bechky, 2006; Davis, Eisenhardt, and Bingham, 2009). For example, in a study of four film projects, Bechky (2006) found that well-established roles give participants enough stability to feel

[1] We appreciate the advice of an anonymous reviewer to focus on leadership processes underlying broad patterns of participation.

comfortable in producing innovative films. Similarly, stable boundary-spanning brokers, defined as individuals who connect otherwise disconnected actors (Tushman, 1977; Fleming and Waguespack, 2006) aid innovation (Hargadon and Sutton, 1997; Burt, 2004). Yet intriguingly, brokers alone may not be enough to ensure diverse participation. As Obstfeld (2005) found in his study of 73 automotive innovations, some brokers are more likely to mobilize diverse participants than others. Brokers who more actively facilitate interactions among employees are more likely to be involved in innovations (Obstfeld, 2005). Overall, this literature indicates that the mobilization of diverse participants over time underlies successful innovation and that this mobilization requires active facilitation by leaders and stable roles, especially brokers who bring together participants. Yet how leaders actually mobilize diverse participants across organizational boundaries at appropriate times is unclear.

METHODS

The research design is a multiple-case, inductive study. Multiple cases permit a replication logic in which the cases are treated as a series of experiments that confirm or disconfirm emerging conceptual insights (Eisenhardt and Graebner, 2007). Emergent theory from multiple-case research is typically more generalizable and better grounded than theory from single-case studies, making it more amenable to extension and validation with other methods (Davis, Eisenhardt, and Bingham, 2007).

The research setting is the computing and communication industries. Organizations in these industries produce a wide range of information technology products, including semiconductors, laptops, mobile handsets, and Internet software. This organizational field is a particularly appropriate research site because the convergence of communications and computing created multiple opportunities for innovation that required technological collaboration across sector boundaries between organizations like semiconductor, hardware, and software firms (Mowery and Rosenberg, 1998; Bresnahan and Greenstein, 1999). Thus collaborations are essential and numerous.

We studied technology collaborations between large, established organizations for several reasons. First, such organizations are likely to have the antecedent characteristics associated with collaboration performance (e.g., extensive collaborative experience), enabling us to focus on collaborative processes without complicating variation. Second, they are likely to have sufficient resources to attract partners and engage in significant R&D, making collaboration likely. Third, their size is likely to preclude their acquiring one another, putting mergers and acquisitions in the background and making collaboration critical.

Dyadic Sample

We selected eight technology collaborations between ten organizations that lasted from one to three years and occurred between 2001 and 2006. We named the collaborations for their primary technological area (e.g., Security). These areas span many relevant categories, from security circuits and firmware (Security) to mobile e-mail applications and operating systems (Mobile Email) to voice-over-Internet-protocol hardware (VOIP Phone). The organizations are disguised with pseudonyms from Shakespeare (e.g., Macbeth). They engage in varied sectors of the computing and communication industries, ranging from semiconductors (Macbeth) to operating systems (Lear, Rosalind) to mobile devices (Rosalind, Portia). Most pairs of collaborating organizations have extensive prior relationships as complementors, buyer/suppliers, joint sales and marketers, and even competitors. Three of the cases are between the same pair (Macbeth and Falstaff). Six organizations are headquartered in the U.S. and four are headquartered internationally, reflecting the global nature of these industries and enhancing the generalizability of our research. Sample details are in table 1.

A major advantage of our design is its focus on collaborations between partners that have the key antecedents of superior collaboration performance, including extensive collaborating experience and dedicated alliance functions (Gulati, 1995a; Kale, Dyer and Singh, 2002). They are also strategically interdependent partners in complementary sectors (e.g., hardware/software, circuits/systems) (Gulati, 1995b). In addition, these partners have multiple prior interactions that created some organizational structures and boundary-spanning ties between individuals and workgroups and are likely to improve performance (Gulati, 1995a; Uzzi, 1997). Both partners also dedicate significant resources to joint development and appropriately govern these collaborations with loose "memorandums of understanding" (MoUs), which are incomplete relational contracts specifying "broad areas of technology exploration" (Grossman and Hart, 1986; Baker, Gibbons, and Murphy, 2002). Finally, these partners are technical and market leaders (i.e., first or second in market share) in their respective domains. Thus they are desirable partners who share the common language of the computing and communications industries (Dougherty, 1992; Lane and Lubatkin, 1998; Ahuja, 2000). Overall, by selecting collaborations with favorable structural antecedents, we can focus on the collaborative process and its implications for innovation performance.

Data Collection and Sources

We used several data sources: qualitative and quantitative data from semi-structured interviews, publicly available and private data from Web sites, corporate intranets, business publications, and materials provided by informants. We conducted 72 semi-structured interviews of 60–90 minutes over 24 months. This resulted in 1,643 transcribed pages of primary source material. We interviewed informants at multiple times and from multiple levels of both organizations. Informants included the executive leads who oversaw the collaboration, strategic alliance directors, product-line general managers, laboratory and technical heads, scientists, and engineers. Interviewing multiple informants at multiple levels and different times leads to richer and more reliable emergent theory (Eisenhardt, 1989; Miller, Cardinal, and Glick, 1997). Finally, an author also worked for several months on R&D collaborations within a partner firm. Our triangulated, longitudinal data from primary sources in the field provide a rich view of technological collaboration.

We mitigated informant bias in several ways (Golden, 1992; Miller, Cardinal, and Glick, 1997). First, we followed interview guides that focused informants on relating chronologies of objective events, behaviors, and facts of the collaboration. Second, we gathered thousands of pages of secondary data both on site and from the media about these collaborations to triangulate our interview

Table 1. Description of Collaboration Cases

Case name	Partner A Partner B	Sector A Sector B	Prior interactions between partners	Initial innovation objective
#1: Security (15 Interviews)	Macbeth Falstaff	Semiconductors Network equipment	Tech and product development, joint sales & marketing, buyer/ supplier, standards, R&D consortia, direct competition	Security circuits and software
#2: Middleware (7 interviews)	Ariel Cleopatra	Systems Software apps	Joint sales & marketing, buyer/ supplier, technology standards	Internet-enabled enterprise middleware
#3: VPN System (7 interviews)	Rosalind Prospero	Mobile devices OS Software	Product development, joint sales & marketing, standards, R&D consortia	Secure networking appliances
#4: Mobile Email (7 interviews)	Rosalind Portia	Mobile devices /OS Mobile devices / software	Technology standards, R&D consortia, direct competition	Mobile email devices and software
#5: E-Commerce Tools (7 interviews)	Lear Mercutio	OS / software apps Online marketplaces	R&D consortia, buyer/supplier	E-Commerce software tools
#6: Wireless Networks (13 interviews)	Macbeth Falstaff	Semiconductors Network equipment	Tech and product development, joint sales & marketing, buyer/ supplier, standards, R&D consortia, direct competition	Network circuits and software
#7: Web Services (6 interviews)	Lear Ophelia	OS / software apps E-Commerce	Joint marketing, buyer/supplier, standards, R&D consortia	Software to access Web sites
#8: VOIP Phone (10 interviews)	Macbeth Falstaff	Semiconductors Network equipment	Tech and product development, joint sales & marketing, buyer/ supplier, standards, R&D consortia, direct competition	VOIP phone and circuits

Case name	Collaboration duration	Complementary technological capabilities	Related technologies possessed by both partners	Internal / external archival data (pages)
#1: Security	30 Months	Circuits / systems	Security firmware	1300 / 1600
#2: Middleware	45 Months	Systems / software	Communications protocols	1100 / 1500
#3: VPN System	25 Months	Systems / applications	Security systems	1500 / 1200
#4: Mobile Email	42 Months	Devices / software	Mobile data infrastructure	1400 / 1100
#5: E-Commerce Tools	18 Months	Applications / Internet	Database software	700 / 1100
#6: Wireless Networks	34 Months	Circuits /systems	RF algorithms	1200 / 1700
#7: Web Services	18 Months	Applications / Internet	Software-design tools	1100 / 1200
#8: VOIP Phone	21 Months	Circuits / systems	TCP/IP components	1000 / 1500

data. Third, we collected data in real time as the collaboration progressed and returned multiple times to conduct site visits. This generated both real-time data to mitigate bias and retrospective data to enable efficient data collection (Leonard-Barton, 1990). Finally, we promised confidentiality to motivate informants' accuracy.

Analyzing Phases of Each Collaboration

The primary unit of analysis in these collaborations is the phase.[2] We defined a phase as an interval of time in which qualitatively similar work activities occurred that differed from activities that came before or after. For example, the technology design phase is distinct from product marketing because design involves various activities such as sketching various blueprints and diagrams and developing computational models, whereas marketing involves courting reference customers, organizing events, and developing communications for different customer segments. Other phases focus on typical new-product development activities such as prototyping and testing (Clark and Fujimoto, 1991). Yet they also include specialized collaborative activities such as developing written agreements and dividing intellectual property. We marked the beginning of a phase when one or more informants from each organization indicated that participants began to work actively on new tasks. We marked the end of a phase when they indicated that these activities stopped (''We began negotiating in February''; ''We really didn't finish until April.''). Moreover, we often used a combination of archival information and interviews to triangulate the beginning and end of phases. Our data allowed us to measure the beginning and end of activities to the month, so though some overlap between the end of old activities and beginning of new activities can occur, we observed clear demarcations between phases at this level of precision.

The number of phases for each collaboration ranged between five and eight, with the exact number depending on the content of the collaboration. For example, the Wireless Networks collaboration had six phases, while the Middleware collaboration had seven. A key difference was that the Wireless Networks developed new products for an existing platform, while the Middleware collaboration involved developing a new product platform and thus involved an extra phase focused on platform development (phase #4). In addition, the duration of phases can vary even when the general nature of the work is roughly the same. Sometimes joint marketing efforts rely on existing channels, while in other cases new channels must be developed. For example, new technologies in the Security collaboration were sold to existing microprocessor customers so that marketing took a relatively short three months. In contrast, selling the products in the Web Services collaboration involved developing a new channel of software developers over five months. The duration of phases ranged from 1 to 12 months. Though managers have some discretion over the content and order of phases, characteristics of the work itself are relevant. For example, reaching an agreement precedes product development, and product development precedes marketing in all collaborations. These coding methods yielded a clear demarcation between phases for each collaboration case.

[2] We appreciate the advice of our editor and anonymous reviewers to clarify the definition and measurement of phases.

Measuring Innovation Performance

During the cross-case analysis of the data, a broad view of innovation performance emerged. Consistent with both the informants in this study and the prior literature, we defined innovation performance as the degree to which collaborations generated new technologies and intellectual property that had a positive impact on product lines and company performance. This definition integrates various aspects of innovation in the literature, including new technologies and codified intellectual property (IP) such as patents created in the process (Griliches, 1990; Grant, 1996a; Ahuja, 2000), the impact these technologies have on the organizations' product lines, including new product releases and improved product platforms (Comanor and Scherer, 1969; Henderson and Clark, 1990; Katila and Ahuja, 2002), and the consequences of innovation such as product performance (Cohen and Levinthal, 1989; Kogut and Zander, 1992; Grant, 1996b). In analyzing the cases, we assessed all these factors. The result is a particularly robust multifactor measure of innovation performance.

We operationalized collaborative innovation performance with five measures: (1) the number of new technologies generated by the collaboration; (2) codified intellectual property; (3) immediate product line impact (e.g., changes to an existing product platform or new product releases); (4) market acceptance of the new technologies, including qualitative evaluations by analysts and immediate financial performance of the products; and (5) participants' perceptions of the overall innovation performance.

We used United States patent applications as our measure of intellectual property (IP). The established organizations in the sample use experienced IP lawyers and tend to have high patent acceptance rates, making patent applications a useful proxy measure of innovation (Comanor and Scherer, 1969; Trajtenberg, 1990). Moreover, for each case, we assessed the collaboration's impact on each partner for at least one year post-collaboration with data on technology exploitation and evaluated product-line impact, defined as product or platform enhancements and new products released as a result of these new technologies (Comanor and Scherer, 1969; Katila and Ahuja, 2002). We conservatively recorded only a few clear instances of performance changes that were a direct result of the new technologies generated by the collaborations (Levin et al., 1987; Narin, Norma, and Perry, 1988). Finally, we supplemented these data with subjective assessments in which informants were asked to rate the overall innovation performance of the collaboration on a 10-point scale. These ratings were averaged across all informants and rounded to the nearest integer and were highly similar across levels of hierarchy—i.e., executives, managers, and engineers—and between partners. Krippendorff's Alpha = .7905, suggesting that this measure has high interrater reliability. Overall, this measure overcomes several shortcomings of prior research, such as limited relevance to innovation (e.g., duration) and narrow focus (e.g., patents only), and is a major advantage of our design.

Data Analysis

We began by writing the chronological case histories of the collaborations. These ranged from 40 to 90 single-spaced pages and took six months to write. We analyzed the chronologies using both within-case and cross-case techniques (Eisenhardt, 1989; Miles and Huberman, 1994). We iterated between the cases and emergent theory and then weaved in relevant literature. Our phase-by-phase analysis of decision making, changes in objectives, and participation patterns is detailed in the Online Appendix (http://asq.sagepub.com/supplemental). In the following sections, we describe the theoretical framework that emerged to explain the striking variation in performance among our collaborations.

ROTATING LEADERSHIP AND COLLABORATIVE INNOVATION

Our collaborations had many similarities. They involved two experienced partners who were motivated to cooperate to develop new technologies, products, and platforms that they could not easily pursue alone. They sought to combine their complementary capabilities in pursuit of their own strategic objectives. For example, one executive asserted, ''This better help us build a new platform!'' while another echoed, ''New products are the only worthy objective.'' They all began with favorable antecedent conditions and even with the same initial process activities: an agreement phase to craft written contracts and a roadmapping phase to do detailed planning. Yet despite these similarities, the collaborations dramatically diverged into widely different innovation outcomes.

For example, Ariel and Cleopatra's Middleware collaboration had high innovation performance, producing a variety of new Internet-based technological features and interfaces, 18 patent applications, and an average subjective innovation performance rated 9 out of 10 by participants. The collaboration enhanced Ariel's software development tool set for large enterprise customers and allowed Cleopatra to develop new software interfaces (APIs) for use by the many small organizations in its software ecosystem. By contrast, Falstaff and Macbeth's VOIP Phone collaboration produced no significant new technological assets, although Falstaff filed four ''conceptual'' patent applications and had an average subjective innovation performance of 2 out of 10. Falstaff's VOIP Phone product would lag behind competitors, while Macbeth would suffer the harsh judgments of technical analysts for another failed Radio Frequency project and ultimately be forced to exit the wireless communications market and sell its business unit. Table 2 summarizes the evidence for the innovation performance of the eight collaborations.

The leadership processes of the collaborations also varied widely. Some partners used what we term a ''dominating leadership'' process wherein a single partner controlled decision making, determined innovation objectives, and mobilized participants. Other partners used a ''consensus leadership'' process wherein they shared decision making, agreed to common objectives, and mobilized participants together. Yet both of these processes had unexpectedly poorer innovation performance than that of partners who used a ''rotating leadership'' process. Rotating leadership involves three components: (1) *alternating decision control* between partners to access their complementary capabilities, (2) *zig-zagging objectives* to develop deep and broad innovation search trajectories, and (3) *fluctuating network cascades* to mobilize diverse participants over time. We contrast these three rotating leadership process components and their influence on innovation performance with the alternative components of dominating leadership and consensus leadership below. Table 3 summarizes the evidence linking rotating leadership and innovation performance.

Table 2. Summary of Evidence for Innovation Performance

New technologies and intellectual property	New and improved products and platforms	Market acceptance and product performance
#1: Security (Macbeth–Falstaff)		
Security improvements to circuits, software, and chipsets. Circuit linkages to network equipment. 19 patent applications, 10 white papers.	Macbeth's processor includes new security and manageability technologies that are featured prominently in its high-end products. Falstaff bases a new line of software around these new technologies.	A prominent OEM becomes a reference customer for the Macbeth-Falstaff combined solution. Analysts foresee industry structure changes based on these high-growth products. Technologies diffuse to data centers first and the server market.
#2: Middleware (Ariel–Cleopatra)		
New robust programming environment for enterprises. New Internet-based middleware that supports virtualization, portals, and authentication. Directory and application server technologies. 18 patent applications, multiple white papers.	Ariel's robust middleware engine used in large-scale enterprise applications. Cleopatra's shifts to new programming language and Internet-based middleware that is more robust and easier to support.	Ariel's tool sets become dominant in Internet development market. Cleopatra's new Internet-based middleware and applications are rated as excellent by industry analysts and gain market leadership in every important segment in the next 3 years.
#3: VPN System (Rosalind–Prospero)		
Improved appliance robustness. Linux-based OS with increased speed, memory, and multi-threading improvements. New secure mobile-VPN and firewall integration components. New intrusion detection and mesh architecture. 18 patent applications, multiple white papers.	Rosalind and Prospero base new integrated firewall / VPN appliance around new Linux OS and emphasize new integration with mobility features as distinctive product advantage.	Customers like robustness and supportability, although the analyst communities focus mostly on new mobile security enhancements.
#4: Mobile Email (Rosalind–Portia)		
Push email software ported to Rosalind's OS. Technologies for 3rd party smartphone vendors including client-email integration, conference calling, speakerphone inter-operability, and security locking. 13 patent applications, multiple white papers.	Portia's basic push-email product available on Rosalind's current generation handsets. Push email and mobile data services available on Rosalind's next generation smartphones.	Develops small ''beta test'' user base for current generation phone market before larger subscriber growth of next generation smartphones. Portia improves its voice quality of service, and Rosalind improves its Rosalind-branded email program offerings.

Average subjective evaluation of innovation performance	Selected quotations regarding innovation performance
Overall = 9 Macbeth = 9 Falstaff = 8	''[Falstaff] really had no strong position in the security area, and we wanted a lever against Lear. Now we [have that] and are able to deliver value to customers in new ways.'' ''Macbeth's numbers are so big that if I moved the cycles by one percent, you know, we get an additional billion dollars. So, the bar is high, but this collaboration . . . had that sort of impact: if we can get the major OEMs signed up to support these technologies next year then they'll want to buy [an additional] ten percent year-over-year contribution while the market grows. So, I really do feel strongly that this was a success.''
Overall = 9 Ariel = 8 Cleopatra = 9	''It was absolutely successful. Actually, it drove a completely new product architecture. I mean, [our middleware] wouldn't exist without [their technology], and that drove their whole new value proposition for their customers and their future destiny. I think that probably no one at Ariel could imagine anymore doing this [technological] evolution without Cleopatra.'' ''[The collaboration] has really changed many of our internal activities. It has sure has had an impact. We had huge competitors like Caliban, Hamlet, and look where they are now! Cleopatra is number one in every segment, in every country.''
Overall = 7 Rosalind = 8 Prospero = 6	''Well, this new project has been reasonably successful.'' ''I think frankly—My honest impression of this is we've under performed as a partner. I think we've done ourselves a disservice because we didn't dedicate ourselves to it. We found that somebody really has to take the lead. Now we're working a little on catch-up.'' ''Basically, certain places we compete, other places we cooperate. The irony is that this is a very successful partnership in terms of revenue, market visibility and market penetration. Luckily, there is a lot of value coming: the market is looking for a specialized [product like our] offering, and I think we definitely bring value to the table.''
Overall = 7 Rosalind = 7 Portia = 7	''There's nothing wrong with the collaboration at the moment, although it's a little bit slow on new technological development compared to what is available if you go to the nearest email vendors.... But I think that Portia's footprint in the market, combined with our attractive brand and devices then—I think the performance is positive.''''It was a hard row to hoe, but now that we're at the other side of it, we have what we wanted to get out of it. I think we've ironed out a lot of kinks.'' ''In the second phase it's more [about] generating revenue.... We are working with them, but it's not a totally smooth road....''

(continued)

Table 2. Summary of Evidence for Innovation Performance

New technologies and intellectual property	New and improved products and platforms	Market acceptance and product performance
#5: E-Commerce Tools (Lear–Mercutio)		
New software tools that link Internet content to client software applications like spreadsheets, email, and web design tools. 7 patent applications, a few white papers.	XML based add-ons available by download from Lear.com, but not as stand-alone client applications. Mercutio sees steady growth of automated transactions through Lear's applications, yet these offer little value for both customer bases.	Prominent joint-marketing and demo events impress industry analysts. Mercutio's power user community adopts some features, demonstrating their desire for transaction-automation tools.
#6: Wireless Networks (Macbeth–Falstaff)		
Mobile router and transceiver technologies with increased bandwidth, range, and memory. 9 patent applications, 5 white papers.	Mobile router device delivered to the military, but with no impact on Macbeth or Falstaff's main product lines. Next generation transceiver technology does appear in the new wireless router product line.	Mobile router product is not launched. Transceiver viewed as incremental ''next step'' building block technology and doesn't result in significant revenue growth. Bundled features get good ratings from analysts, but generate little excitement with customers.
#7: Web Services (Lear–Ophelia)		
Web services linkages between application linkages to e-commerce database. 5 patent applications, 1 white paper.	Lear's document processing application has limited access to Ophelia's e-commerce data.	Technologies not marketed broadly; download hidden on a Lear.com website with thousands of other downloads. Feature gains no acceptance with developers and analysts do no reviews.
#8: VOIP Phone (Macbeth–Falstaff)		
None 4 patent applications, but no white papers.	Falstaff's VOIP phone product line will not have the option to use Macbeth's communications architecture in the near future.	Falstaff's VOIP phone generates little revenue or excitement from analysts.

Average subjective evaluation of innovation performance	Selected quotations regarding innovation performance
Overall = 7 Lear = 8 Mercutio = 6	"On releasing [Lear's new software suite], people were saying Lear, you know, is not as hip as some of those web companies. But, now with Mercutio, we showed integration, and I think that resonated with a lot of people." "With Mercutio it seems like there were a lot of . . . cooks in the kitchen . . . and everybody was adding their own ingredient to the recipe . . . so coordination was pretty difficult. We were kind of struggling with . . . how many features we put into this solution.""We would have been successful without Lear."
Overall = 5 Macbeth = 4 Falstaff = 5	"Now, we are actually engaged with them and they are building stuff on our technology. But I honestly don't think that the value for [us] is really adequately defined. And, you know, I think that's OK because we are trying to build a relationship and are willing to sacrifice a little bit to get there." "Right now it seems [we] sort of we missed that real strategic focus—like what are we trying to do, and what feature would we cut because of the lead-time involved. When we are starting to engage at a real problem solving level, then that'll be a marked change."
Overall = 5 Lear = 5 Ophelia = 5	"Now, the application itself, was it the most compelling broad reach? No, no it wasn't." "For [our other collaborations], we designed a [large] PR campaign. This level of [intense PR planning] didn't happen for Ophelia." "We walked away friends. Most collaborations you may walk away bad. We thought we made something good happen and got attention. Now, I'm not really as metrics driven as I should be, so we didn't think about it from that perspective."
Overall = 2 Macbeth = 2 Falstaff = 4	"I think I would say both sides did very poorly, right? I think there were miscommunications about expectations." "We ultimately failed to get to an agreement. If we had figured that out earlier, we could have saved a lot of wasted time." "The process wasn't working because when we got to the second phase it all fell apart."

Table 3. Summary of Evidence Linking Rotating Leadership and Collaborative Innovation

	Collaborative Process				
	Overall pattern	Alternations in decision control	Zig-zagging objectives	Fluctuating network cascades	Innovation Performance
#1: Security (Macbeth–Falstaff)	Rotating leadership	*Extensive* 3	*Extensive* 7	*Extensive* 69% Different and 52% New participants	*High*
#2: Middleware (Ariel–Cleopatra)	Rotating leadership	*Extensive* 4	*Extensive* 6	*Extensive* 68% Different and 50% New participants	*High*
#3: VPN System (Rosalind–Prospero)	Rotating leadership	*Extensive* 3	*Extensive* 8	*Moderate* 50% Different and 29% New participants	*High*
#4: Mobile Email (Rosalind–Portia)	Rotating leadership	*Extensive* 3	*Extensive* 8	*Moderate* 62% Different and 31% New participants	*High*
#5: E-Commerce Tools (Lear–Mercutio)	Dominating leadership / Rotating leadership	*Moderate* 2	*Moderate* 3	*Moderate* 50% Different and 25% New participants	*Medium*
#6: Wireless Networks (Macbeth–Falstaff)	Consensus leadership	*None*	*Moderate* 5	*Limited* 38% Different and 20% New participants	*Low*
#7: Web Services (Lear–Ophelia)	Dominating leadership	*None*	*Limited* 2	*Limited* 24% Different and 18% New participants	*Low*
#8: VOIP Phone (Macbeth–Falstaff)	Consensus leadership	*None*	*Limited* 1	*Limited* 13% Different and 8% New participants	*Low*

Alternating Decision Control Accesses Complementary Capabilities

A key impetus for technological collaboration is combining the complementary capabilities of the two partners to produce superior innovation. But though this combination might seem easy to achieve, it is actually challenging to access capabilities that are embedded in often very different organizations with their own rules, unique personalities, and structures. Nonetheless, we found that the approach to decision making in the various phases of the collaboration is likely to facilitate or hamper this access. In particular, three decision-making patterns were relevant. One is decision making that is unilaterally controlled by a single partner who makes most decisions in most phases of the collaboration. A second is decision making that is mutually controlled by both partners through consensus choice for most decisions in most phases. A third pattern is decision making that alternates unilateral control between the partners through the various phases of the collaboration. While the first two patterns have speed and motivational strengths, the third seems to trigger greater access to both partners' capabilities and enhance innovation performance.

We assessed the decision-making patterns by examining the major decisions in the collaborations. First, we identified major decisions and decision makers, noting when partners made decisions unilaterally or mutually. We defined a major decision as any explicit choice that materially affected the collaboration. These decisions are mainly related to specific technical and operational issues but also included strategic issues such as which technologies to pursue and how to do so and how to include particular technologies in specific products. We classified each decision as *unilateral* or *mutual* based on who made the choice, i.e., representatives from one partner or both partners, respectively. Fortuitously, informants from both partners typically gave highly consistent designations, explaining, for example, ''We let Mercutio control the marketing deadlines,'' or ''Cleopatra's team made that decision.'' The number of major decisions in each phase ranged from one to six. This phase-by-phase analysis of each collaboration is detailed in the Online Appendix (http://asq.sagepub.com/supplemental). An excerpt of this analysis for the first three phases of one case (Security) is detailed in table 4, for illustrative purposes.

Based on the assessment above, we next analyzed who controlled decision making in each phase and across phases. Because collaborative innovation involves accessing the capabilities of different partners at different times, we focused on changes in decision control. Of particular importance are decision-control alternations, which occur when the organization making most of the unilateral decisions in one phase is different than the organization making most unilateral decisions in the prior phase.[3] Alternations can be either planned or unplanned. Sometimes partners agree that one firm's capabilities are better matched to activities in the next phase and so decision making switches (planned). At other times, one partner seizes (or is given) decision control, often triggered by unexpected external events (unplanned). Collaborations fell into three categories based on whether phases were predominantly characterized by *unilateral* decision control by one partner, *mutual* decision control among partners, or *alternating* decision control between unilateral phases of control by both partners. The number of *decision control alternations* is our first measure of leadership rotation.

A telling example of alternating decisions is the VPN System collaboration between Rosalind and Prospero. The aim was a novel virtual private network (VPN) system that would allow users to access corporate intranets from offsite locations. This required both software application expertise from Prospero, a leading software vendor, and operating system (OS) and mobile expertise from Rosalind, a prominent hardware and systems vendor. From the beginning, both partners agreed that Prospero should control decisions in the design phase (#2) because its applications expertise would have the more significant influence on adoption by customers. At first, Prospero's managers assumed they would also lead the subsequent phases—platform development (phase #3) and application porting and design (phase #4) —because of the importance of applications in these activities. But after discussions between Rosalind's and Prospero's managers, it became clear that the operating system, which

[3] Of course, not all transitions between phases involve alterations (e.g., sometimes one partner maintains control). We also tried alternative measures of alternations, for example, also including transitions from mostly mutual to mostly unilateral. The general findings are robust to these other operationalizations. For this we appreciate the suggestion of an anonymous reviewer.

Table 4. Excerpt from Online Appendix of Phases 1–3, Case #1: Security – Macbeth (M) & Falstaff (F)*

	Phase (length) and focus	
	Phase #1 (1 month) Agreement–craft written agreement about basic structure of collaboration	Phase #2 (10 months) Roadmapping–high-level alignment of technology standards and milestones
1. Decisions (Alternations) Macbeth unilateral Mutual Falstaff unilateral	F&M	F,F,F,F
2. Changes in objectives	Initial objectives: Develop new integrated circuits and system software that improves enterprise network security using M's circuit F's system expertise.	1. Jointly develop three new security and manageability technologies. 2. Decouple circuit and system software marketing.
3. Participation Activation cascades	M Director → F Sales Manager → F CTO → F SVP and technical leads	F CTO → F CDO, F SVPs and various F directors → various M directors, two M project managers → M Marketing Manager; F SVP and M Director → M and F legal reps
Different from prior:		70%
New to collaboration:		70%
Technological outcomes		Roadmaps with common industrial objectives

(*continued*)

Rosalind controlled, was critical. As a Rosalind manager explained, ''The way it works is they don't have our source code, and [we don't have theirs]. That's the way it is.'' While Prospero could design applications with the current operating system, managers realized that they could develop significantly better applications if Rosalind applied its operating system expertise to rewrite their OS using Linux. This was a real dilemma for Prospero's managers. Although ceding decision control of the next phase (platform development) to Rosalind would mean accessing Rosalind's considerable operating system expertise to develop a valuable new Linux-based operating system, Prospero would probably be unable to control other decisions that would simultaneously occur. A Prospero manager explained why managers ultimately agreed to cede control to Rosalind:

> We've been trying to pitch Linux to them for years and years but their messaging in the marketplace was that their legacy OS was special. We don't believe that. From the Prospero perspective, we really need them to switch to Linux before we start the [software application] innovation per se, and only they could do that. Usually

Table 4. (continued)

	Phase (length) and focus	Totals (summaries)
	Phase #3 (5 months) Design–crafting detailed plans for new technologies, platforms, and products	7 Phases (30 months)
1. Decisions (Alternations) Macbeth unilateral Mutual Falstaff unilateral	(P) M,M,M	Extensive alternation 3 Alternations
2. Changes in objectives	3. Use new technologies in one new M product and one new F product.	Extensive zig-zagging 7 Objectives changed
3. Participation Activation cascades	M CTO → M engineering VP → two M project managers → M lab director → M security/ managability development teams; M CTO & M VP → F CTO and CDO → F security team	Extensive fluctuation
Different from prior:	78%	69% Different participants (weighted average)
New to collaboration:	78%	52% New participants (weighted average)
Technological outcomes	Design documents for two technologies	Innovation performance: 19 patent apps., 9 Subjective evaluations, New circuits and firmware.

* Only the first three of the seven phases of the Security case from the Online Appendix are shown here for the illustration. (U) = Unplanned alternation; (P) = Planned alternation, and → = Participant activation.

> Prospero just makes all the decisions, and pushes Rosalind to take it or leave it, but we really needed them to do this first.

Managers from both partners concurred that this planned shift in decision control enabled tapping into Rosalind's operating system expertise to develop a robust, new Linux OS platform. The same Prospero manager admitted, ''The platform works. [Moving to Linux] should help us reduce costs and enhance the distinctiveness of the Rosalind/Prospero product. This way, Rosalind can take pieces of Prospero's software and find areas to fit it in. That should produce new features.''

After the platform development phase (#3), Rosalind returned decision-making control to a Prospero team with application expertise in graphical user interfaces (GUI). Based on its GUI expertise, that team led the interface design for the security application, making major decisions affecting the customer experience during the application porting and design phase (#4). As a Rosalind manager reflected, ''We found that somebody really had to take the lead.''

Although they would use a joint engineering team from both partners, managers from both sides intended Prospero to retain control in the next phase, application development (#5). The expectation was that many innovative application features would emerge. But in parallel, Prospero's senior technical executives were pursuing a major acquisition. An executive explained, ''With this acquisition, we get the product offering and brand. They are perfectly aligned with our vision and are an ideal complement to our products.'' After two months, the acquisition stumbled. As a result, several of Prospero managers, who were intimately involved with the collaboration, turned their attention to the acquisition fallout. After weeks of silence, Rosalind's managers chose to take over the joint engineering team and continue the phase without Prospero's key executives. As a Rosalind manager said, ''We took over!'' Consequently, Rosalind's executives made unilateral decisions about the technical scope of the product that reflected their expertise and strategic objectives. For instance, they directed the team to prioritize mobile security technologies and features because Rosalind had more strategic interest and deeper technical expertise in these technologies. Thus Rosalind led an unplanned alternation of decision control.

Later, Prospero's executives returned to an on-schedule collaboration that was close to key milestones. While the emerging VPN product reflected Rosalind's expertise in mobile security, it also fit Prospero's requirements. A Prospero manager noted the value of shifting decision control: ''I think frankly—my honest impression of this is we've under-performed as a partner. I think we've done ourselves a disservice because we didn't dedicate ourselves to it. . . . But, you know, they really saved us.''

In contrast, less successful collaborations (E-Commerce, Wireless Networks, Web Services, VOIP Phone) used either mutual or unilateral decision making. For example, Lear's Web Services collaboration with Ophelia combined Lear's software expertise with Ophelia's Internet infrastructure and database expertise. Lear, a leading software developer, planned to make the major decisions in every phase of its collaboration with Ophelia, a major Internet company. During the roadmapping phase (#2), Lear's managers made a ''take it or leave it'' offer in which Lear would unilaterally develop software to access Ophelia's customer database. Ophelia's sole contribution would be to grant Lear access to its database and provide minor input on the design of the Internet infrastructure. Asked about complementary expertise, Lear's technical lead focused on Lear's expertise and improvements to Lear's applications, ''This marries the two together: rich [Internet] document creation and the ability to pull that content into the application. We had products looking for a solution . . . it was a natural win.'' Despite some reluctance, Ophelia's executives agreed to Lear's proposal, hoping they would informally influence Lear's decisions. One Ophelia manager was optimistic: ''Some say 'we don't want that 800 pound gorilla in our space.'. . . but a lot of what happens at Lear is through personal relationships. If you can use personal relationships then you don't have to go in with official approval to get things done. Things can happen very quickly.'' Yet, as the collaboration evolved, Lear's managers continued to make all major decisions.

In later phases, Lear's managers continued to make all decisions. Consequently, Ophelia's managers abandoned their early optimism and openly worried about how they would apply their Internet infrastructure capabilities to the collaboration. One Ophelia manager noted, ''Lear's [application] group really didn't make it very easy to build integrated solutions with them, or even use [their technologies].'' In addition, this same Ophelia manager noticed that his colleagues lost the motivation to engage in the collaboration. They became ''afraid of working with Lear'' and fearful that ''bad things might happen.'' Ophelia's participants worried that their inability to influence decisions would make it difficult to apply their capabilities to the project and lead to a failed collaboration. As described below, their fears were realized.

By contrast, Falstaff and Macbeth used mutual decision making in their Wireless Networks collaboration by engaging in consensus building with agreements sealed ''on a handshake.'' The collaborative objective was to combine Falstaff's wireless systems capabilities and Macbeth's circuit expertise to create new technologies and products in the ''Wireless LAN'' area. As one manager noted, ''[the main idea] is to use Macbeth's fast [silicon] and Falstaff's Ethernet IP on these new [wireless standards].'' The managers of both partners explicitly committed to mutual decision making, which they had previously used in a successful marketing collaboration. As one manager said, ''We really leveraged the smooth processes in the marketing collaboration.'' As a result, they sought agreement on major decisions. But regrettably, this required extensive discussion that took time and created misunderstandings.

With mutual decision making, decision roles became increasingly unclear in later phases. For example, a key misunderstanding emerged about the complex issue of whether and how Macbeth would use Falstaff's technical certification process. Whereas Falstaff thought that Macbeth was fully committed to Falstaff's certification requirements, Macbeth understood that it would only ''follow the spirit'' of Falstaff's certification process. Certification was a ''deal breaker'' for Falstaff because this networking company needed to ensure that all products used the same networking standards. As a Falstaff executive described, ''For [our relationship] with Macbeth, we start by engaging through our certification program. This must be our narrow focus for now . . . and later on we can expand beyond that.'' By contrast, Macbeth's managers thought that certification did not apply to technology collaborations. As one said, ''Their certification program is just for extensions to wireless standards. [It is mainly] for client vendors to support [and] help Falstaff differentiate against their competitors.'' The two proceeded, thinking that they were in agreement, but they were not. Later, despite extensive discussion, Macbeth and Falstaff managers had difficulty reconciling their widely differing views on certification.

Innovation performance. Alternating decision control is likely to improve innovation performance because it facilitates partners' access to their complementary capabilities. By controlling decisions at various times, each partner is able to make the crucial choices that bring in desired capabilities to the collaboration and is more motivated to do so. For example, alternating control of the VPN System collaboration (described above) three times allowed Rosalind and Prospero to apply their different capabilities. The alternation that gave Rosalind control of phase #3 allowed it to decide how to deploy its operating system expertise to create a particularly robust system. This in turn gave Prospero the Linux system that it desired because this system would allow development of more novel applications. This then led Prospero to bring in its advanced applications expertise. Further, designing a new GUI (graphical user interface) for applications on Rosalind's new Linux-based operating system led to unexpected innovations in Prospero's prototyping methods. More unexpectedly, the unplanned alternation in control to Rosalind during Prospero's acquisition distraction accessed Rosalind's deep mobile capabilities and produced VPN mobility features that became what industry analysts would call the product's "most distinctive" features. As one said, "These features allow mobile users to access information . . . when a VPN is created in accordance with security policies. All data is secured . . . the users benefit from an experience that is intuitive and easy to use." Moreover, Rosalind's unexpected assumption of decision control allowed Prospero to then use its own capabilities in a complementary, but unanticipated way in later phases. Ultimately, this collaboration generated a VPN product with superior mobile features, speed, memory, and unusually robust mobile integration that would become a market leader.

A key point is that the high-performing collaborations had both planned and unplanned alternations. The common pattern is to begin with planned alternations in the first few phases with unplanned alternations in later phases. Partners seemed to choose planned alternations to ensure that known capabilities from both partners were utilized. A Security manager noted, "We want them as a co-creator of [technologies] and that means making them heavily involved. . . . We tried to stay out of their hair." Unplanned alternations often emerge later when one partner unexpectedly recognizes that its capabilities are well suited to new problems or when external events trigger a change opportunity. The prior planned alternations may prepare partners to adapt favorably to later unplanned alternations. Another manager summarized his view of planned and unplanned alternations: "Does it really matter how we get there . . . as long as we get our shot?"

In contrast, collaborations with unilateral decision making were less able to access the capabilities of the non-leading partner. For example, in the Web Services collaboration described above, Ophelia engineers delivered the specified Internet technologies (e.g., APIs, database scripts) requested by Lear but took little initiative to seek the "best" technologies within their organization. Ophelia's managers, for instance, knew that an elegant technical solution to an Internet database problem existed in their search-engine division, but they did not bring it to the collaboration. They feared that without decision control, they would be unable to use this new technology well. As one said, "I didn't really know if they needed it," and "I didn't want to stick my neck out." In retrospect, using Ophelia's leading-edge search technology would have substantially improved the resulting product by expanding the range of applicable Web services, and Lear's technical leaders later regretted not finding this "missing link." According to one Lear manager, "We wanted to demonstrate [the product] as a smart client application. One of the things was that it needed to be able to consume Web services." Ultimately, the Web Services collaboration produced a simplistic prototype with narrow utility. As an observer said, "Lear created a solution that looked pretty basic and rudimentary compared to what some of their developer communities [could] come up with."

Finally, in collaborations with mutual decision making, it was ironically also difficult to access both partners' capabilities, albeit for different reasons. Here, unclear decision-making roles and the slow pace stalled access to capabilities. For example, the confusion about whether to use Falstaff's certification process in the Wireless Networks case (described above) led to circuits that did not fulfill these requirements and needed redesign. Without certified circuits, Falstaff was unable to apply its detailed knowledge of wireless interfaces in the next phase. Waiting for redesigned circuits drastically slowed the collaboration and postponed innovation. As a Macbeth executive complained, "It pains me to no end. Now Falstaff is saying, 'We can't do this in time." Ultimately, Falstaff's executives pushed to scale back the collaboration in order to complete certification, and made significant changes to their management team for the collaboration. As one Falstaff manager reflected, "With the wireless collaboration . . . [now we are] . . . asking what we are really trying to do, and what would we cut. These are the real problems to solve [now]."

An alternative explanation to decision patterns is that some capabilities are inherently more difficult to access or combine. But this explanation is unlikely in our data, because similar capabilities were involved in both more and less innovative collaborations, as shown in table 1, above. Furthermore, our collaborations typically bring together partners with the capabilities that are typical bases of complementarity throughout the numerous collaborations in these industries (e.g., circuits/systems, devices/software). Rather, alternating control seems to enable partners to access their complementary capabilities more effectively. When a partner controls decisions in a phase, its managers are better able to know which of its own capabilities to access. Even when a partner does not control a phase, its managers are more motivated to assist by offering its own capabilities. Thus, by controlling decision making unilaterally, organizations access their own capabilities and ensure that partners do so as well when alternations occur. Partners are better able to enlist complementary capabilities by examining their partner's outputs when they gain control. Alternating decision control overcomes the tendency of partners to overly rely on their own resources.

Zig-Zagging Objectives Generate Deep and Broad Search Trajectories

Successful innovation relies on deep and broad search trajectories in the technology space (Rosenkopf and Nerkar, 2001; Katila and Ahuja, 2002). Deep search enables efficient cumulative improvements along specific technical trajectories, while broad search, such as by combining partners' complementary capabilities, creates novelty. But though this blended search may seem easy to achieve, it is not so obvious how partners who have different objectives actually coordinate such search trajectories. We found three relevant patterns of technology objectives.

One pattern often occurs when collaborations are led predominantly by one partner. Because such partners engage in little incorporation of their partner's perspectives, they rarely change objectives. They may make progress toward these objectives, but since other objectives are rarely explored, the resulting search is often narrow and lacks breadth. A second pattern often occurs when both partners share leadership of the collaboration. Sometimes the partners may agree to change objectives, but they often make slow progress because they need to gain consensus about what to do. Given limited time, the resulting search is often shallow and lacks depth. In contrast, collaborations following what we term "zig-zagging objectives" often emerge when partners frequently alternate control of phases. Zig-zagging objectives trigger search depth because the partners often use their phases of unilateral control to make cumulative technological progress toward their preferred objectives. But zig-zagging objectives also trigger search breadth because leading partners often shift objectives from those of their partner in prior phases. The number of *changes to collaborative objectives* was our second measure of the rotating leadership process. Table 3, above, summarizes the changes and the Online Appendix (http://asq.sagepub.com/supplemental) provides details.

We defined a collaborative objective as any high-level strategic goal related to the joint development of technologies, products, or platforms. Typically, partners agree to the initial objectives in the collaboration's first phase. Yet initial objectives often outline only the basic opportunity (e.g., Mobile Email, VOIP Phone) and leave important objectives open (e.g., target market). We observed that objectives can change in three ways: partners can eliminate, switch, or add objectives (see Online Appendix). Examples include when partners switch from a proprietary to an open-source strategy, eliminate the use of an old technology, and add a target market. Partners change objectives when managers make explicit decisions to alter objectives or when events force changes, such as when R&D experiments indicate one technical alternative is better than others and when running out of time effectively eliminates an objective.

Portia and Rosalind's Mobile Email collaboration illustrates zig-zagging objectives. The initial objectives focused on building smart phones with email functionalities. The objectives changed nine times during the collaboration. For instance, when Portia led the roadmapping phase (#2), it focused on the objective of making its mobile email software work on Rosalind's mobile devices. Yet soon Portia's managers realized that Rosalind's phone platform would need to be redesigned to allow Portia's email application software to install seamlessly and to work with a wide variety of wireless service providers. A Portia manager explained these new objectives:

> This is about propagating software such that those devices could work with us. . . GSM, CDMA, GPS . . . we need to regularly support all these standards with all the carriers including the Cingulars, T-Mobiles, and Verizons of the world. We are connected to so many different things in the system. . . . We need to [learn how to] license our technology to other handset manufacturers.

Portia added a new objective to develop a more modular phone platform that would leverage new wireless standards that Rosalind handsets normally did not support.

Often zig-zagging objectives emerge because organizations adjust their objectives in response to decisions and outcomes resulting from their partner's control in a prior phase. For instance, when decision control switched to Rosalind in order to integrate Portia's email software with a new user interface during the product porting phase (#3), Rosalind's managers realized that the new modular platform required important changes to Portia's software to improve the end-user's emailing experience. Rosalind's managers argued that a better back-end interface was "necessary to ensure high-quality service" from the major U.S. telecommunication carriers. Portia's mangers were reluctant to accept this new objective because of the extra time that pursuing the related new search trajectory would take: "We want to learn . . . but at the beginning, it took a really long time [to make] the first basic and limited client. Some friction came from that. It was lots of development work, but not a lot of results or revenues." Yet despite these disagreements, Portia's executives ultimately yielded to Rosalind's request to change the objectives by redesigning the back-end interface.

By contrast, when one partner dominates, this partner often blocks changes to objectives and thereby narrows search trajectories. For example, Lear's unilateral control of the Web Services collaboration led to Lear's choice of objectives with little input from its partner, Ophelia. During the agreement phase (#1), the collaboration was expected to create value for both partners. The initial objectives involved access to various Web sites by combining Ophelia's Web services technologies with Lear's software application suite. Ophelia's managers pushed the Lear team to consider the larger possibilities of Web 2.0 technologies outside of traditional ''client-side'' software applications but were ultimately unsuccessful. An Ophelia manager recalled:

> We tried to convince them of the potential of these technologies. We even looked at NASDAQ, which is the best example. They basically used a financial version of XML. We invested a lot of money in showing Lear that [Lear's product] was like a productivity version that consumed a lot of data . . . . but this evangelization is hard.

In spite of Ophelia's efforts, Lear's managers refused to expand the objectives to other product-applications of Web services technologies. As one Lear manager noted, ''We at Lear wanted to demonstrate [our products] as a smart client application. We defined this as the ability to consume Web services.'' The resulting search trajectory moved steadily toward Lear's lesser aspiration of integrating Ophelia's database with its application, missing major opportunities to innovate in the fast-growing Web 2.0 space.

Finally, when partners share leadership, they often make no changes to objectives or a few changes that usually diminish their initial aspirations. The collaboration ends up following shallow search trajectories. In the Wireless Networks case, for example, some participants wished to add new objectives during the technology development phase (#4). Yet because changes in objectives required sign-off from managers in multiple business units in both companies, they never received approval. As one manager said, ''This seems slow. We're just waiting [for Falstaff] to find the right manager. They need to bless the meetings.'' These managers either questioned the collaboration's value or tried to impose competing requirements. The resulting delays prolonged engineering activities such that milestones were missed. Eventually, disappointing progress reviews led to new executive leadership at Falstaff. Managers tried to impose a new objective using resources from other business units in the hope of salvaging the collaboration. In so doing, they significantly lowered their aspirations to an easier objective: ''Now we just want to have one successful in-depth relationship in the wireless space. We want to make sure there are three features that get adopted into Falstaff's wireless product line, and then into Macbeth's product line.''

Innovation performance. Zig-zagging objectives enable partners to search for potential innovations deeply within phases and broadly across phases as partners shift objectives. For example, early changes to objectives allowed Portia and Rosalind to ensure that a new set of carrier requirements was incorporated into the handset design in the Mobile Email case. Later changes in objectives led to an unexpected combination of a ''new'' user interface with an ''old'' software platform that was more robust than competitors' products: ''We provided features [that worked on the old] protocols. It sounds easy, but . . . this is a robust solution. The competition is already in the application layer, but now we stretch down into the deepest ISO layer to a really low level where you handle the radio signal on the network. This is the reason it works so well.'' Such search made it difficult for competitors to copy their solution. One Rosalind manager summarized the valuable innovative combination: ''It's been a hard road to hoe, but now that we're on the other side . . . [we see that the impact] is including their footprint in the market and our attractive brand. It is very positive.'' After eight changes to objectives, the innovative Mobile Email collaboration generated a new phone platform and multiple handset products with push email and various smartphone applications.

By contrast, when managers refuse to change the objectives to incorporate their partner's perspectives, they often fail to explore alternatives within the broad technology space and, ultimately, to innovate.[4] Moreover, when one partner dominates, the changes that do emerge often focus on responding to unexpected failures. For example, after limiting the product applications in the Web Services collaboration, Lear's managers refocused product development to target a much narrower market segment that would use Web services in only one application. An Ophelia manager complained, ''[Lear's] bar is too low for us. For Ophelia, we really want to reach more people and ultimately have mass-market appeal.'' Lear ultimately achieved its objective—combining Web services software with its applications—but in a routine way that was not innovative. A Lear manager admitted, ''Now, the application itself, was it the most compelling broad reach? No, no it wasn't.''

Finally, when partners share control, they often initiate some changes to objectives but they progress slowly toward achieving them. Prior research suggests that failing to meet objectives can lead to early dissolution of collaborations (Doz, 1996). Consistent with this view, one of our consensus cases, the VOIP Phone collaboration, was abandoned after a relatively short 21 months and six phases because of slow progress toward objectives. Yet slow progress does not always trigger dissolution. For example, after wireless chips were slow to develop during the technology development phase (#4) of the Wireless Networks collaboration, the partners consensually chose to reduce the number of chip features but continued the collaboration. This collaboration lasted 34 months with six phases, approximately average for our cases. Eventually, the partners agreed to five changes in objectives that led to workable products based on moderate improvements in technological performance. As one participant said, ''Those changes really saved us.'' The search trajectory, however, was relatively shallow compared with the trajectories of more innovative collaborations, and the resulting innovation was incremental at best. Another participant admitted, ''We ultimately did make a product. But it seemed we missed that strategic focus.''

An alternative explanation is that collaborations sometimes have inherently less ambitious objectives from the start. So changes to objectives are unlikely, and innovation will be limited. Yet this explanation seems unlikely because the initial objectives of the collaborations indicate comparably high aspiration levels across cases, such as ''We bet the company on this.'' Each collaboration also received extensive financial resources to fund day-to-day activities, extensive time and scrutiny from top managers, and assignment of multiple participants

[4] We appreciate the suggestions of an anonymous reviewer to consider how different processes might be modified to achieve different outcomes. So, for example, while dominating partners may have found other means to incorporate partners' perspectives, rotating leadership forces partners to do so.

for many months (described below). Moreover, all collaborations initially pursued opportunities that ultimately became important markets. Taken together, there is little evidence that failed collaborations were inherently less ambitious.

Rather, the data indicate that changing objectives enables partners to search the technology space broadly for innovations as they seek to achieve new objectives. These changes to objectives often define new technical problems, and so engender search for new ways to solve them. As a result, the partners search for innovations along fresh technological trajectories, leading to broader search and better innovations. At the same time, the partners retain enough stability in their objectives to create relatively deep search through which technical progress accumulates.

Fluctuating Network Cascades Mobilize Diverse Participants

Successful innovation typically requires leaders to mobilize diverse individuals to participate at different, appropriate times (Ibarra, 1993; Obstfeld, 2005). Yet prior research is relatively silent on how leaders might actually do this. In contrast, we observed a common mobilization pattern: in every phase of the collaborations, one or several people began a cascading mobilization of participants by contacting other individuals who in turn involved others. These cascades often mobilized networks of executives, managers, and engineers that spanned the two organizations (Davis, 2011).[5] But though all collaborations have cascades, there are differences in whether and how these cascades change across phases.

One pattern is a relatively stable cascade that repeatedly mobilizes the same participants who are predominantly from the same partner. That is, a stable cascade mobilizes the same participants from one organization throughout the collaboration. A second pattern is a stable cascade that mobilizes the same participants, but from both organizations. In contrast, a third pattern is fluctuating cascades in which leaders mobilize different, often new participants across phases and encourage others to involve different, new participants as well. The result is the mobilization of diverse participants over time. Like a waterfall whose flow shifts, fluctuating cascades vary the perspectives and resources applied to the collaboration.

We assessed participation in a cascade by tracking who participated in each phase, who mobilized them to do so, and in what order the mobilization occurred. For example, in the cascade Jane→Bob→Dave and Jill, it was Jane who began the cascade by enlisting Bob. Bob then simultaneously enlisted Dave and Jill. We measured an individual's participation in a cascade as occurring when two or more informants stated that this person worked on the collaboration, and we then tracked who enlisted his or her participation. We measured a set of cascade mobilizations as occurring in a sequence (e.g., Bob then Dave) when two or more informants could confirm that one person's

[5] In other research, we found that managers intentionally rewire these networks, sometimes forming and sometimes dissolving ties, to ensure that participants are connected at multiple levels in the hierarchies of both organizations. Though rewiring is no doubt important, these networks stabilize quickly, typically after the first phase, and most managerial efforts are spent facilitating interactions between participants who already have ties, suggesting that it is also important to understand how organizational processes shape how actors in the network come to participate in the collaboration. We appreciate the suggestion of an anonymous reviewer to clarify this distinction.

activation followed another's activation; otherwise, we conservatively recorded two activations as occurring in parallel (e.g., Dave and Jill) if we could not confirm this sequence. For ease of exposition, we term the first active participant in a phase as the cascade ''source.'' The source need not be senior to the next active member. In fact, cascade sources are often (but not always) project managers who enlist executives later in a cascade. In that sense, these activation cascades are not synonymous with directed network ties by which hierarchy is typically measured.[6]

Next, we assessed cascade fluctuation in each phase. Fluctuation occurs when the cascade in one phase is followed by a different cascade in the next phase. For example, the cascade above may be followed by the cascade Bob→Dave→Andrew in the next phase; Bob and Dave provide continuity across phases, while Andrew is new. We measured fluctuation in two ways. The first is the percentage *difference in participants between successive phases*. For example, if ten people participate in the current phase and only two of them did not appear in the prior phase, then the percentage of different participants in the current phase is 20 percent. This measure captures the fluctuation between two phases. The second is the percentage of *new participants in each phase*. This captures entirely new participants. For example, if one of the ten people in the example above begins work in the collaboration for the first time, then the percentage of participants in the current phase who are new is 10 percent. We computed both measures—different participants and new participants—for each phase, and then averaged them across phases to generate two measures of fluctuation for each case. Table 3, above, summarizes the results, and the Online Appendix (http://asq.sagepub.com/supplemental) provides the details. We also observed that fluctuations often occurred because of qualitatively different tasks in the new phase, in which different expertise seemed valuable; for example, Dave brings Andrew into marketing activities because of Andrew's detailed customer knowledge.

The security collaboration provides a good illustration of fluctuating cascades. This collaboration sought to develop new circuits to enable better network security. As Falstaff and Macbeth alternated control and changed objectives, managers mobilized many different and new participants in most phases. For example, as shown in the illustration in table 4, the design phase (#3) began when Macbeth's chief technology officer (CTO) directed his engineering vice president (VP) to prepare a design proposal for Falstaff's executives to review. Macbeth's CTO further encouraged this VP to mobilize others with critical expertise from both organizations. As one Falstaff employee explained, ''Macbeth always had this internal plan about how to use [Security circuit] technologies, and we started talking a lot about how we could use it on communications equipment. We were looking at each of our places in the ecosystem and thought, 'Gosh, wouldn't it be great if our products could have some kind of trustworthy association to improve security.''' Macbeth's VP continued the cascade by turning to his trusted subordinates, including two technical project managers, to help formulate the technical details of the ''advanced Security'' proposal for Falstaff. The team of three worked on the proposal until they found the ''right language'' for joint development. They then had a

[6] We appreciate the comments of an anonymous reviewer in suggesting we distinguish fluctuating cascades from the network structure of hierarchy.

breakthrough meeting in which they mobilized Falstaff executives. As one member described it, "Then we had this breakthrough meeting where we finally figured out how to pitch this to Falstaff. It became very clear . . . we would focus on getting a collaboration agreement figured out and, if we're going to get embarrassed, we'll just get embarrassed together."

Unbeknownst to Macbeth's participants, Falstaff participants called their security product managers to assess Macbeth's proposals. As one manager explained, "We had Peter and Maria in the room as Falstaff's executive sponsors," and it was not until "the next series of meetings that they brought in their lower level people to go into the bits and bytes." Overall, the design phase (#3) enlisted 78 percent different and new participants. Intriguingly, the resulting cascade added diverse participants from both organizations in ways that surprised the source of the cascade, Macbeth's CTO.

Participation fluctuated again as Falstaff's managers took the lead in the next phase, prototyping (#4). Falstaff's VP began the new cascade when he mobilized a trusted alliance manager who, in turn, enlisted an experienced engineering director to lead a Falstaff security engineering team to build prototypes. During the prototyping phase, seven different participants (88 percent of the total eight) were mobilized, six of whom were new to the collaboration (75 percent). A director and security team who had worked in prior phases were also mobilized in phase #4 and provided continuity.

Mobilizing Falstaff's engineering director was critical in this phase because he had deep connections into Falstaff's product groups and also knew security experts at Macbeth. Before this engineering director was mobilized, Falstaff's alliance manager admitted to "just sort of making it up, assuming this is what we're going to need." Even Macbeth's managers recognized a noticeable difference when this director was activated. Using a waterfall metaphor, one manager explained, "The beginning of Falstaff's waterfall seems slow. It seems slow for the water to fall into their product groups. . . . But he helped us reach their [security and hardware product] groups. People told us Falstaff was really product oriented. Now we're having that mindshift—they want to expand on the basic themes and show how they fit into a broader picture." Macbeth and Falstaff's product groups then worked together to develop prototypes that would become the basis of their new products.

In contrast, some collaborations have stable cascades. For example, collaborations that are controlled by a dominating partner often mobilize the same cascade that goes down the chain of command of the controlling firm. Yet because this partner never relinquishes control, few participants are mobilized from the other firm. For example, Lear generated similar cascades in each phase as it retained unilateral control of its Web Services collaboration with Ophelia. After the agreement phase (#1), Lear's executives always began cascades by calling the same two project managers. As a result, there was little diversity among participants. For example, the roadmapping phase (#2) mobilized 29 percent different and 29 percent new participants. The next platform development phase (#3) repeated the same cascade with no different or new participants. Sometimes, however, Lear executives did mobilize Ophelia participants. But Lear's co-leads would always call the same Ophelia manager who would then direct the lower-level employees to work on the collaboration. Although as a Lear manager described, "It took very little effort. We just talked to [Ophelia's project manager]." Lear failed to mobilize diverse participants.

Finally, after each phase was almost complete, the Ophelia project manager would mobilize his boss, Ophelia's VP of technology platforms, to approve the phase. Ophelia's project manager explained, ''Getting signoff from my boss wasn't hard. He just looked at it and said, 'That looks pretty good. I guess it will further our goals. Let's do it.'''

Limiting the involvement of Ophelia to the same managers and engaging them in quick ''sign-off'' duties in the early phases of the Web Services collaboration created obstacles to mobilizing Ophelia's technical platform experts when they were especially needed in later phases. These experts waited until their executives became personally involved before becoming engaged themselves. Even then, they were reluctant. For example, only 14 percent different and 14 percent new participants were mobilized in the product development phase (#4). These stable cascade patterns can be traced back to the roadmapping phase (#2), in which very few new participants were mobilized in the high-level planning of technology standards and milestones. The contrast with the innovative Security collaboration is striking—i.e., 29 percent new participants (i.e., two new people) compared with 70 percent new participants (i.e., seven new people) during the equivalent roadmapping phases (#2) in the Security collaboration.

Finally, collaborations with consensus control often also have stable cascades. These cascades often involve significant participation from both firms and have a pattern of ''maximum involvement'' that the initiating managers hope will mobilize a single large team to work together in every phase. Yet because of the high time commitment that these collaborations often require, managers were often able to mobilize fewer participants than they wished. They ended up with relatively stable cascades with stagnant participation from the same over-involved employees. For example, the VOIP Phone collaboration produced stable cascades: 33 percent different and 33 percent new participants were mobilized in the project scoping phase (#2), but no different and no new participants were activated in the subsequent technology development phase (#3). The recurring cascade involved the same pair of managers from both organizations, who always called on the same executives and then mobilized the same cross-functional team of functional experts and engineers in every phase. One manager claimed, ''We aim for maximal involvement.'' Managers asked participants to stay involved in all phases of the collaboration and waited until this lengthy activation cascade was complete before beginning the next phase.

This cascade pattern ossified over time. Team meetings became longer and more frequent. As one engineer described, ''This is just taking so long. We're just waiting.'' Moreover, although many participants were obliged to attend most meetings in each phase, many phases actually required fewer participants. Not surprisingly, potential new participants avoided this project because of the high and seemingly pointless time commitment of mobilizing in every phase. For example, several prominent technology experts, who might have rescued the collaboration from technical failure, refused to participate because they did not understand why they should attend every marketing meeting. Thus, ironically, initiating managers were unable to change their cascades to mobilize valuable experts in later phases.

Innovation performance. Fluctuating cascades mobilize diverse, new participants. By initiating cascades with different individuals and then encouraging them to continue mobilizing new and relevant people, the executives who initiate fluctuating cascades enhance the range of knowledge and perspectives without wearing down participants. The result is better innovation performance, as the Security collaboration illustrates. As described above, its fluctuating cascades involved new and different participants from various labs, divisions, and functional groups in each phase. The partners initiated cascades that mobilized 67 percent different and 44 percent new participants, on average, across phases. CTOs from both Falstaff and Macbeth provided continuity and orchestrated the initiation of these cascades by mobilizing diverse, yet relevant individuals and directing mobilized individuals to do the same. The collaboration secured beneficial diverse technical expertise in semiconductor design, chipsets, firmware, interfaces, and systems software from both organizations.

Consistent with prior research (Klein et al., 2006), executives are crucial to fluctuating cascades. They assert control over the initiation of cascades in ways that fit with the task demands of the phase. For example, as described above, executives initiated a cascade that resulted in mobilizing a technical director with security expertise that was critical in later phases. But these executives also initiated a cascade that mobilized lower-level engineering teams with expertise in computer networking, operating systems, and servers that was also critical to solving problems. As a Falstaff manager noted, ''We were making advances in network security with linkages to the server but we really needed control on the client. Collaborating with Macbeth's team on their chipset was an obvious candidate. . . . Now we are able to deliver value to customers in new ways.'' Managers attributed these and other innovations to their partner's expertise, mobilized through fluctuating cascades. As a Macbeth manager noted, ''We use a smaller team, or even one person, to be an architect and begin to flesh out the technical concepts, and then they gained access to the networking division, the enterprise group, and the communications group. Eventually we got through those barriers and once we did, things were on autopilot.'' These initiating executives also encouraged others later in the cascade to mobilize similarly diverse people. Moreover, these fluctuating cascades often engaged only relevant individuals and thus avoided the collaboration ''fatigue'' that plagued the stable collaborations that tried to mobilize many individuals for every phase. Overall, the Security collaboration was highly successful. It produced 19 patent applications as well as new and commercially successful products for both firms that solved complex security problems for enterprise customers and consumers. As one executive exclaimed, ''So, I really do feel strongly that this was a success.''

By contrast, stable cascades activate the same participants. When these cascades are dominated by one firm, knowledge diversity is limited and innovation performance diminishes. For example, the Web Services collaboration involved only 24 percent different and 18 percent new participants, on average. Lear's executives finally recognized during the product development phase (#4) of the Web Services collaboration that they lacked enough knowledge of Ophelia's technologies to reach milestones on time. By that time, potential Ophelia participants were wary and even disinterested in the collaboration. Yet the disadvantages of stable cascades often become apparent only later in the collaboration. When it became clear that the collaboration would generate only rudimentary Web services integration, Ophelia's VP proclaimed the collaboration ''dead on arrival.''

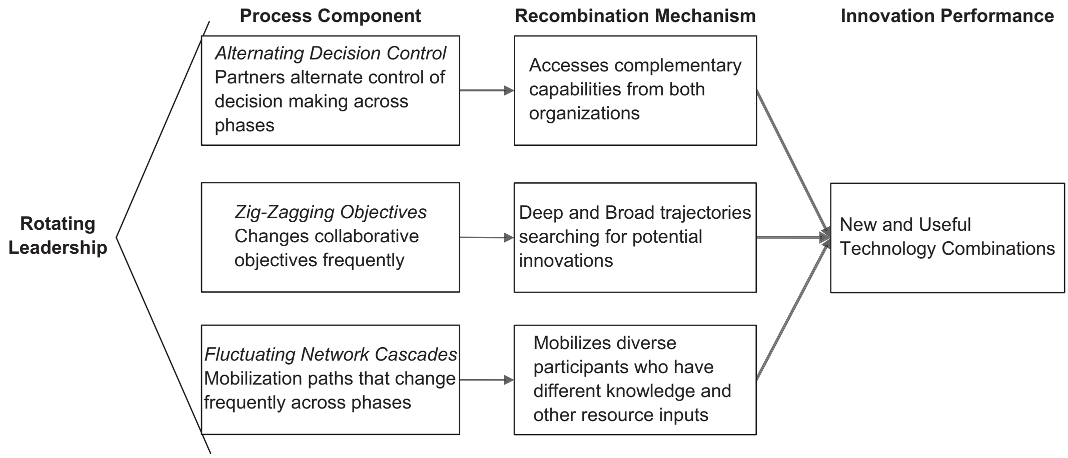
Finally, although collaborations that involve shared leadership are able to mobilize participants from both firms, they too often have stable cascades that limit diverse participation and diminish innovation performance. While attempting to gain broad participation, these collaborations also require extensive communication and complex coordination that drain participants and cause potential new participants to avoid participation. For example, managers of the Wireless Networks collaboration explicitly aimed for ''maximum involvement'' in every phase. Involving everyone in every meeting generated ambiguity about who was in charge and discouraged new potential participants with key expertise from joining. As a result, participation in these collaborations stagnated. Particularly in later phases, collaboration leaders were often unable to mobilize needed new participants. Overall, the Wireless Network collaboration suffered from too little diversity, especially in later phases, and had mediocre innovation performance.

An alternative explanation to fluctuating cascades for mobilizing diverse participants is that our collaborations differed in the degree to which diverse participants were needed. In this explanation, participants are assumed to automatically join relevant collaborations, and stable cascades simply reflect collaborations that did not require diversity. But this explanation is unlikely to be true. Our collaborations often had many of the same phases and yet had very different patterns of cascades (e.g., new participants in the product development phases of more vs. less innovative collaborations, like Security and Web Services). In short, although it seems that new participants might automatically join as appropriate, they in fact do not. Moreover, it is likely to be unrealistic to expect that participants can access the important knowledge of non-participants through informal practices like conversation because technical knowledge is typically tacit and difficult to transfer (Hansen, 1999; Rodan and Galunic, 2004). Fluctuating cascades are also important because those who initiate cascades often do not know which participants might be needed. They often have limited knowledge of participants beyond their local networks (Krackhardt, 1990; Casciaro, 1998). Overall, fluctuating cascades assemble diverse participants, a key mechanism that underlies successful innovation.

DISCUSSION AND CONCLUSION

We began by noting that despite some research linking structural antecedents to innovation in technology collaborations, there was little understanding of the collaborative processes that actually generate innovations. By selecting cases that share structural antecedent conditions, our study allowed for a greater focus on collaborative processes that are fundamental to collaborative innovation. Strikingly, despite sharing the structural antecedents in prior research, the collaborations we studied had widely varied innovation performance. Even partners that had strong innovative capabilities, appropriate governance forms, and longstanding embedded relationships can struggle with collaborative innovation. Our results provide insights about how different collaborative processes shape differences in recombination across organizational boundaries. Collaborations using two processes that may appear useful—consensus leadership and dominating leadership—ultimately generated less innovation than collaborations using a third process, rotating leadership.

Figure 1. Theoretical logic linking rotating leadership and collaborative innovation.



Our core theoretical contribution is to research on the organization of innovation. We describe how our rotating leadership construct links to innovation performance as shown in figure 1. Rotating leadership includes three components: alternating decision control, which enables both partners to make unilateral decisions that access their complementary capabilities, zig-zagging objectives, which frequently change technological objectives and redirect search trajectories, and fluctuating network cascades, which mobilize different and new participants across phases of the collaboration. As we describe below, rotating leadership better facilitates collaborative innovation than dominating and consensus leadership processes because it is likely to activate three major mechanisms related to the recombination of knowledge, technologies, and other resources across boundaries. These mechanisms include accessing complementary capabilities from interdependent partners with redundant structures, conducting deep and broad search for potential recombinations with a common technological trajectory, and marshalling diverse inputs to recombination from different participants in the boundary-spanning network.

Recombination Mechanisms in Collaborative Innovation

The first mechanism that underlies successful collaborative innovation is accessing complementary capabilities and resources from both organizations. Prior research suggests that the tacit and complex technical knowledge of capabilities is difficult to transfer, integrate, and recombine (Hansen, 1999; Rodan and Galunic, 2004). Though these features of knowledge certainly present challenges, we suggest that accessing complementary capabilities is particularly difficult because it requires alternation of control between partners. Although managers in dominating organizations believed they could access complementary resources from their partners without relinquishing control to them, they had troubles doing so because leading partners were unable to discern the basis of specific complementarity, and non-leading partners were less motivated to assist them without having decision control. Marshalling complementary capabilities from both partners seems to involve a difficult paradox—

unilateral control for both organizations—that is resolved by separating intervals of control over time through a series of alternations. And in contrast to shared control with consensus leadership, alternating control allows clear roles and the true basis of complementarity to emerge after participants examine their partner's behaviors and outputs in prior phases of control. Thus the temporal separation of control through alternating decision control allows both partners to access complementary resources.

The second mechanism is deep and broad search for potential innovations. This search pattern is by no means an inevitable outcome of simply accessing complementary capabilities. Although deep search can emerge from cumulative invention, prior research suggests that broad search is particularly difficult to achieve because innovative development involves uncertainty about the value of various recombinations, potentially long time frames, and a wide variety of possible technological trajectories that are difficult to evaluate in advance or even after the fact (Dosi, 1982; Dougherty, 1990; Henderson, 1995; Tripsas, 1997). We add to this literature by noting how objectives change collaboratively and what happens when they fail to do so. The stable objectives that often occur with dominating leadership fail to change not because dominating partners necessarily plan in advance all innovative activities (actually these partners clearly improve and react to conditions on the ground, often improving existing technologies incrementally). Instead, the failure is due to difficulty in taking their partners' perspectives and changing objectives. Consensus trajectories fail not because of a lack of planning (actually many conflicting plans emerge). Instead, these partners struggle to select and execute a single plan and thereby improve technical performance. Zig-zagging objectives allow partners to extend deep search trajectories in new broad directions as partners change objectives.

A third mechanism is accessing different recombination inputs from the diverse participants in a boundary-spanning network. Prior research suggests that brokers and boundary-spanning ties spur innovation because they are more likely to access diverse information (Tushman, 1977; Beckman and Haunschild, 2002; Burt, 2004; Obstfeld, 2005). But each of the collaborations that we studied included brokers and boundary spanners. This alone did not guarantee that diverse participants would be mobilized to bring their unique resources to the collaboration. Mobilizing diverse resources is difficult not only because diverse resources may not be present in a given network structure, but also because it is difficult to involve different team members who hold diverse resources to participate at different times. When compared with dominating and consensus leadership processes, both of which rely on mobilizing very similar participants across phases, fluctuating network cascades solve the problem of mobilization diversity.

Network Theory and the Performance of Dynamic Interorganizational Relationships

This study also contributes to network theory by providing a better understanding of the performance of interorganizational relationships. Some prior studies drawing on network theory assume that interorganizational ties are successful if they are long lasting or if they produce new ties. Other studies assume that structural antecendent conditions such as firm size, age, and experience will ensure successful ties. But though some structural conditions may be necessary (e.g., trust, capabilities, size) (Gulati, 1995b; Uzzi, 1997; Stuart, 1998), these conditions are not sufficient for success. They do not sufficiently constrain collaborative processes to determine a priori the outcomes that unfold. This presents a fundamental challenge for managerial action and scholarly explanations of performance. For example, we observed that a leading partner's strong R&D capabilities can drive executives to prefer dominating leadership, whereas strong embedded relationships innovation-oriented may lead partners to prefer consensus leadership. Yet strong capabilities and embedded relationships per se do not strictly determine whether consensus and dominating processes, respectively, emerge. Both of these structural antecedents can also yield rotating leadership. We conclude, therefore, that a process perspective productively complements the pervasive structural view to explain more fully the performance of network ties between organizations.

Considering process components separately and collectively may offer the most potential for explaining a broad range of innovation-oriented collaborations. An example is R&D alliances in the pharmaceutical industry, where asymmetric collaborations between large drug and small biotech companies are the norm (Doz, 1988; Owen-Smith and Powell, 2003). Large drug companies may desire innovative collaborations with small biotech firms, but a problem arises if their well-established routines for controlling decision making in these asymmetric relationships make it difficult for them to alternate control. In this context, we might expect dampened alternation but sufficient fluctuation, resulting in partial innovation benefits at best. Thus such differences in power and resources may imply a different weighting to process components.[7] Our E-Commerce case is instructive because it was a moderately performing collaboration that mixed dominating and rotating leadership. Although Lear's managers intended to control the entire collaboration, their plan was thwarted for one phase (#4) in which control alternated unexpectedly to Mercutio and then later unexpectedly back to Lear. As a result, this case provides our best test available for the idea that unplanned rotations can be effective even without support from planned rotations. The net effect of alternation in this collaboration was to break Lear's inward focus and central planning, radically change the objectives, and rescue this collaboration from total failure. This suggests that even a subset of rotating leadership components can provide some benefits. Future research could explore this further.

Rotating Leadership and Symbiotic Relationships

A final theoretical contribution resolves a puzzle in the network literature on interorganizational relationships and organizational adaptation. Typically, long-lived relationships are thought to become inertial and less beneficial as the opportunities for interpartner learning and recombination become exhausted with time (Hamel, 1991; Doz, 1996; Hargadon and Sutton, 1997; Fleming, 2001). Even the long-lived, socially embedded relationships that have been studied involved mostly routine exchanges in stable environments in which adaptation was not a primary concern (Gulati, 1995b; Uzzi, 1997). The puzzle is how organizations maintain so-called symbiotic relationships, which continue to

[7] We thank an anonymous review for suggesting we consider rotating leadership in the context of asymmetric power and resources.

be adaptive for long periods of time despite the tendency to become inertial. An important example is the multidecade relationship between Intel and Microsoft, as Burgelman (2002: 341) noted in his study of Intel:

> [Intel's CEO] Andy Grove described the relationship . . . as ''two companies joined at the hip.'' While constantly vying for perceived leadership of the PC industry and jealously guarding their own spheres of influence (software for Microsoft and hardware for Intel) most of the time the two companies were able to maintain their symbiotic relationship.

How do organizations develop symbiotic relationships that combine longevity and mutual adaptation? Rotating leadership may be part of the answer because of its capacity to facilitate innovative development over a series of collaborative alliances. Prior research shows that innovations are often precursors of adaptive changes to strategies and organizational structure (Greve and Taylor, 2000). We found some evidence linking rotating leadership with adaptive changes to strategy and structure. Specifically, partners used new technologies, products, and platforms from innovative technological collaborations to enter new markets (Security, Middleware, Mobile Email), shift to more open IP regimes (Middleware, VPN System), and create new business units (Security, Middleware, VPN System). By contrast, less innovative technology collaborations lead organizations to exit existing businesses (Wireless Networks), cede new markets to competitors (E-Commerce, VOIP Phone), and dissolve or sell business units (Wireless Networks, Web Services). In dynamic environments, these positive adaptations may have a generative effect. By facilitating mutual adaptation, rotating leadership may create a context in which new collaborations emerge and symbiotic relationships are extended in time. Of course, not all managers use the same processes in all collaborations, and not all collaborations between symbiotic partners need always use rotating leadership. For example, only one of three of Macbeth and Falstaff's collaborations in this study used rotating leadership, but it was used in the collaboration that innovated most extensively. Yet it is still reasonable to expect that even the occasional use of rotating leadership could underlie the longevity of these relationships if the resulting innovations generate new collaborations.

Boundary Conditions and Relevance to Dynamic, Interdependent Environments

As in all research, it is important identify key boundary conditions. We note two major ones. First, rotating leadership is likely to be particularly relevant in interdependent environments. In environments like the computer industry in which value chains are disaggregated and technical leadership is divided among firms (Bresnahan and Greenstein, 1999; Adner and Kapoor, 2009), rotating leadership solves the underlying boundary-spanning recombination problems that emerge. In these industries, building innovative products often involves changing architectures that span sector boundaries (Jacobides, 2006; Ozcan and Eisenhardt, 2008). By contrast, non-interdependent industries may have many competing firms that lack clear complementarities, and technology collaboration is both less common and less important.

Second, rotating leadership is likely to be particularly relevant in dynamic environments in which collaborations are highly unpredictable. Rotating leadership often involves unplanned alternations, unexpected changes to objectives, and a shifting array of participants that are useful in contexts in which unforeseen combinations must be developed for value to be created. Therefore we expect rotating leadership to be most useful in dynamic markets in which genuinely new technological opportunities are emerging, and a process that generates unpredictable outcomes is likely to be germane (Davis, Eisenhardt, and Bingham, 2009).

Overall, our theoretical framework reaches boundary conditions in non-interdependent and non-dynamic industries in which organizations lack useful technological complementarity and the need to develop surprisingly novel and useful combinations (i.e., innovations). In these industries, dominating or consensus processes may be well suited to collaborations, given the costs of alternating control. Finally, rotating leadership is likely to be relevant beyond interorganizational collaborations. We expect that it applies to any technology collaboration in unpredictable environments that crosses the boundaries of groups that have complementary capabilities. These collaborative innovation phenomena include cross-business-unit collaborations within an organization, cross-discipline collaborations within an R&D unit, and cross-group collaborations in innovation communities outside of organizations where the fundamental mechanisms that underlie innovation are the same. If our emergent theory of rotating leadership survives further empirical test, it could provide a richer account of the collaborative innovation phenomena that are increasingly relevant in dynamic and interdependent industries.

Acknowledgments

We are especially grateful for the insightful comments and generous support of Mark Granovetter, Riitta Katila, Rebecca Henderson, Ezra Zuckerman, Kate Kellogg, Nandini Rajagopalan, Susan Silbey, Deborah Ancona, and Roberto Fernandez. We also thank seminar participants at the Consortium on Competitiveness and Cooperation (CCC), West Coast Research Symposium, STVP seminar, Harvard Business School, INSEAD, MIT's Sloan School, Northwestern's Kellogg School, Pennsylvania State University, University of California at Davis, University of California at Irvine, University of North Carolina, University of Washington, University of Toronto, London Business School, IESE, Wharton Technology Entrepreneurship Conference, Organization Science Winter Conference, MIT-Harvard Economic Sociology Seminar, and MIT Distributed Leadership Seminar for helpful comments. Support for this research was provided by the National Science Foundation (IOC Award #0621777), the Stanford Technology Ventures Program, and MIT's Sloan School of Management. Finally, we thank Philip Anderson and three anonymous reviewers for their helpful comments. An earlier version of this paper won the Academy of Management Newman Award for Best Paper from a Dissertation and the Technology Innovation Management Division Best Paper Award.

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