A PROCESS THEORY OF KNOWLEDGE COMBINATION ROUTINES IN PROJECT-BASED ORGANIZATIONS

By

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ABSTRACT

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The purpose of this dissertation is to understand the process of innovation through knowledge combination in organizations. My particular interest is how firms manage knowledge combination to produce ongoing novel outputs. Central to my framing is a conceptualization of knowledge combination as an organizational capability expressed in routines. Knowledge combination experiences generate learning that changes routines and guides subsequent performances. Ongoing innovation occurs both as a direct output of knowledge combination routines and as such routines themselves undergo change. These distinctive characteristics of knowledge combination are extended and clarified using exploratory empirical studies based on 16 project-based firms and agent-based computer simulation modeling.

DEDICATION

I dedicate this work to parents, both of whom enriched my life with their love, sacrifice, support, and prayer.

이 논문을 위해 사랑으로 이끌어주시고 격려해주신 양가 부모님
(최철기, 강금옥 / 이용헌, 박정수)께 바칩니다.

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INTRODUCTION

Combining distributed and specialized knowledge is one of the primary roles of firms (Grant, 1996a; Grant, 1996b; Kogut & Zander, 1992). Different knowledge is embedded and distributed across individuals within an organization (Hayek, 1945; Tsoukas, 1996). Firms create new technology, products, and services by combining existing knowledge (Nelson & Winter, 1982; Schumpeter, 1934). Knowledge combination has been embraced as an unobserved process for a variety of organizational phenomena: knowledge creation (Nahapiet & Ghoshal, 1998; Nonaka & Takeuchi, 1995); dynamic capability (Teece, Pisano, & Shuen, 1997), internationalization (Buckley & Carter, 2004), innovation (Collins & Smith, 2006; Henderson & Clark, 1990; Schumpeter, 1934; Smith, Collins, & Clark, 2005), ambidexterity (Benner & Tushman, 2003), and absorptive capacity (Cohen & Levinthal, 1990).

Knowledge combination remains under-theorized, with most studies employing it as an unobserved explanation rather than exploring its process. Theorists invoke knowledge combination as process logic to explain the causal relation between observed inputs and outcomes (e.g., Collins & Smith, 2006; Taylor & Greve, 2006). This approach does not directly address directly how knowledge combination actually occurs in organizations and cannot describe or explain the key events and their sequence. Further effort is required to develop a process theory of knowledge combination in organizations that builds upon recent studies examining this topic (e.g., Gardner, Gino, & Staats, 2012; Yang, Phelps, & Steensma, 2010; Yayavaram & Ahuja, 2008)The purpose of this dissertation is to enhance our understanding of the process of knowledge combination within organizations. In addition, by conceptualizing knowledge combination as organizational routines, this dissertation considers knowledge combination as a series of ongoing organizational actions rather than as a punctuating event. The overall question of this dissertation is: *how do firms organize knowledge combination to generate ongoing novel outputs*?

With the goal of advancing the understanding of knowledge combination process within organizations, this dissertation is organized as follows. Chapter 1 provides a new theoretical framework for knowledge combination, recognizing that knowledge combination occurs at different levels within organizations: intrapersonal and collective (interpersonal). In addition, Chapter 1 characterizes collective knowledge combination as organizational routines: knowledge combination routines (KCRs). Chapter 1 explains the knowledge combination process in terms of interactions between the ostensive and performance aspects in organizational routines (Feldman & Pentland, 2003).

Chapter 2 builds from the conceptual arguments of Chapter 1 and conducts multiple exploratory case studies. Case studies in 16 project-based firms reveal that firms can produce ongoing novel outcomes by means of knowledge combination routines (KCRs). This implies that organizations that continuously provide new customized products and services rely on fairly consistent repeated processes to combine knowledge. Chapter 2 empirically examines the components of KCRs: problem definition, team formation, and problem execution. In addition, this study identifies organizational contingencies that influence problem definition, team formation, and problem execution.

Chapter 3 builds a computational model of team formation and examines how organizational structure affects team formation efficiency under different project characteristics. This chapter considers the effects of two alternative organization structures—functional and team-based—and a set of project attributes on the time required to staff project teams. The agent-based computational model in Chapter 3 is firmly grounded in the findings of multiple case studies in Chapter 2. The findings of Chapter 3 suggest that the effect of organizational structures on team formation efficiency is contingent on the project attributes. In addition, this model highlights transactive memory as a key mechanism for team formation.

In sum, these three chapters develop a process theory of knowledge combination in organizations. Each chapter is designed to be both integrated into the core themes of the dissertation (knowledge combination routines) and with clear modularity for future publication in a traditional journal format.

Chapter 1

ONGOING INNOVATION THROUGH KNOWLEDGE COMBINATION ROUTINES

OVERVIEW

This chapter elaborates a theory of the process of knowledge combination in organizations. I begin by distinguishing collective knowledge combination from intrapersonal knowledge combination. Collective knowledge combination carries implications for knowledge transfer, the role of artifacts, and the importance of coordination. Central to my framing is a conceptualization of collective knowledge combination as an organizational capability expressed in routines. Knowledge combination experiences generate learning that changes routines and guides subsequent performances. Ongoing innovation occurs both as a direct output of knowledge combination routines and as such routines themselves undergo change.

INTRODUCTION

“*To produce means to combine materials and forces within our reach.... To produce other things...means to combine these materials and forces differently” (Schumpeter, 1934: 65).*

One of the fundamental ways for firms to create new knowledge is to combine existing knowledge (Fleming, 2001; Kogut & Zander, 1992, 1996; March, 1991; Nelson & Winter, 1982; Schumpeter, 1934). For example, when communication technology combined with information technology, cell phones were transformed into personal computers. When traditional combustion engine technology was combined with electronics and batteries, hybrid cars emerged. Bringing together the music and television broadcasting businesses produced MTV.

Previous literature associates knowledge combination with knowledge creation (Nahapiet & Ghoshal, 1998; Nonaka & Takeuchi, 1995; Yang et al., 2010), innovation (Collins & Smith, 2006; Henderson & Clark, 1990; Schumpeter, 1934; Smith et al., 2005; Taylor & Greve, 2006), absorptive capacity (Cohen & Levinthal, 1990), and dynamic capabilities (Eisenhardt & Martin, 2000; Teece et al., 1997), resulting in competitive advantages (Grant, 1996a, 1996b) and internationalization opportunities (Buckley & Carter, 2004) for firms. However, knowledge combination remains undertheorized, with most studies invoking knowledge combination rather than exploring the process. Further effort is required to develop a theory of knowledge combination in organizations that builds upon the recent studies examining this topic (e.g., Collins & Smith, 2006; Fleming, 2001; Yang et al., 2010; Yayavaram & Ahuja, 2008).

This study advances the theory of knowledge combination in two ways. First, it distinguishes and explains knowledge combination at two levels of analysis: intrapersonal and collective. Prior research often makes the individual the locus of knowledge combination. This intrapersonal focus makes knowledge transfer an essential mechanism to access new knowledge for combination. However, intrapersonal knowledge combination is just one possible approach to knowledge combination within organizations. Knowledge also can be combined at the collective level by connecting—rather than transferring—individuals' specialized knowledge. I contend that the collective level is a common and efficient alternative way to combine distributed knowledge within organizations and, as such, the emphasis within knowledge combination research should shift from *transfer* to *connections* to explain much of the knowledge combination that occurs in organizations.

Second, this study characterizes the process of knowledge combination as an organizational routine. As such, I can draw upon the routines literature for background to develop a theory of the knowledge combination process. In particular, this study extends to knowledge combination a theoretical framing in terms of the ostensive and performative aspects of organizational routines (Feldman & Pentland, 2003). The performative aspect represents specific actions within knowledge combination routines and it consists of three subprocesses: problem definition, team formation, and project execution. The ostensive aspect, which guides the knowledge combination subprocesses, develops through the accumulation of declarative, transactive, and procedural memory over time. The interplay of the ostensive and performative aspects frames an understanding of the knowledge combination process and its dynamics. Within an understanding of knowledge combination as routinized collective action, innovation is an ongoing organizational process and capability. Problem changes, human agency, interactions among actors and actions, and unavailability or turnover of organizational members can be sources of change in knowledge combination routines. The dynamics of knowledge combination routines explain how innovation arises out of routinized actions and it suggests a duality of innovation and operations within organizations.

This study begins by describing knowledge combination. I distinguish knowledge combination processes at the intrapersonal and collective levels. Then I recast knowledge combination as organizational routines with ostensive and performative aspects. This sets up a description of the process and dynamics of knowledge combination routines and their implications for innovation.

KNOWLEDGE COMBINATION WITHIN ORGANIZATIONS

Knowledge combination is the process of bringing together different kinds of knowledge to produce integrated outputs. My definition of "knowledge combination" is equivalent to "knowledge integration" as used by Okhuysen and Eisenhardt (2002) to signify a process by which several individuals combine their uniquely held knowledge to create knowledge (see also Grant, 1996a, 1996b). The definition of this paper encompasses "knowledge recombination" as a special case creating an *unprecedented* combination (Nahapiet & Ghoshal, 1998; Rodan & Galunic, 2004). The knowledge combined is both declarative (know-what) and procedural (know-how). The integrated outputs take the form of performed services and physical products. The generation of an integrated result that connects distinct kinds of knowledge distinguishes knowledge combination from proximate knowledge that is never truly combined.

In general, there are two ways to innovate when combining knowledge. First, novel knowledge combinations occur by connecting previously unassociated knowledge (e.g., Buckley & Carter, 2004). Second, a combination process can reconfigure knowledge previously associated (e.g., Nahapiet & Ghoshal, 1998; Yayavaram & Ahuja, 2008). Galunic and Rodan (1998) identify these two forms of combinative innovations as *syntheses* and *reconfigurations*.

Intrapersonal Knowledge Combination

Knowledge combination can occur within an individual. For instance, the sole inventor, scholar, or designer combines prior knowledge to create new ideas, technologies, and products. Intrapersonal knowledge combination draws upon knowledge already possessed by individuals. However, individuals might lack some of the necessary knowledge due to various constraints such as lack of time, resources, opportunities, attention, or motivation. For knowledge combination to remain an intrapersonal process, individuals must address recognized knowledge deficits by acquiring the needed knowledge; hence, they engage in search, which if successful results in knowledge transfer. When one party learns vicariously from another's experience, knowledge has transferred (Argote, 1999; Singley & Anderson, 1989). Internalizing knowledge is logically prior to combining knowledge intrapersonally. Hence, the current literature recognizes knowledge transfer as a key process associated with knowledge combination.

This emphasis on knowledge transfer directs attention to social networks that serve as conduits of knowledge (Mors, 2010; Rodan & Galunic, 2004). For example, Rodan and Galunic (2004) showed that diversity in network content positively affects a manager's innovation performance through knowledge transfer. Simmelian ties generate individual innovations by enhancing knowledge transfer (Tortoriello & Krackhardt, 2010). Simmelian ties occur when the parties in a dyadic tie are each reciprocally connected to a common third party (Krackhardt, 1999). Mors (2010) examined how the density of a manager's relational network affects that manager's ability to access and integrate diverse information and, eventually, personal innovation performance.

Computational modeling studies also emphasize knowledge transfer for intrapersonal knowledge combination. For instance, March's (1991) model allowed individuals to change the combination of their beliefs as a consequence of socialization through an organizational code that reflected the dominant beliefs among better performing individuals (cf. Kane & Alavi, 2007). Miller, Zhao, and Calantone (2006), Kim and Rhee (2009), and Fang, Lee, and Schilling (2010) modeled direct person-to-person learning resulting in new intrapersonal combinations of beliefs. Similarly, Chang and Harrington (2007) allowed interpersonal learning based on an experience-weighted attraction rule, in which favorable learning experiences strengthen the probability of further learning exchanges in the future. In these models, beliefs acquired from superior performers produce new knowledge combinations within individuals.

I should distinguish *possessing* diverse knowledge from *combining* such knowledge. Possessing diverse knowledge is a necessary, not sufficient, condition for knowledge combination. Empirical and modeling research focusing on interpersonal knowledge transfer often leaves the intrapersonal knowledge combination process unexplored. Unless transferred knowledge is linked with existing knowledge, knowledge learned from others remains merely a *potential* component for combination and no unique combinative output results.

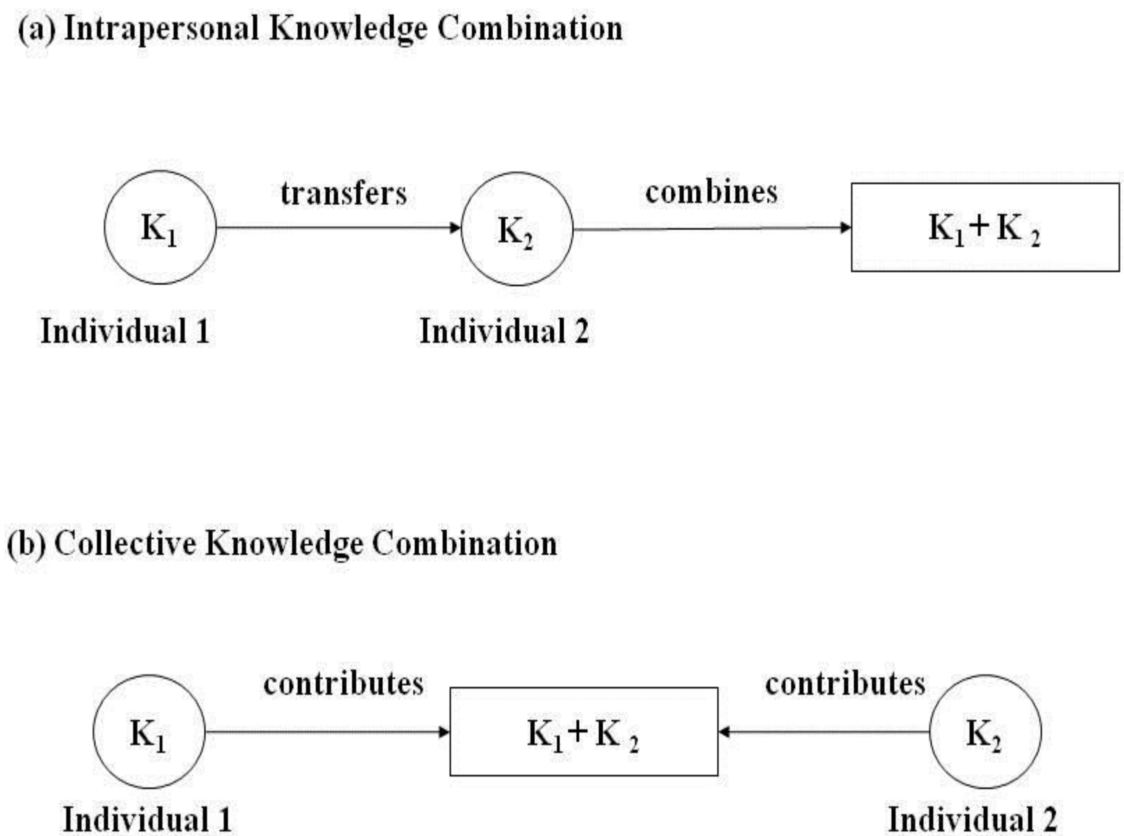
Transferring knowledge is very costly and time consuming—particularly when the knowledge is tacit (Galunic & Rodan, 1998; Polanyi, 1962; Polanyi, 1967) . Buckley and Carter (2004) identified three categories of barriers that inhibit transferring knowledge for combination: geographic distance (which reduces awareness of others' knowledge and inhibits communication), knowledge boundaries (due to differences in individuals' expertise, norms, and languages), and opportunism (expressed as unwillingness to share information). Grant (1996b:114) concluded that "*transferring* knowledge is not an efficient approach to *integrating* knowledge. If production requires the integration of many people's specialist knowledge, the key to efficiency is to achieve effective integration while minimizing knowledge transfer through cross-learning by organizational members” [emphasis in original]. Similarly, Postrel (2002) indicated that organizations solve the problem of combining individuals’ specialized knowledge without achieving overlapping understanding through knowledge transfer.

From a knowledge-based view, organizations exist to provide an efficient alternative to intrapersonal knowledge combination (Kogut & Zander, 1992, 1996). The potential for efficiency gains shifts the locus of knowledge combination from the individual to the collective level.

Collective Knowledge Combination

Collective knowledge combination occurs by connecting specialized knowledge across individuals (Grant, 1996b). Figure 1 depicts graphically how collective and intrapersonal knowledge combination differs. For intrapersonal knowledge combination, an individual possessing knowledge K_1 engages in search and acquires the additional knowledge K_2 for subsequent combination ($K_1 + K_2$). In contrast, when knowledge combination occurs at a collective level, knowledge transfer may be unnecessary. Instead, individuals pool their specialized knowledge through simultaneous or sequential activities. Linking the knowledge distributed across individuals within an organization makes the combination process a collective phenomenon. The term “collective” denotes individuals acting as a group (Weick & Roberts, 1993) and interrelating with others with a focus on shared goals (Morgeson & Hofmann, 1999).

Figure 1
Intrapersonal and collective knowledge combination



Compared with intrapersonal knowledge combination, collective knowledge combination has distinct implications for knowledge transfer, artifacts, and coordination. Table 1 provides an overview of the characteristics of intrapersonal and collective knowledge combination discussed in the rest of this section. The top row of Table 1 emphasizes that in the move from intrapersonal to collective knowledge combination *connections* among individuals displace *transfer* as the key means for accessing knowledge.

Table 1
Differences between intrapersonal and collective knowledge combination

	Intrapersonal knowledge combination	**Collective knowledge combination**
Key mechanism	Knowledge transfer	Knowledge connections
Knowledge transfer	Prior to combination Intentional Complete	Simultaneous with combination Unintentional Limited
Artifacts	Tools Externalize results	Boundary objects Products or performances
Coordination	Irrelevant	Essential

Knowledge transfer. Although I have emphasized that collective knowledge combination avoids the need for costly knowledge transfer, the process nevertheless provides opportunities to learn from others. However, knowledge transfer in collective knowledge combination takes a different form from that in intrapersonal knowledge combination.

First, knowledge transfer occurs during the combination process. In intrapersonal knowledge combination, knowledge transfer necessarily precedes the combination process (Figure 1a). At the collective level, knowledge transfer is not logically prior to combination. Instead, transfer can occur simultaneously with combination. Learning from others can be an unintended byproduct when individuals participate in collective knowledge combination (Lindkvist, 2005).

Second, knowledge transfer in collective combination occurs to a limited extent compared to that in intrapersonal knowledge combination. Rather than acquiring the entirety of the knowledge combined, participants learn select parts of others' knowledge—generally, those that relate closely to their own knowledge and facilitate coordinated effort. Group members share enough of their knowledge for others to benefit from their knowledge without having to learn what the others know (Buckley & Carter, 2004).

Artifacts. Groups combining knowledge often use and produce artifacts. Artifacts include tangible objects such as prototypes, designs, models, machines, blue prints, and maps. Artifacts embed the knowledge of their creators and convey such knowledge between people (Bechky, 2003a; Carlile, 2002). Artifacts aid coordination by communicating information about tasks (Bechky, 2003b) and participants' knowledge (Carlile, 2002). Boundary objects enable individuals with different specialized knowledge to collaborate (Carlile, 2002, 2004). As products, artifacts serve as the medium for connected knowledge. Tangible products store the outcomes of prior collective knowledge combination efforts for subsequent use (Hargadon & Sutton, 1997).

Artifacts are not the only possible outcome from collective knowledge combination. Collective performances are another expression. Whereas artifacts store combined knowledge, collective performances aggregate the actions of individuals. Hence, what distinguishes artifacts from performances is the shift from things (nouns) to actions (verbs) as outcomes. A performance can use and even generate artifacts that capture aspects of the participants' knowledge, but the performance transcends the contents of such artifacts (Polanyi, 1962). The sheet music used by an orchestra is such an artifact. The actions of the musicians create a sensory experience that endures only (and imperfectly) in the memories of the participants and observers. Participants in a collective performance adjust to others' actions not only by following shared plans or shared mental models, but also by heedfully attending to one another

(Druskat & Pescosolido, 2002; Weick & Roberts, 1993) and improvisation (Miner, Bassoff, & Moorman, 2001; Moorman & Miner, 1998b)

Like teams, an individual may use artifacts as tools in an intrapersonal knowledge combination process. Whereas products or performances are necessary for collective knowledge combination (i.e., they are the results), individuals have the option of engaging in knowledge combination as a cognitive exercise that produces neither of these outcomes. In such cases, products and performances are optional ways to externalize one's combined knowledge (for future recall or sharing with others).

Coordination. Because contributions to collective knowledge combination are interdependent across multiple individuals, they require coordination (Buckley & Carter, 2004; Grant, 1996b). Coordination involves integrating or linking together disparate actions by different people and managing interdependencies to accomplish a collective set of tasks (Kozlowski & Bell, 2003; Van de ven, Delbecq, & Koenig, 1976). Grant (1996b) suggested that coordination is a key mechanism to connect individuals' specialized knowledge. Coordination can precede knowledge combination, but often coordination and execution occur simultaneously as an expression of collective improvisation (Moorman & Miner, 1998a).

Individuals have opportunities to learn which participants have which knowledge, thereby building their transactive memories (Wegner, 1987). Transactive memory provides an efficient means to access knowledge beyond one's expertise through relationships with others (Bechky, 2006; Brandon & Hollingshead, 2004). Through their experience working together, participants also can develop procedural knowledge about how to work together (Cohen & Bacdayan, 1994). Organizational members draw upon their accumulated transactive and procedural knowledge to coordinate subsequent collective knowledge combination. Such coordination often occurs through lateral self-organizing, rather than hierarchical planning and control(Zoethout, Jager, & Molleman, 2006). By definition, coordination is largely irrelevant to the intrapersonal knowledge combination process. Whereas the need for knowledge transfer makes intrapersonal knowledge combination time consuming and costly, coordination among participants makes collective knowledge combination complex and challenging.

Having clarified the key features that distinguish collective knowledge combination from intrapersonal knowledge combination, I now turn my attention to framing theoretically the collective knowledge combination process. Identifying collective knowledge combination as an organizational routine allows us to gain insights into the process and its dynamics from the routines literature.

COLLECTIVE KNOWLEDGE COMBINATION AS A DYNAMIC ORGANIZATIONAL ROUTINE

Organizational Routines and Knowledge Combination

Previous studies acknowledge organizational routines as a key mechanism for combining knowledge (Argote, McEvily, & Reagans, 2003; Grant, 1996b; Hargadon & Sutton, 1997; Kogut & Zander, 1992; Nelson & Winter, 1982). These studies portray routines as forms of organizational memory that repeatedly combine knowledge according to established patterns. However, routines also can be sources of novel knowledge combinations. For example, Hargadon and Sutton (1997) studied an organization with routines to acquire, store, and retrieve knowledge in order to create new combinations of old ideas. Such routines carry out the organization's intention to innovate. Routines serve as *carriers* of established knowledge combinations and as *sources* of new knowledge combinations. Routines differ along a continuum in their relative emphases on these two purposes.

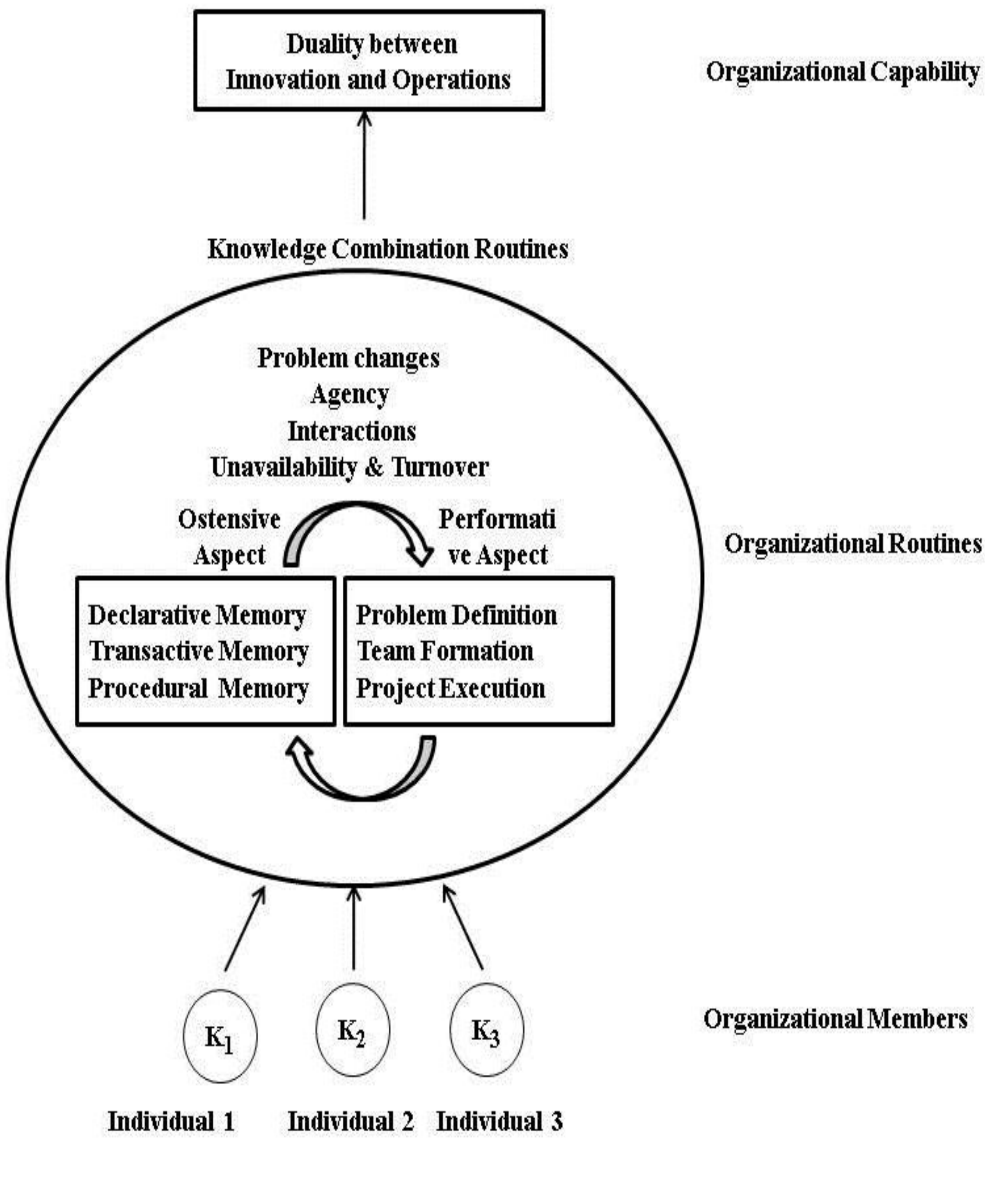
Feldman and Pentland (2003: 96) defined a routine as "a repetitive, recognizable pattern of interdependent actions, involving multiple actors." Collective knowledge combination qualifies within this definition of organizational routines. First, collective knowledge combination involves multiple actors whose actions are interdependent. Unlike intrapersonal knowledge combination, collective knowledge combination brings together specialized knowledge distributed over multiple individuals within an organization. Actors express their knowledge through actions, not just mental processes, and jointly produce knowledge combinations through their interactions. Second, collective knowledge combination is an ongoing and recurring pattern within many organizations. Although major innovations may not be daily occurrences, the work of generating knowledge combinations is ongoing. Third, knowledge combination reflects learned patterns. Efficiency and effectiveness improve by accumulating knowledge combination experiences in organizational memory. For instance, Yayavaram and Ahuja (2008) showed that semiconductor firms form coupling patterns by linking knowledge elements over time. Ongoing and repetitive knowledge combination develops patterns of ties connecting individuals, thereby forming intraorganizational networks that link together existing knowledge. Connections between actors, actions, and knowledge content areas make up observable repeated patterns in collective knowledge combination routines.

In sum, *a knowledge combination routine is a repeated pattern connecting distributed knowledge within an organization, involving multiple actors to generate customized outputs.* Organizational participants who possess specialized knowledge repeatedly collaborate with each other to produce products and services and their collective actions develop into cognitive and behavioral patterns for combining knowledge.

In the past, routines were considered a source of organizational rigidity (Gersick & Hackman, 1990) and inertia (Hannan & Freeman, 1984)due to their stability. Nelson and Winter's (1982) chosen metaphors for routines, such as "genes" and "memory," portrayed routines as a source of stability. However, more recent studies describe continuous change within routines (Feldman, 2000; Feldman & Pentland, 2003; Pentland & Rueter, 1994) and present them as sources of organizational flexibility (Feldman, 2000; Feldman & Pentland, 2003). This revised understanding has led to the development of new theory focused on routine dynamics. This study extends this line of research to knowledge combination. In particular, I build on the distinction between the *performative* and *ostensive* aspects of organizational routines (Feldman & Pentland, 2003) to advance a process theory of knowledge combination.

Figure 2 summarizes my overall theoretical framing of collective knowledge combination as a multilevel phenomenon. Beginning from the bottom of the figure, the process involves individuals with distinct knowledge who join together in teams that collectively combine their knowledge. Experiences working together in teams to combine knowledge produce learning and actions that generate a repeated pattern of collective knowledge combination. Cumulative experience and changes in knowledge combination routines give rise to an organizational capability for ongoing innovation. The rest of this chapter explains the various aspects of this theoretical framing.

Figure 2
Multilevel perspectives for collective knowledge combination



The type of organization that we have in view is *project- based*. Project-based firms organize most of their internal and external activities in projects (Hobday, 2000; Lindkvist, 2004) and create systems for performing project tasks (Lundin & Söerholm, 1995; Sydow, Lindkvist, & DeFillippi, 2004). Projects are organizational activities characterized by particular goals and time limits, and the set of competencies that they require (Sydow, Lindkvist, & DeFillippi, 2004). Project-based firms set up temporary teams to combine and reconfigure their existing knowledge to meet clients' demands. For project-based firms, combining knowledge is not a rare event; instead, it is an ongoing and recurring process that characterizes its operation and provides the firm's basis for generating economic value. Project-based firms are prevalent in a variety of industries that produce customized solutions for clients—such as professional services, cultural experiences, and complex products (Hobday, 2000).

Performative Side of Knowledge Combination Routines

The *performative* side of a routine is its particular instantiation consisting of specific actions taken by specific people at specific times (Feldman & Pentland, 2003). For my topic, the performative aspect refers to the actions taken by organizational members involved in collectively combining knowledge. The actions associated with collective knowledge combination fall into three specific subprocesses: problem definition, team formation, and project execution. As I move from the performative aspect to the ostensive aspect, I will connect these three subprocesses to three forms of memory—declarative, transactive, and procedural.

Problem definition. Responding to problems generally requires diagnosing their nature and searching for potential solutions (Cyert & March, 1963). By bringing their needs and expectations, clients play a critical role in defining the problems that project-based firms address (Hobday, 2000). However, the problems that clients bring to organizations often require clarification; thus, initial work focuses on problem definition. Organizational members examine a problem and identify which knowledge is required to advance toward its resolution. Furthermore, they need to analyze the relations among the required knowledge for clues that guide their knowledge combination effort. The constraints and opportunities identified through the problem-definition subprocess guide subsequent steps in the knowledge combination process. The identification of needed knowledge and the sequencing of tasks in the combination process define the resulting project plan.

One approach to problem definition is to relate a current problem to a past problem through analogical reasoning (Gavetti, Levinthal, & Rivkin, 2005). Simon (1962: 480) notes, "One way to solve a complex problem is to reduce it to a problem previously solved—to show what steps lead from the earlier solution to a solution of the new problem." Another basic technique to clarify a problem is to divide it into a number of components where knowledge available within the organization applies. Through the *means-end analysis*, a problem is factored into existing knowledge that corresponds to each task (March & Simon, 1958), thereby identifying the knowledge that the organization must combine to complete a project.

Two specific challenges to problem definition are *task ambiguity* and *problem underspecification*. A task is ambiguous when the knowledge needed is unapparent from clues within the problem (Siemsen, Kamdar, Subramani, & Li, 2011; Sommer & Loch, 2004). Ambiguity arises from the impenetrable nature of the problem itself or lack of awareness and relevant knowledge on the part of those attempting to diagnose the problem. A problem is underspecified to the extent that different tasks could equally fulfill the problem's requirements. Underspecified problems give the organization latitude to choose the kinds of knowledge used and the way to combine them; they provide space for creative constructivist responses.

Team formation. To combine knowledge, it is essential to bring together individuals who possess specialized knowledge (Okhuysen & Eisenhardt, 2002). A team is a critical platform for accomplishing the collective work of combining knowledge (Guimera, Uzzi, Spiro, & Amaral, 2005; Wuchty, Jones, & Uzzi, 2007). Team size, knowledge diversity, and team experience affect the outcomes from collective knowledge combination efforts (Aime, Shamsie, & Johnson, 2010; Taylor & Greve, 2006). Staffing decisions affect the knowledge available for subsequent combination, as well as the efficiency and effectiveness of the team's work.

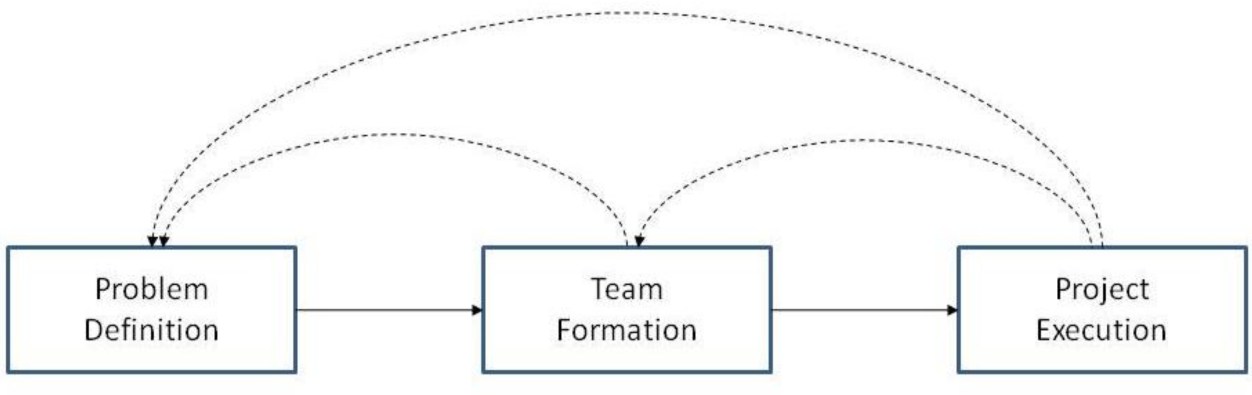
Typically, projects are assigned at their outset to a project manager who takes the lead in forming the team by identifying and inviting members. The project manager taps her network of relationships within the organization to identify individuals with knowledge relevant to a project. Members added to the team bring their own social networks from which to identify further team members. In a decentralized process, team members are empowered to both identify and invite other members onto the team. Complex and cross-functional projects may require project teams composed of subteams with differentiated responsibilities or multi-team systems (Marks, Dechurch, Mathieu, Panzer, & Alonso, 2005).

Project execution. Knowledge gets combined when team members perform together the tasks needed to resolve a defined problem. One of the characteristics of collective knowledge combination is that each individual has responsibility for certain tasks that require specialized knowledge (Enberg et al., 2006). Individuals' skillful actions expressing procedural knowledge and guided by declarative knowledge accomplish tasks and, ultimately, complete projects.

Collective knowledge combination goes beyond acts of intellect and a simple division of labor; it includes social behaviors among interdependent actors (Huang & Newell, 2003). As highlighted earlier, the interdependent nature of collective knowledge combination demands that attention be given to coordination (Buckley & Carter, 2004; Grant, 1996b). Participants' shared understandings help to resolve differences in interpretations and combine different perspectives successfully (Carlile, 2004; Dougherty, 1992).

Although there is a logical progression in moving from problem definition to team formation and then project execution, the process is not strictly unidirectional. Figure 3 depicts the steps in the process in their logical sequence from left to right (following the solid-line arrows); however, it also includes iterative loops that circle back to prior steps (dotted-line arrows). These iterative loops acknowledge that teams may return to earlier steps even as they progress through team formation and project execution. Learning during project execution may reveal new constraints and opportunities that cause the team to reanalyze and redefine the problem. Team members may be added as needs arise over time and changes in team composition alter the eventual process for completing a project.

Figure 3
Performative aspects of knowledge combination routines



Ostensive Side of Knowledge Combination Routines

The ostensive side of routines refers to abstract patterns of action (schemas) that provide individuals with guidance and explanations for performing routines (Feldman & Pentland, 2003).

Generally, the understandings that form the ostensive side of a routine are distributed among organizational members, rather than stored in a single individual or repository (such as a manual of operating procedures) (Feldman & Pentland, 2003, 2008). Pentland and Rueter (1994) compared the ostensive aspect of a routine to a grammar that enables many possible expressions. The ostensive aspect bounds how an organization connects knowledge, but by underdetermining the performance, the ostensive aspect allows for flexible and varied expressions of a routine. Guidance from the ostensive aspect is critical to delimiting knowledge combination because the set of possible knowledge combinations increases exponentially with the number of knowledge elements available (Fleming, 2001).

Memory is essential to the formation of routines, as well as their persistence (Argote et al., 2003; Nelson & Winter, 1982; Walsh & Ungson, 1991). Paoli and Prencipe (2003) suggested that memory reduces the need for search by saving prior successful experiences that guide future action. Over time, as individuals discover and remember successful actions, memory displaces search, thereby informing actions and generating recognizable, repeated problem-solving patterns. Recently, Miller, Pentland, and Choi (2012) connected the ostensive aspect of organizational routines to three different kinds of individual-level memory—procedural, declarative, and transactive—and specified distinct roles for each in forming and changing organizational routines. Here we elaborate the roles of these three kinds of memory in the ostensive side of knowledge combination routines.

Declarative memory. Declarative memory stores “know-what” (Singley & Anderson, 1989). It contains understandings of many sorts, such as facts, descriptions, narratives, and propositions. Declarative knowledge is, in principle, articulable, although often declarative knowledge provides background understandings that are neither focal nor articulated while working on a project (Polanyi, 1962). Declarative knowledge serves two roles in the knowledge combination process. First, it enables individuals to recognize the need or opportunity for knowledge combination. Individuals diagnose problems and infer appropriate responses based on their declarative knowledge (Miller, Pentland, & Choi, 2012). Declarative knowledge enables individuals to examine a problem and, from clues within the problem, determine the tasks to perform and the knowledge required. Furthermore, even when an individual or team cannot determine through direct investigation what knowledge is required, memories of past problems can yield presumptions that guide what needs to be done through analogical reasoning (Gavetti et al., 2005). In sum, declarative memory stores knowledge relevant to diagnosing problems and drawing inferences that guide subsequent problem-solving actions.

Second, declarative knowledge can be the content brought together in project execution. This is most clearly seen in the creation of products, where the products themselves serve as stores of knowledge brought together in unique configurations. Such knowledge can be rediscovered by reverse engineering products. However, performances also contain identifiable declarative knowledge. For example, participants in a meeting cite data and theories; the cast performing a play embodies a narrative. In these ways, performances, just as products, serve as media for conveying declarative knowledge.

Transactive memory. Once members determine what needs to be done to address a problem, they still need to search for people with the relevant competencies. Transactive memory ("know-who") guides the search for knowledge to supplement one's own expertise (Wegner, 1987). By storing assessments of who knows what, transactive memory enables individuals to treat others as external stores of diverse knowledge (Wegner, Erber, & Raymond, 1991). This reliance upon others makes possible knowledge specialization and collaboration.

Transactive memory allows individuals to approach others on an as-needed basis to tap expertise that is impossible for any single individual to internalize and retrieve.

By definition, connecting differentiated knowledge distributed over individuals is essential for collective knowledge combination (Lindkvist, 2005). Through the use of transactive memory, organizations bring together project teams consisting of members who possess knowledge relevant to addressing the distinct facets of particular problems. Transactive knowledge maps task requirements to specific individuals who can work together as a team that combines distinct areas of expertise (Brandon & Hollingshead, 2004).

Procedural memory. Procedural memory stores the capacity for skillful action ("know-how"). Procedural knowledge is demonstrable (through task performance) but never fully articulable; it always has a tacit dimension (Polanyi, 1962). Additionally, procedural knowledge confers an ability to respond appropriately to others' actions. Procedural memory enables individuals to collaborate effectively with others when performing routines (Cohen & Bacdayan, 1994). Hence, procedural knowledge encompasses both the capacity to perform tasks independently and collaboratively. As noted earlier, the ostensive aspect of organizational routines is not a single shared understanding; instead, it combines the diverse situated understandings of participants (Feldman & Pentland, 2003; Pentland & Feldman, 2008). Hence, although participants involved in knowledge combination draw upon their procedural knowledge to facilitate their work together, the process requires communication and adjustments during the interaction.

Drawing upon and applying declarative knowledge always requires procedural competence (Polanyi, 1962). As such, procedural knowledge complements declarative knowledge during problem definition and project execution. Likewise, forming a team calls for procedural knowledge that complements transactive knowledge. However, to the extent that the tasks involved in problem definition, team formation, and project execution differ, so the needed specific complementary procedural knowledge differs across these stages. For instance, relating to a client is essential to problem definition, negotiating with potential members arises in team formation, and coordinating tasks occurs during project execution.

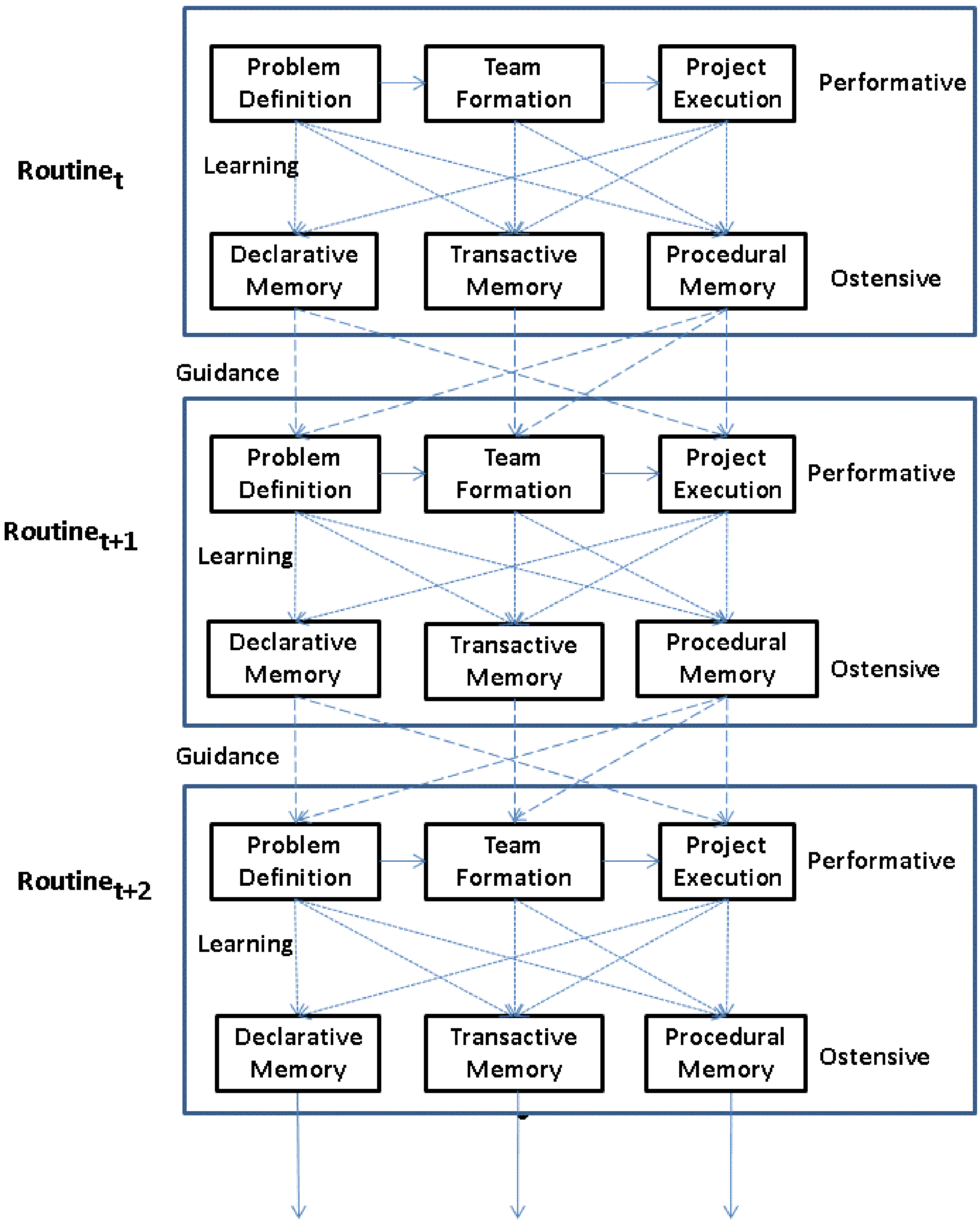
Mutuality of the Performative and Ostensive Sides

Thus far, I divided the performative aspect of knowledge combination routines into three key subprocesses: problem definition, team formation, and project execution. Furthermore, I described the ostensive aspect of knowledge combination routines as consisting of three forms of memory—declarative, transactive, and procedural. The relation between the ostensive and performative aspects of organizational routines is mutual and iterative (Feldman & Pentland, 2003) as illustrated in the center portion of Figure 2. The performances of organizational members create, maintain, and modify the ostensive aspect. In turn, the ostensive aspect guides and accounts for particular performances. The result is a path-dependent process. The dependence of performances on learning from prior experiences continues with each iteration of the knowledge combination process. Knowledge combination routines form and evolve as the organization completes a series of projects over time.

Figure 4 presents details of the dynamics between the ostensive and performative aspects of knowledge combination routines. Horizontally, the diagram follows the three steps that make up the performative process of the routine (as in Figure 3). Learning arising from project experience accumulates in declarative, transactive, and procedural memory. Problem definition and project execution experiences contribute to declarative memory. Individuals have opportunities to gain new declarative knowledge through search and interpersonal knowledge transfer but, as argued earlier, such learning is limited because it is difficult and costly. Possibilities for adding to transactive memory occur throughout all three subprocesses. Whereas team formation explicitly identifies who knows what, knowledge revealed by team members during problem definition and project execution also accrue to transactive memory. Likewise, growth in procedural memory can result from any of the three subprocesses, but—as noted earlier—the relevant kinds of procedural memory differ across the subprocesses. Through practice, individuals hone their personal procedural skills, but the primary opportunity for new procedural learning relates to coordinating interdependent actions among individuals. Hence, the most necessary and accessible learning outcomes from performing knowledge combination routines are transactive knowledge and procedural knowledge for interpersonal coordination.

Accumulated knowledge then guides the organization's response to the next problem. The three categories of memory making up the ostensive side inform the routine's performance differently. Particular forms of memory play distinctly prominent roles within each of the knowledge combination subprocesses. Declarative knowledge guides problem definition and project execution, but has no direct bearing on team formation. Transactive knowledge primarily informs team formation. Procedural knowledge—of its various sorts—enters into all three subprocesses. Knowledge combination routines form and evolve as the organization completes a series of projects over time.

Figure 4
Dynamics of a knowledge combination routine



In line with Feldman (2000, 2003) and Feldman and Pentland (2003, 2008), my contention is that routines—which are patterned—produce novel outcomes. Distinctive performances of a routine produce new associations among existing knowledge. Furthermore, the routines themselves are dynamic (i.e., the action patterns of routines change over time). Changes to knowledge combination routines occur in the ongoing interplay between their ostensive and performative aspects. Novelty arises both within a particular performance of a routine and across performances (i.e., the horizontal and vertical dimensions of Figure 4). *Hence, innovation occurs both as a direct output of knowledge combination routines and as the ostensive aspect of these routines undergoes change.* The knowledge and experience gained and expressed in knowledge combination routines make up an organization's capability to innovate.

Sources of Change in Knowledge Combination Routines

Now I turn my attention to identifying the specific sources of change in knowledge combination routines. Although specific to knowledge combination, my presentation addresses the general question of how change arises in organizational routines (see Feldman, 2000, 2003; Feldman & Pentland, 2003).

Problem changes. Discussions of change in organizational routines have given insufficient attention to variation in the problems arising in organizations' operating contexts as a causal factor. An organization is an open system that responds to the varied and changing needs of its clients. A continual stream of new problems provides organizations with opportunities to apply their knowledge in different ways (Hargadon & Sutton, 1997). Problems differ in their complexity (Fang, Lee, & Schilling, 2010; Nickerson & Zenger, 2004; Simon, 1962) as well as in the kinds of knowledge that they require, and both of these differences force adjustments in routines.

New problems provide learning opportunities that change the ostensive side of knowledge combination routines. As project team members confront a new situation, they apply understandings from prior project experiences and update their memories based on their exposure to the new situation (Skilton & Dooley, 2010). During problem definition, team formation, and project execution individuals update their declarative, transactive, and procedural memories. New problems stimulate new connections among disparate knowledge, new relations among individuals, and new ways of acting individually and collectively. All aspects of the ostensive and performative side of knowledge combination routines are open to revision in the face of problem changes.

Agency. Pentland and Feldman (2003) suggested agency as the source of ongoing changes in the performances of organizational routines. The agency explanation for novelty in routines emphasizes the autonomy of individuals within the collective performance. Unreflective and mindless action is present to some extent in routines, but the courses of action individuals choose hold possibilities for motivated and effortful innovation.

Agency draws upon learning from past experiences but responds to the present situation by imagining alternatives, making choices, and enacting new possibilities (Emirbayer & Mische, 1998). Due to human agency, even though the ostensive aspect guides the possibilities for action within a routine, its constraints do not strictly determine the actions that people take (Pentland & Rueter, 1994). Individuals can innovate even in contexts characterized by rules and social expectations (Bourdieu, 1990) and they can modify actions to make sense of what they are doing (Weick, 1995). The new actions that come from exercising human agency modify the ostensive aspect of routines through the iterative relation between the performative and ostensive aspects.

Changes in individual actions in knowledge combination routines come from various interrelated processes, including reflection (Archer, 2007), imagination (Weick, 2005; Weick, 2006), creativity (Amabile, 1988), and improvisation (Moorman & Miner, 1998a, b). Feldman (2000) suggested four drivers of initiatives to change routines based on observed outcomes from performances: (1) actions do not produce the intended outcomes, (2) actions create new problems, (3) actions develop new opportunities, and (4) actions produce what was intended but participants see ways to improve. These responses reflect—at an individual or group level—behavioral responses to performance feedback (Cyert & March, 1963) and the search for new opportunities (Carter, 1971).

Interaction. Routines involve multiple actors whose actions are *interdependent* (Feldman & Pentland, 2003). Hence, problem changes and the exercise of individual agency tend to have ripple effects throughout a routine as others adjust to an emerging sequence of actions. Individual initiatives may have unforeseen and unintended consequences elsewhere in a project's execution.

While solving problems together, participants in collective knowledge combination discuss their ideas with each other and receive evaluative feedback (Lindkvist, 2005). Important collective learning occurs as individuals express their ideas and beliefs and challenge each other's views (Argyris & Schön, 1978). Participants have opportunities to transform and modify their knowledge while making themselves open to influence (Carlile, 2004). For instance, meetings in project teams stimulate participants' imaginations, raise new questions and clues about solutions, and align expectations and actions (Enberg, Lindkvist, & Tell, 2006). Productive dialogue includes self-distanciation and opens up new distinctions concerning tasks and knowledge (Tsoukas, 2009). These interactions stimulate co-evolution of differentiated knowledge (Lindkvist, 2005).

The changes in knowledge combination routines that come from interactions with others characterize evolving communities of practice. Participants develop and share noncanonical practices as they interact (Brown & Duguid, 1991).

Personnel unavailability and turnover. Because individuals matter to the performance of routines, the unavailability of individuals—due to attending to conflicting activities or permanent departure from the organization—is a further source of change in routines. When participants in knowledge combination routines become unavailable or leave the organization, they take their personal memories with them (Carlile, 2004). This implies that the absence of organizational members disturbs established knowledge combination routines. Because the ostensive aspect is distributed across participants (Feldman & Pentland, 2003), organizational members rely upon and are less than perfect substitutes for others' ostensive understandings of a routine. When specialization and interdependence are high, unavailability of regular participants is quite disruptive and—at the extreme—renders the remaining participants' knowledge unusable.

Turnover brings replacements into the organization, but new hires are never perfect substitutes for the experienced individuals who departed; they bring different beliefs and experiences to the knowledge combination process. Their very presence makes the context for their performance and learning unique relative to the organization's prior experience. If newcomers are outsiders who lack relationships with existing team members, their insertion into the routine causes disruption and holds the potential to generate novel and creative outcomes (Skilton & Dooley, 2010). Hence, changes in the organization's membership introduce variations in the performative and ostensive aspects of knowledge combination routines.

DISCUSSION

I began this study by explaining how knowledge combination can occur either individually or collectively within organizations. Whereas intrapersonal knowledge combination emphasizes *transferring* knowledge to an individual, collective knowledge combination *connects* individuals with specialized expertise (Figure 1). These contrasting processes can be seen in the organization learning literature focused on knowledge transfer (e.g., Osterloh & Frey, 2000) and transactive memory systems (e.g., Lewis, Lange, & Gillis, 2005), respectively. These two different knowledge combination mechanisms have the distinguishing characteristics summarized earlier in Table 1. The conceptual and empirical differences between the intrapersonal and collective levels of analysis should guide future research examining the structures and processes of knowledge combination.

I have argued that knowledge transfer often is not cost effective—particularly when knowledge is complicated and tacit. Hence, organizations meet the requirements of knowledge combination by bringing together people who possess specialized knowledge (Buckley & Carter, 2004; Grant, 1996a; Grant, 1996b; Kogut & Zander, 1992; Postrel, 2002; Tsoukas, 1996). Such processes feature social networks as mechanisms for connecting knowledge rather than as conduits for transferring knowledge. An emphasis on the processes connecting individuals with diverse knowledge within organizations would complement the prevailing research emphasis on knowledge transfer and produce a more comprehensive theory of knowledge combination.

Related to the shift from the individual to the collective level as the locus of knowledge combination, I characterized knowledge combination as an organizational routine. Feldman and Pentland's (2003) distinction between the ostensive and performative aspects of routines framed my presentation of the nature and dynamics of knowledge combination. My study identified problem definition, team formation, and project execution as the specific subprocesses within knowledge combination routines. Furthermore, I tied these three subprocesses to three types of memory—declarative, transactive, and procedural—that make up the ostensive side of knowledge combination routines. Moving beyond the process of executing a single routine (Figure 3), I analyzed the dynamics of knowledge combination routines over the course of repeated projects, in which an iterative mutual relation between the ostensive and performative aspects emerges (Figure 4).

My description of key constructs and their sequencing and dynamics over time advances a process theory (see Van de ven & Poole, 1995) of knowledge combination. In particular, my analysis reveals that different types of knowledge play unique roles in the knowledge combination process. Declarative knowledge is important to defining problems and executing projects. Transactive knowledge guides the formation of teams. Procedural knowledge enables the actions and interactions involved all three subprocesses, thereby complementing transactive and declarative knowledge.

Also, the three subprocesses making up the performative side of knowledge combination routines contribute differently to organizational learning. Figure 4 summarizes which subprocesses can contribute to forming which kinds of memory. Problem definition and project execution provide opportunities to update all three kinds of memory, whereas the team formation process contributes only to transactive and procedural memory. Although there are many potential learning opportunities, I argued that the primary learning outcomes from performing knowledge combination routines are transactive knowledge and procedural knowledge for interpersonal coordination.

My study also contributes to the routines literature. I elaborated the ostensive aspect of routines by specifying how the three types of memory involved form and examining their unique roles in guiding knowledge combination routines, thereby extending a recent study by Miller et al. (2012). That earlier study relied upon a simplified characterization of the roles of declarative, transactive, and procedural memories to suit the method of agent-based modeling, whereas the current study presents a richer and more nuanced description of how these three forms of memory work together in the ostensive side of routines. More generally, my presentation addresses the important—and still open—question of how change arises in organizational routines (see Feldman, 2000, 2003; Feldman & Pentland, 2003). My study responds to the recent call to explain how behaviors that are patterned and persistent generate creative and novel outcomes (Salvato & Rerup, 2011).

Because knowledge combination is one of the primary ways to generate innovations (Henderson & Clark, 1990; Nelson & Winter, 1982; Schumpeter, 1934; Taylor, 2010; Yang et al., 2010), the process and dynamics of knowledge combination routines carry important implications for organizations. To the extent that knowledge combination is routinized in organizations, innovations are not merely episodic (i.e., punctuating) events or driven by exogenous environmental shifts (cf. Barley, 1986; Romanelli & Tushman, 1994). Instead, knowledge combination routines are sources of ongoing innovation. Performances of knowledge combination routines can differ from one occurrence to the next due to problem changes, human agency, interactions among actors and their actions, and disruptions due to unavailability or turnover of organizational members. Distinct performances of a knowledge combination routine revise participants' ostensive understandings of the routine. Accordingly, knowledge combination routines are both *sources* and *objects* of innovation. Each performance of a routine has the potential to generate a novel outcome and alter the routine itself. In this way, firms develop routines that sustain an organizational capability for repeated innovation.

By implication, ongoing operations and innovation are integrally related. Combining knowledge is the operational core of project-based firms (Enberg et al., 2006). As such, operations and innovation are interdependent and mutually enabling (as depicted in the top portion of Figure 2). The relation between operations and innovation is a duality—rather than a dualism—that aligns with the duality of stability and change (Farjoun, 2010).

Schumpeter (1987) argued that innovation gets routinized as economic development gradually leads to greater specialization. Similarly, other studies in economics suggested that under competitive market pressures firms systematize innovation and make innovation a predictable and controllable process through standardized R&D (Baumol, 2002a, b). This study complements this thesis at the level of industries and the macroeconomy by focusing on the intraorganizational process of innovation through knowledge combination routines.

The process theory of this paper has implications for the practice of project management. The most notable message is that projects are platforms for ongoing innovation. Project teams are simultaneously the locus of operations and innovations. Managers must balance stability and change across projects. Excessive focus on stability in project management undermines opportunities to innovate, but dramatic changes in routines can nullify lessons learned from past projects. Key steps for managing routines include (1) filtering and routing the projects that receive attention, (2) determining the scope and incentives for individual agency, (3) establishing teams and their interaction processes, and (4) scheduling individuals' assignments and limiting turnover.

The scope of this paper is limited to knowledge combination routines in project-based firms. Some organizations do not face a stream of client-generated problems and rarely respond by forming teams that bring together diverse knowledge. Repetition is essential to routine formation (Feldman & Pentland, 2003; Pentland, 1992), so when compared with project-based firms, firms that address dissimilar and infrequent problems are likely to take an ad hoc approach to problemistic search (Cyert & March, 1963) with limited learning carrying over from one problem-solving experience to the next. Future research should explore how problem variety and frequency affect the process of knowledge combination in organizations.

This study addresses the lack of an established process theory of knowledge combination in organizations by presenting a general framework. Researchers can advance further this process theory by examining the details of its subprocesses and contingencies. In particular, empirical research can generate contextualized theories of the middle range (Boudon, 1991; Merton, 1992). For instance, intensive longitudinal case studies could examine in depth how the collective knowledge combination process functions in different kinds of organizations. Case studies also can enrich the process theory offered here by specifying organizational and individual factors that influence problem definition, team formation, project execution, and the learning process over time.

This study combined distinct streams of research for the sake of advancing the theory and practice of knowledge combination in organizations. I hope that this study encourages further integration of research on knowledge combination and routines to understand how ongoing innovation occurs in systems of distributed knowledge.

Chapter 2

A PROCESS THEORY OF KNOWLEDGE COMBINATION ROUTINES

OVERVIEW

This study examines how firms manage knowledge combination for ongoing production of novel outputs. Multiple case studies in sixteen project-based firms reveal that firms can introduce ongoing novel outcomes by means of knowledge combination routines (KCRs). KCR enables a firm to come up with novel outputs by relying on common procedures. This study clarifies the process of knowledge combination in organizations by analyzing KCRs. KCRs consist of three events: problem definition, team formation, and project execution. Problem definition sets a scope for knowledge combination. Team formation influences available knowledge and problem execution unites this knowledge. This study identifies organizational contingencies that influence each stage in the process.

INTRODUCTION

Diverse knowledge is distributed across individuals within an organization (Buckley & Carter, 2004; Hayek, 1945; Tsoukas, 1996). One of the primary roles of firms is to combine this distributed knowledge and to do so more effectively and efficiently than markets (Grant, 1996a; Grant, 1996b; Kogut & Zander, 1992). Knowledge combination is the process of bringing together different kinds of knowledge to produce integrated outputs (Nahapiet & Ghoshal, 1998; Okhuysen & Eisenhardt, 2002; Rodan & Galunic, 2004). Knowledge combination supports a variety of organizational phenomena such as knowledge creation (Nahapiet & Ghoshal, 1998; Nonaka & Takeuchi, 1995), dynamic capabilities (Teece et al., 1997), internationalization (Buckley & Carter, 2004), innovation (Collins & Smith, 2006; Henderson & Clark, 1990; Schumpeter, 1934; Smith et al., 2005), ambidexterity (Benner & Tushman, 2003), and absorptive capacity (Cohen & Levinthal, 1990).

Researchers have often treated knowledge combination as a punctuating event, rather than as an ongoing repeated organizational process. By this account, sporadic problems drive innovation search that culminates in combining existing knowledge to create new products (Katila, 2002). Disruptive exogenous forces—such as new technologies (Barley, 1986) or environmental changes (Romanelli & Tushman, 1994)—can drive organizations to combine knowledge in new ways. Adopting the view that knowledge combination is an occasional problem-driven response provides little basis for considering knowledge combination as a process for generating continuous innovation (Brown & Eisenhardt, 1997; Hargadon, 2003; Hargadon & Sutton, 1997; Hargadon, 1998). This study examines project-based firms where knowledge combination is an ongoing and recurring phenomenon, rather than a punctuating event.

Knowledge combination remains under-theorized, with most studies employing it as an unobserved explanation rather than exploring the process. Theorists invoke knowledge combination as a process logic to explain the causal relation between observed inputs and outcomes (e.g., Collins & Smith, 2006; Taylor & Greve, 2006). This approach does not address directly how knowledge combination actually occurs in organizations and cannot describe or explain the key events and their sequence. Further effort is required to develop a process theory of knowledge combination in organizations that builds upon recent studies examining this topic (e.g., Gardner et al., 2012; Yang et al., 2010; Yayavaram & Ahuja, 2008). In response, this study puts forward such a theory by examining empirically how firms manage knowledge combination for ongoing production of novel outputs.

Evidence from this study reveals that organizations establish routines to manage knowledge combination to generate ongoing novel outcomes. Knowledge combination routines (KCRs) are *repeated patterns of action connecting distributed knowledge within an organization, involving multiple actors to generate customized products and services.* A KCR gives organizational members a common framework and guidance for combining knowledge across different projects; it enables a firm to come up with novel outputs by relying on common and repeated procedures.

This study advances a process theory of knowledge combination by analyzing the components of KCRs. KCRs consist of three stages: problem definition, team formation, and problem execution. Problem definition sets a scope for knowledge combination. Team formation influences available knowledge and project execution unites this knowledge. This study identifies organizational contingencies that influence problem definition, team formation, and problem execution.

Because there is little research and theory addressing the knowledge combination process, this study takes a theory-building approach based on multiple case studies. Theory building from case studies is a research strategy suited to understanding how a focal phenomenon works (Eisenhardt, 1989; Eisenhardt & Graebner, 2007). The next section describes the sample, the data collected, and the analytical techniques used. Following this is a description of the findings that emerged from the data and their implications for understanding knowledge combination processes. The final section discusses broader implications from this study.

METHODS

Sample

The context of this study is project-based organizations (PBOs). A PBO organizes around the performance of projects and creates systems to do so (Lundin & Söerholm, 1995; Sydow, Lindkvist, & DeFillippi, 2004). PBOs are prevalent in a variety of industries such as cultural production, professional consulting services, engineering, construction, and manufacturing. PBOs combine knowledge distributed among organizational members to meet clients' recurring demands for customized solutions (Enberg, Lindkvist, & Tell, 2006; Lindkvist, 2005). Projects are the core operating activity of PBOs that provides their basis for generating economic value.

This study examined sixteen PBOs located in the Midwestern U.S. The sampling approach employed—theoretical sampling (Glaser & Strauss, 1967)—chooses cases for theoretical reasons, not statistical reasons. The goal of theoretical sampling is to select cases that replicate or extend the emergent theory (Eisenhardt, 1989). Chosen firms (1) organize most of their activities in projects for external customers (Hobday, 2000), (2) deploy teams that consists of members that bring specialized knowledge (Lundin & Söerholm, 1995; Sydow et al., 2004), and (3) have more than 20 employees. The third criterion suits my interest in organizations that repeatedly put together project teams with distinct membership. Whereas small organizations involve the same members working together repeatedly on project teams, the number of possible combinations of team members increases disproportionately with organization size.

Table 2 provides a brief overview of the participating firms and the subjects interviewed. Company names are pseudonyms to assure the respondents' anonymity. The cases were chosen from distinct industries to increase the generalizability of the resulting theory of the knowledge combination process. XY Marketing, MH Furniture, and ST Service are large firms that have specialized departments that handle customized projects for clients so the interviews focused on people from those departments. In addition, ST Service and ST Furniture are divisions of the same company.

Data Collection

Data came from three sources: (1) in-depth interviews, (2) follow-up e-mails and phone calls, and (3) archival sources relevant to knowledge combination.

I first collected information about participants' backgrounds through an online survey covering their job description, seniority, and project experience. Appendix A provides the questionnaire. I made sure that participants had work experience relevant to explaining the knowledge combination process in their firm. The major data source was 93 in-depth interviews during 2011with individual informants from all sixteen cases. Of these, 79 were conducted in person at the company's facility and 14 over the telephone.

Table 2
Case descriptions

Case	Pseudonym	Industry	# of employees	Interviews			
				Senior managers	Project managers	Team members	Total interviews
1	AB Architecture	Architectural design	130	1	2	3	6
2	CD Foundry	Foundry manufacturing	700	1	3	2	6
3	EF Construction	Construction	150	1	3	1	5
4	FG Design	Architectural design	501	1	2	3	6
5	HI Media	Social media consulting	70	3	1	2	6
6	JK Construction	Construction	150	3	1	1	5
7	LM Architecture	Architectural design	250	2	4	0	6
8	LO Computer	Computer software	150	2	2	3	7
9	QR Consulting	Medical Consulting	90	1	2	3	6
10	ST Service	Office space consulting	3000	1	4	0	5
11	ST Furniture	Furniture manufacturing	3000	2	1	1	5
12	UV Accounting	Accounting consulting	2497	1	2	3	6
13	VT Furniture	Furniture design	181	2	2	3	7
14	WV Chemicals	Chemical manufacturing	203	1	2	3	6
15	XY Marketing	Marketing consulting	1800	3	2	2	7
16	ZA Architecture	Architectural design	85	1	1	3	5
Totals				26	34	33	93

For the in-depth interviews, an interview protocol was developed in order to increase the reliability of the case studies (Yin, 1994).[1] The protocol consists of open-ended questions to focus on facts, events, and direct assessments of knowledge combination experiences. The contents of the interview protocol evolved iteratively over time (Eisenhardt & Graebner, 2007). Appendix B provides the final interview protocol.

The participants for each case came from three hierarchical levels—senior managers, project managers, and project team members—and from different functional areas. Informants from different hierarchical and functional positions provide a rich understanding by drawing attention to complementary aspects of organizational phenomena (Eisenhardt, 1989). Furthermore, comparing accounts from multiple informants allows researchers to identify respondents' idiosyncratic biases (Miller, Cardinal, & Glick, 1997).

Each interview lasted 45 to 70 minutes. I recorded the interviews with the informants' permission and kept all responses confidential. When clarification was needed, short follow-up questions were raised via email or telephone. During the interviews, I obtained access to archival materials relevant to understanding the knowledge combination process such as organizational charts, project flow charts, document templates, job descriptions, and project management manuals.

Even though this study accessed organizational members for collecting data, the unit of analysis is the organization, not project teams or individuals. Individuals serving as informants can provide relevant information about collective processes and constructs (Morgeson & Hofmann, 1999).

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[1] Nine pilot interviews were conducted to test potential interview questions. The pilot respondents had significant experience and expertise with project management and product development in automotive, medical instrument, furniture design, heath care, and consumer products.

Data Analysis

An inductive theory generating approach was adopted for analyzing the data (Strauss & Corbin, 1990). I integrated the field notes for each case with archival data, corporate documents, and background surveys for the purpose of triangulation (Eisenhardt, 1989) and followed the three-step coding procedure suggested by Miles and Huberman (1994). First, the data were broken into thought units that vary in length from a phrase to a sentence to several sentences. Second, the thought units were organized into emergent categories. Third, the emergent categories were integrated into "core categories (constructs)" to create a theoretical framework that depicts the knowledge combination process for ongoing customized outputs. While analyzing data with NVivo9, I wrote analytic memos to synthesize different pieces of data into recognizable patterns and themes and explore the relations of different concepts to one another (Miles & Huberman, 1994).

I adopted case histories for two analyses: within-case and across-case (Miles & Huberman, 1994). Within-case analysis allowed a detailed description of patterns characterizing the knowledge combination process in each firm to emerge. Through within-case analysis, I produced a case summary for each sample firm. After all within-case analyses were finished, I conducted an across-case analysis to generalize constructs and relations (Miles & Huberman, 1994). The emergent relations across constructs were refined with the use of replication logic in which each case serves to confirm or disconfirm inferences drawn from the others (Yin, 1994). The next section lays out the emergent theoretical framework that describes and explains the knowledge combination process used by the sample firms to generate customized outcomes.

RESULTS

Knowledge Combination Routines

PBOs face a stream of projects from clients. Each project presents a unique set of possibilities and constraints. Each client has its own vision, preferences, and expectations. These differences across clients cause variations in project duration, complexity, and budget. The senior manager of FG Design told me, “Every project for us is a prototype. Everything we do is one of a kind. And I think when we forget that, our creativity starts to erode. We have to remember that every project for us is a prototype project, one of a kind.” PBOs face the challenge of continuously providing customized solutions for unique client problems.

Projects change but a PBO’s problem-solving process remains consistent. For instance, the project manager of EF Construction told me, “I guess our service is pretty standard. We have procedures on how we handle each process." The director in CD Foundry noted, “We make everything fit in our small box.” Here “everything” stands for the varied requests of clients. The “small box” indicates the firm’s general casting process. Paradoxically, organizations that continuously provide new customized products and services rely on fairly consistent repeated processes to combine knowledge. In other words, PBOs establish routines for combining knowledge in novel ways. Knowledge combination routines (KCRs) are repeated patterns of action connecting distributed knowledge within an organization, involving multiple actors to generate customized outputs (cf. Feldman & Pentland, 2003).

KCRs consist of the core activities that produce the services and products of project-based firms. For instance, KCRs in FG Design reflect the principles that are commonly applied in the building design process. KCRs in HI Media include a common approach to guide corporate social media marketing through Youtube, Facebook and Twitter. An engineer at CD Foundry observed, “Products are different in shape and geometry and that kind of thing…. The development and design in products are similar if that makes sense at all. We are still looking for similar attributes among different products even though they are shaped differently… So it’s a standard even though they look different.”

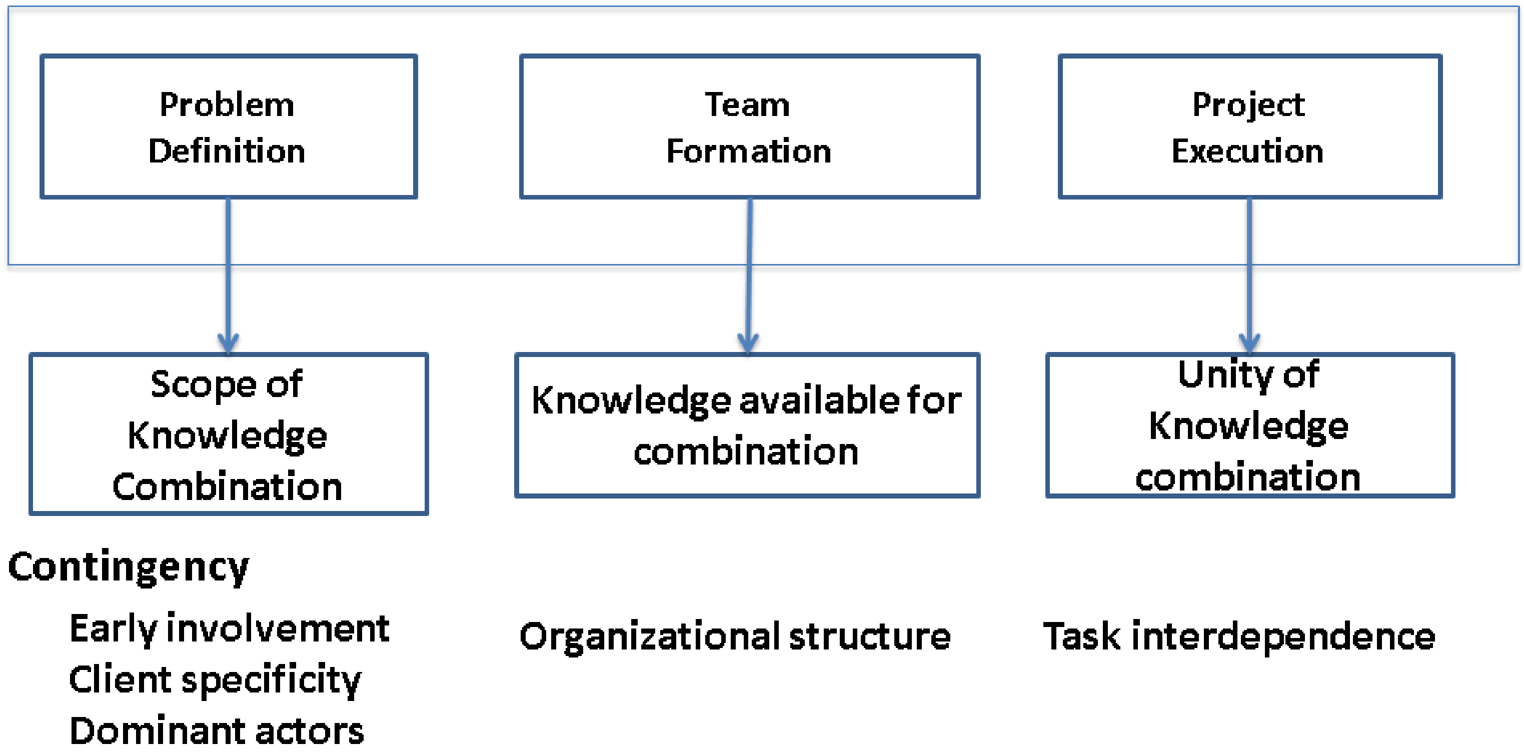
All 16 participating firms have KCRs. Beyond the interview data, the presence of KCRs was borne out by archival data such as workflow charts, check lists, activity plans, project management manuals, and standardized templates. Except at QR Consulting, KCRs exist at the organizational level. In these 15 cases, organizational members consistently apply KCRs across different project teams and product divisions. In contrast, QR Consulting has developed distinct KCRs at the team level. QR Consulting consists of eight permanent teams and each team has its own KCR even though they provide very similar consulting services. A senior manager told me that QR Consulting has grown rapidly in recent years so they did not have time to develop standardized processes across their teams. In addition, he explained that the company heavily emphasizes customization for each client and this emphasis creates different processes across project teams. The absence of an organization-level KCR reduces the consistency of practices and quality across projects.

I was able to observe how a firm develops a KCR in one of the cases. As noted previously, QR Consulting has not developed organizational KCRs unlike the other sample firms. When I conducted interviews, QR Consulting had a task force team to develop consistent practices and steps across different teams for their medical consulting services. Organizational members from a variety of project teams and functional departments have held a series of meetings. They added and deleted certain steps and tried to specify the responsibilities of each tasks. This shows that firms intentionally design KCRs by selecting core principals and roots for its business rather than simply relying on the emergence of KCRs from repeated knowledge combination experience. In other words, the repetition of knowledge combination provides learning opportunities for firms while responding to a stream of diverse requests from their clients. In addition, assessment and selection from these experiences clarify the KCRs that produce the repeated and recognizable pattern of actions for knowledge combination.

Generalizing across cases, KCRs consist of three subprocesses: problem definition, team formation, and project execution. Nine pilot studies alerted me to these three processes and I was able to identify and confirm the presence of these three subprocesses in KCRs from interview data and archival data across all 16 cases. Even though cases share common steps, it does not follow that KCRs are identical across the cases. The KCR of each company adopts different practices and ways to perform each subprocess for their specialized products and services.

Problem definition sets the scope for knowledge combination. Team formation influences the knowledge available for combination. Project execution unites knowledge. Each event is contingent on different organizational factors. The next three subsections describe sequentially each of these subprocesses and identify contingencies relevant to each. Figure 1 provides an overview of key points from this discussion, including the implications of each subprocess and the relevant contingencies.

Figure 5
Components of knowledge combination routines



Problem Definition

After obtaining projects from clients, firms engage in problem definition. They set the boundary, direction, requirements, and goals for a project during this phase. To define a problem, PBOs begin by identifying the needs and expectations of the client. Speaking of clients, a project manager from FG Design reported, “Their needs should be well-defined. The expressed needs of the client should be understood by all project team members.” PBOs translate client needs and expectations into key project parameters such as requirements, scope, schedule, and budget. A clear definition of the problem at an early stage can reduce unnecessary and costly changes in the future.

PBOs clarify clients’ needs in various ways such as meeting with clients, conducting field research, taking surveys, and holding town-hall meetings. For instance, XY Marketing conducts discovery meetings with their clients in every project. The purpose of these meetings is for a project team to develop a strong understanding of the clients’ requirements. A group of people, consisting of a representative from each department, visits a client for one to two days. Representatives ask the client questions from lists prepared by their departments before the visit. XY Marketing uses this meeting to understand how the client business operates and how its marketing logistics service applies to the client. LM Architecture conducts research about applicable regulations, including the local environmental regulations and building codes. They also examine the site and existing view, which influence the design. Firms usually prepare contractual documents as the outcome of problem definition. Contracts usually include a statement of scope, timeline, budget, responsibilities for both parties, and deliverables outcomes.

PBOs do not simply accept the needs and requests as presented by clients. Instead, they bring their own expertise to evaluate and modify clients' characterizations. For instance, a director of manufacturing system in VT Furniture described this point:

> *Interviewer*: So you cannot take it (design) as is.
> *Director*: No, you can't. You've got to filter it! You've got to, you've got to, you've got to filter it in common sense. You'd better filter in the engineering behind it, the manufacturing capabilities, the materials, and the strength. You have to filter it through a lot of those things to make sure that the client understands, as well as the internal folks, why we are doing and what we are doing…. We've had many, many examples. Many examples where clients had design intent and by the time it filtered through the engineering group and our manufacturing group, the concept changed completely. And it was for the good. It was for the good of the client."

PBOs are trying to leverage their KCRs across problems and problem modification makes projects compatible with established KCRs. If firms do not have opportunities to influence the nature of projects through modifying the problem definition, they will have difficulty applying their KCRs. Two interrelated factors affect the ability of PBOs to shape clients' problems: (1) how early they get involved and (2) the degree of specificity in the client's initially presentation of the problem.

When PBOs get involved at an early stage, they are more likely to influence the nature of projects. Early in projects, clients are still flexible about the scope and goals, but commitments made over time reduce client flexibility. Hence, the later PBOs get involved with clients, the fewer opportunities they have to reflect their own expertise in the project design. A project leader in VT Furniture described the importance of early involvement:

> *Project leader:* We try to get involved as early as possible with them. So before the product even goes off to bid, before anything happens we get involved and they are asking us, "I got this concept. Does that connection look ok? Is that material right? " And so basically we are almost their consultants from an early on stage… It is critical for us to get involved in the design stage.
> *Interviewer:* Why is it critical?

> *Project leader:* Because we can influence the product design in the best way… Generally working with us upfront we utilize all that experience and all that knowledge going into design… That is really where we shine. It is really where we stand above our competitors.

The specificity of the initial problem that clients bring to PBOs varies as described in Table 3. Most firms (12 cases) receive requests from clients framed as abstract and general ideas such as “I need to build a new office,” or “I need to promote the awareness of our brand through the use of social media marketing.” In contrast, four firms (VT Furniture, JK Construction, EF Construction, and CD Foundry) receive specific requests from clients in the form of drawings, models, and prototypes. For instance, clients of VT Furniture bring designs and drawings and ask whether they are manufacturable.

These contrasting degrees of problem specificity present a tradeoff for PBOs. When clients clearly understand their needs and bring specific requests, problem definition proceeds efficiently but there is little room for PBOs to reflect their expertise. A mechanical engineer at CD Foundry gave an example of how a specifically-defined problem can affect a project’s progress adversely:

> Some of the things we receive are, as an example, a General Motors’ casting that in a machine shop, will actually be their tier 1 supplier to GM. They get the casting, the model blue print from GM and accept it that way and they send it to us and we see things we want to change and that’s very difficult to do. They would like to accommodate it but then they have to go back to General Motors in this example and try to get modifications done and sometimes that’s, you know, like pulling teeth. General Motors will say that this is what we want. You have to accommodate that shape you know.

In contrast, ambiguous problems grant the PBO autonomy and discretion to impose their own definition but if clients have very ambiguous ideas, the PBO might not receive enough input to characterize the problem. In this case, the PBO needs to make some assumptions and invest time to narrow down what the client needs.

Table 3
Initial problem specification in problem definition

Problem specification	Firms	Modification Opportunity	Problem ambiguity
High	4 firms CD Foundry EF Construction JK Construction VT Furniture	Low	Low
Low	12 firms FG Design HI Media JK Construction LM Architecture LO Computer QR Consulting ST Service MH Furniture UV Accounting WV Chemicals XY Marketing ZA Architecture	High	High

The dominant actors in problem definition vary across the cases as summarized in Table 4. In four companies (TC Chemical, LO Computer, QR Consulting, and ST Service), sales people mainly lead problem definition. For example, in OP Computer sales people identify the needs of clients and develop the software purchase order for clients. Only after a purchase order is completed does a project manager and a project team get involved. A potential pitfall of this approach is that sales people—or any single functional group—bring limited expertise to defining the problem and assessing the feasibility of proposed solutions. In the other 12 firms, project managers lead problem definition or at least get involved with problem definition alongside sales people. Project managers provide technical and functional expertise that can mitigate the risk of ill-defined problems.

Table 4
Dominant actors in problem definition

Actors	Firms	Problem definition
Sales people	4 firms LO Computer ST Service MH Furniture WV Chemicals	Less comprehensive
Project manager	12 firms AB Architecture CD Foundry EF Construction FG Design HI Media JK Construction LM Architecture QR Consulting UV Accounting VT Furniture XY Marketing ZA Architecture	Comprehensive

Team Formation

Knowledge in PBOs is embedded in individuals and distributed throughout the organization (Enberg et al., 2006). By forming project teams, PBOs bring together individuals with complementary relevant knowledge (Reagans, Zuckerman, & McEvily, 2004; Sosa & Marle, 2012). In this sense, a team is a critical platform for accomplishing the collective work of combining knowledge (Guimera et al., 2005; Wuchty et al., 2007).

The organization structure is a key factor influencing how project teams are formed. Organization structure affects the search for team members, team member mobility, and team stability. Table 5 summarizes the findings for team formation.

Table 5
Organizational structure and team formation

Organization structure	Firms	Team member search	Team member mobility		Team Stability
			High	Low	
Functional structure	6 firms CD Foundry, LO Computer MH Consulting ST Furniture VT Furniture XY Marketing	Most effort Extensive coordination	All 6 firms		Low
Market-based structure	3 firms AB Architecture QR Consulting WV Chemicals	Least effort Localized	AB Architecture	MG Consulting TC Chemicals	Very high
Matrix structure	7 firms EF Construction FG Design HI Media LM Architecture JK Construction, UV Accounting ZA Architecture	Medium effort Bounded	All 7 firms		High for existing clients Low for new clients

Functional structure. Under a functional structure, project teams form by pulling people from different functional departments. In XY Marketing, a typical project team consists of people from client service, operations, planning and engineering, information and technology, and project management. When a client awards new business to XY Marketing, the director of the project management department assigns the project to a project manager. Then the project manager contacts the vice president of each functional department and explains the requirements of the project to them. The vice presidents in the functional departments ultimately decide who will be involved in the project under the project manager's supervision.

Under a functional structure, the search for project team members is an extensive process requiring substantial effort. Because organizational members do not have formal attachments to particular clients or industries, they are free to work on a variety of projects. By implication, the pool of potential project team members is large. Project managers may need to engage in considerable discussion and negotiation to garner support from the directors of functional departments who control the allocation of human resources.

The flow of people is hindered very little by the boundaries of existing project teams when forming a team under a functional structure. Because organizational members do not have strong associations with particular clients or industries, firms have flexibility to move people around to different projects. Accordingly, member mobility across project teams is high. For instance, MH Consulting provides workplace environment evaluation and workplace change consulting service for their clients. Project leaders contact various departments of the organization such as sales, engineering, local dealers, design, and workplace consultants. They bring onto a temporary project team people who can fulfill specific aspects of client needs.

Team member stability across projects is very low under a functional structure. Project teams are temporary and organizational members have weak relationships and lack formal ties. Team members often lack previous experience working together. Even though some clients offer repeated business, it is hard to carry over the same team from one project to another unless the firm size is small.

Market-based structure. In a market-based structure, organizational members belong to project teams that focus on specific industries and clients. For instance, AB Architecture has project teams specializing in healthcare, K-12 schools, transportation, and business development, and each team consists of a project manager, architects, designers, and engineers. New projects are assigned to project teams based on the client industry.

Under a market-based structure, the effort involved in team formation is low because project teams are stable. Because the search for knowledge is usually limited to within the boundary of an existing project team, the search process is localized. The search for new team members usually occurs when a project team recognizes that it lacks particular specialized knowledge for a project. Hence, the search for knowledge starts out within the established local network and only becomes more extensive if local search proves ineffective.

The degree of inter-team member mobility varies across the three sample firms following a market-based structure depending on the rigidity of existing team boundaries (see Table 4). QR Consulting rarely exchanges members across different project teams. As noted earlier, QR Consulting does not have organizational-level KCRs; instead, each project team in QR Consulting develops its own KCRs. Team-specific KCRs present barriers to mobility across project teams. In AB Architecture, team boundaries are very flexible and permeable and team member mobility is high. Team members frequently work for other teams. For instance, an architectural designer on a healthcare team can work for government and industrial building teams if necessary. Team member exchange across project teams allows AB Architecture to form project teams with appropriate knowledge while reducing unnecessary redundancy (i.e., people who have similar knowledge) across project teams.

Matrix structure. A matrix structure is the hybrid combination of functional and market-based structures.   In a matrix structure, each organizational member belongs to a functional department and also specializes by industry or client. For instance, FG Design employees belong to functional departments based on expertise such as mechanical engineering, electrical engineering, structural engineering, site planning, and interior design. Simultaneously, they report to studio leaders who have specialized industry expertise: commercial, healthcare, higher education, K-12, and science and technology. A studio leader and a project manager discuss the details of projects and team formation with functional leaders who eventually provide team members to them.

Like the functional structure, the matrix structure forms a new team for each project. Each member in functional departments has ongoing associations with particular industries and clients so the search for team members with relevant knowledge is focused and bounded. Even though organizational members in a matrix structure have industry and client attachments, their team boundary is not as strong as in a market-based structure. Team members readily move across project teams in a matrix structure but the scope of mobility is limited by associations with particular markets. For example, in HI Media, functional leaders assign their members to industries; as a result, people in each function tend to work consistently with the same major clients across their project experiences.

Under a matrix structure, team member stability across projects depends on whether projects come from established or new clients. If a project comes from a new client, the firm must put together a project team by searching for appropriate people from each function. However, if an existing client brings a new project to the firm, the firm redeploys team members who previously worked for this client. The opportunity for repeated collaboration with other team members is higher than in a functional structure because matrix organizational members associate with certain clients. However, the attachment with clients is not as strong as under a market-based structure so repeated collaboration among team members occurs less frequently.

In similar ways, the opportunities for repeated collaboration with clients are higher than in a functional structure but lower than in a market-based structure.

Project Execution

In project execution, coordination is a key issue. Each team member applies his or her specialized knowledge while performing tasks that allow considerable latitude for individual discretion (Gardner et al., 2012). However, interdependence among team members' tasks gives rise to the need for coordination (Thompson, 1967). Coordination links together separate tasks that are performed by different team members (Van de ven et al., 1976). Through coordination, team members bring their distinct knowledge together to produce integrated outputs (i.e., products and services). The empirical evidence gathered during this study points to the importance of project managers and artifacts for coordinating team efforts.

Project managers. A project team consists of team members and a project manager. Team members perform tasks based on their specialized knowledge. Project managers are generalists who adopt an overall view of projects. A project manager is the focal person to coordinate interdependent tasks performed by team members. Project managers orchestrate coordination among project team members and between the project team and its client in three ways: by establishing a plan, remaining consistent, and communicating.

First, project managers develop a specific and coherent project plan. Project team members have specialized knowledge and they bring different perspectives to projects (Bechky, 2003a; Hargadon & Sutton, 1997). Their views of a project can be limited to their focal task and they have substantial discretion about how to implement assigned tasks. However, with a plan developed by a project manager, the team can gain a holistic view of the project (Lindkvist, Soderlund, & Tell, 1998). In general, project plans show a sequence of steps among individual tasks. For example, LM Architecture conducts formal project planning sessions for every project. Each team member develops detailed schedules and task lists. Based on the input from team members, the project manager develops an overall project plan. The plan includes task lists for team members, schedules, and milestones to meet the scope, budget, and timetable for a project. Through the plan, team members can see how their work relates to others' and they can consider and anticipate others' work while performing their own tasks. In short, a project plan provides a common framework that allows team members to perform their tasks and to collaborate with each other (Brown & Eisenhardt, 1997).

Second, project managers bring continuity to projects. Team members enter and exit during projects. In general, people in PBOs have multiple projects going at the same time. Because of this, team members do not get involved with one project from the beginning to the end; instead, they are involved actively with a project at a certain stage and then move to another project. For instance, at LO Computer, the account managers in sales are involved at an early stage to obtain orders from clients. Program testers get involved with a project at the end so as to write a manual for a program and test the program in the client's office. Project managers, in contrast, get involved with the project from the beginning and stay to the end. Regardless of exit and entry by team members, project managers make sure that a project stays within its budget, timeframe, and scope (as set out in the project plan) by monitoring activities and tracking progress.

Lastly, project managers are a hub of communication needed to effect knowledge combination. A reliable pattern of communication enhances coordination among participants in the knowledge combination process (Gardner et al., 2012). Through communication, members become aware of others' contributions (Bunderson & Sutcliffe, 2002). Project managers connect the dots among team members and between the project team and clients by becoming a hub of communication. The centrality of the project manager within the social network enhances the efficiency of communication by giving everyone involved a go-to person for information and decision-making.

Due to task interdependence, there is ongoing communication among project team members that shares information and facilitates coordination. The project manager directs and controls this communication to a certain degree. A project management manual in LM Architecture advises, “A project manager needs to serve as the traffic cop for project information.” Each team member reports to the project manager information that influences the scope, budget, and schedule of the project. The project manager then disseminates information to the affected person(s).

Project managers develop common ground for team members by disseminating consistent information to them. Common understanding is a critical factor for efficient knowledge combination (Grant, 1996a; Grant, 1996b). By providing common information to all, project managers facilitate development of a collective mind (Weick & Roberts, 1993), shared mental models (Klimoski & Mohammed, 1994), and shared meaning (Bechky, 2003b) among team members. For example, a project manager in HI Media provides to all team members a document called “Job Starters” in a kickoff meeting. This document explains the what, how, and why of a project. “Job starters” guide team members throughout project execution. In their organization, the term “download” refers to accessing the same information about projects from project managers. Project managers actively organize team meetings that allow team members to gain consistent information through interacting with each other (Enberg et al., 2006).

At the same time, the project manager is the main communication channel in the team-client relationship. Even though team members communicate with clients, their communication is about technical aspects and with clients' operational personnel. In contrast, project managers mainly communicate with clients' senior managers about strategic issues and direction.

It is important for a project team to receive information and evaluative feedback from their client at key points during project execution. A project manager in LM Architecture told me:

> Right now I got a client. The biggest problem we have with this client, the nicest people in the world, but you give them a set of draw documents and in their own document they say we will review this within one to two weeks (and) we will have a meeting and we will move to next phase. We give them documents, 'Are you ready to meet with us?' 'Well I've got training for three weeks.' You know? You can't get with these guys, and all of sudden, your schedule starts to slide because they can't get together with you, and it is happening on a regular basis."

Project managers inform the client about the progress of projects and bring the client's feedback to the project team. Their dual role involves representing the project team to the client and representing the client to the project team. A project manager in HI Media described this role of project managers by saying, "I would like to think of the account team (project management department) as the glue. We're there for the strategy development and the client approved that. We're there for the creative development. We present creative concepts to the client. We're there for the technology development up to all along the way sharing things with the client, making sure things are going smoothly is our role."

The liaison role of project managers between project teams and clients enables project teams to effectively respond to project changes. Even though project plans developed by project managers anticipate many issues in advance, unexpected events always arise during project execution and bring changes to projects. Although project changes come from multiple sources, changes from clients are the most impactful. A senior manager of JK Construction explained the challenges when clients change their minds:

> *Senior manager*: A lot of times, changes occur because the client has changed their mind on something. Those are generally more of a problem because what you've done now is kind of circle all the way—you are in construction—[but] you kind of circle all the way back to the start of the ideas and the concepts… You know, something [as] simple as moving, they decide they want a kitchenette in the conference room on the opposite side. You have to move cabinets and now you have to move plumbing and electrical for the microwave and coffeemaker. Depending on when this occurs in the process, you know, a lot of this work could've already been done. Now it has to be redone over here. There is waste involved if the change occurs too late. But there is also if it isn't too late, you may have to stop the process to accommodate this change before you can move forward with the rest of the building. So changes are disruptive.
> *Interviewer*: Especially from the client side?
> *Senior manager:* Yeah, if there were an owner request. If the change results from just poor documentation, usually it means you are still doing the same thing you were going to do. You are just fixing a problem in that process. Changes from the client side generally introduce a whole new set of requirements or scope. They are more difficult.

When projects change, communication is critical to adjusting efficiently and effectively. Efficient communication through project managers permits information about changes to flow among team members and to clients. As soon as project managers discover potential changes in a project, they communicate them to their project teams. The team assesses the implications of the changes for project cost, quality, time, and scope and develops several possible responses. The project manager then conveys this information to the client and helps the client make a decision about whether to pursue the change or not. Even though PBOs cannot predict or control changes, immediate assessment of changes helps mitigate project disruption and cost overruns.

Artifacts. Artifacts include tangible objects such as prototypes, designs, models, machines, blue prints, and maps. A project team uses and produces artifacts during the course of their work. Artifacts facilitate coordination by communicating information relevant to carrying out tasks (Bechky, 2003a). Project team members may differ in their language, practices, and conceptualization of a project, and these differences make it difficult for them to collaborate (Bechky, 2003b). Artifacts enable individuals to identify interdependencies among tasks while they work individually (Enberg et al., 2006).

For instance, ZA Architecture, LM Architecture, and FG Design use a Building Information Modeling software program called Revit. Architectural designers see how different functional engineers interpret their initial design while looking over their 3D drawings in Revit. Lines and dots in drawings contain design information and drawings developed by team members exist as one model. Due to this integration feature, Revit detects incompatible features across different designs. For instance, if a new drawing from a structural engineer is not compatible with the existing drawing of mechanic engineers, the program warns the structural engineer of a potential design clash.

In addition, artifacts help project managers to play their role as coordinators. Project managers use a variety of documents as the components of a plan such as Gantt charts, checklists, and to-do lists. Among the 16 sample organizations, 10 PBOs use project management software. Project management software centralizes relevant information about the project in one place. Using project management software, project managers can distribute consistent information to their team members. Furthermore, project managers leverage prototypes, models, and drawings to communicate with clients. For example, HI Media often shows webpages to their clients to explain the progress of projects.

In addition to the role of artifacts in coordination, PBOs use artifacts to store the outcomes of prior projects efforts for subsequent use (Hargadon & Sutton, 1997). For instance, TC Chemical stores project details (chemical components, characteristics of clients, and feedbacks from field workers) in a database. Organizational members can search previous projects in the database by client, year, product type, and name. Artifacts are a form of organizational memory reflecting learning from past project experiences.

The prominence of project managers and artifacts depends on the types of tasks required by a project and their interdependence. According to (Thompson, 1967), task interdependence can take various forms. Table 6 categorizes the sample firms into two groups based on the nature of the task interdependencies that they face: sequential or reciprocal

Table 6
Prevalence of project managers and artifacts in task interdependence

Task Interdependence	Firm	Project managers	Artifacts
Sequential	5 firms CD Foundry LO Computer QR Consulting MH Furniture VT Furniture TC Chemical	No official project managers	Less developed No project management technology
Reciprocal	11 firms AB Architecture EF Construction FG Design HI Media JK Construction LM Architecture ST Service UV Accounting XY Marketing ZA Architecture	Designated project managers	Highly developed Project management technology

Five firms have sequential task interdependence. Project teams in these firms are cross-functional but there are few joint activities and little communication among team members. Each team member performs his or her assigned tasks and then hands off the project to another team member. For instance, in VT Furniture, engineers modify clients' designs then the manufacturing people take over. Similarly, in TC Chemical, a project moves from sales to the laboratory and then to a customer service department to conduct a field test. Firms with sequential task interdependence do not have designated project manager positions. Lab managers take on the role of project manager in TC Chemical. However, their involvement with projects is limited compared to project managers in other firms. In addition, firms with sequential task interdependence do not rely extensively on artifacts or project management technology for coordination purposes. In VT Furniture, a designer uses 3D Computer Aided Design software to develop designs, not to allow team members to understand others' tasks.

In contrast, under reciprocal task interdependence team members get involved repeatedly throughout projects and there is frequent communication and interaction among team members. For instance, in JK Construction, even though project managers, superintendents, accountants, and engineers have their own responsibilities in a project, all of them constantly get informed about others' progress and consider it for their own tasks. PBOs with a reciprocal task structure develop formal roles for project managers as coordinators who establish a plan, remain consistent, and communicate (as described above). They rely heavily on artifacts and make use of project management technology to facilitate coordination and communication among team members.

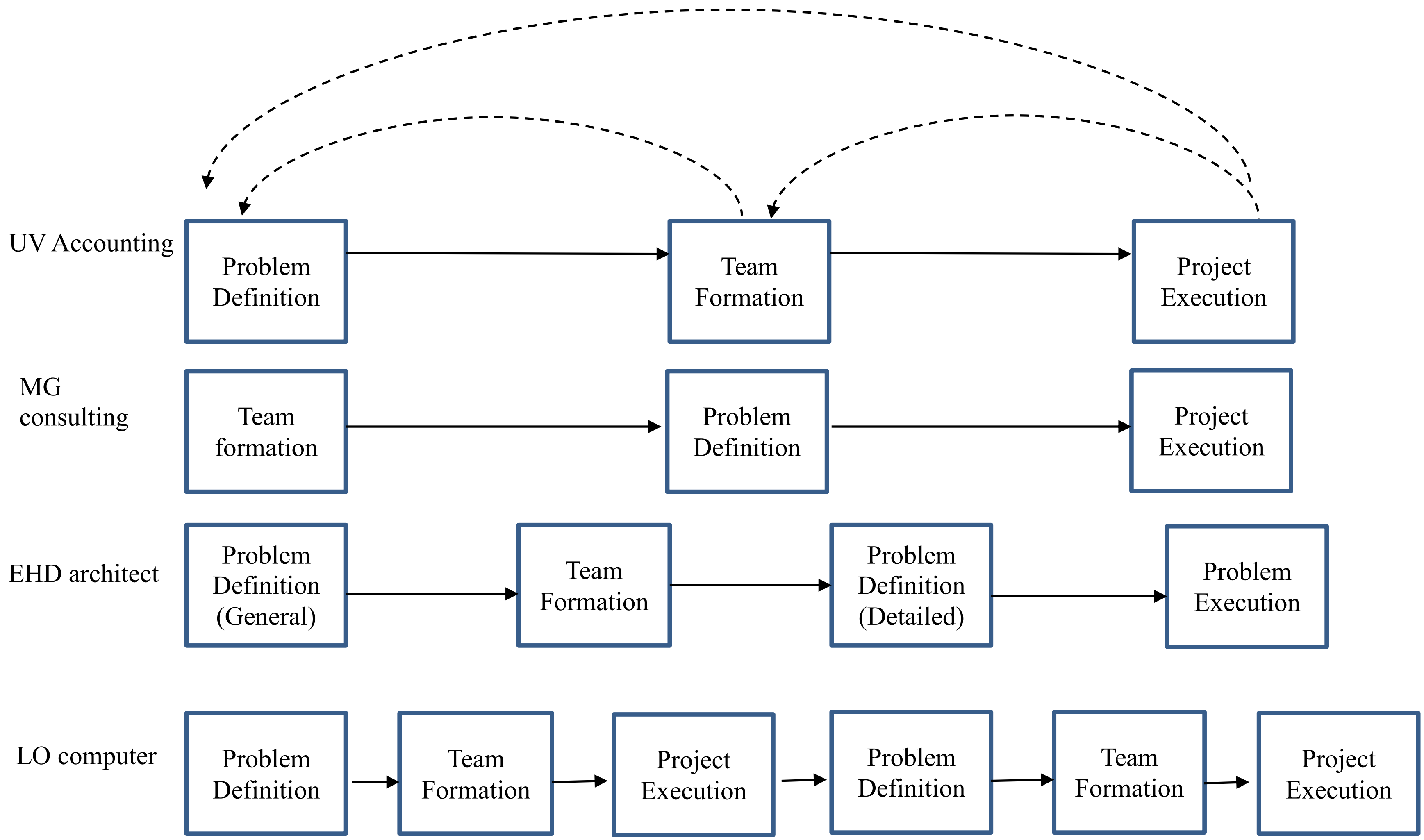
Sequences of Knowledge Combination Routines

Although there is a logical progression in moving from problem definition to team formation and then project execution, the process is not uniform across organizations nor is it strictly unidirectional. Teams may return to earlier steps even as they progress through team formation and project execution. Learning during project execution may reveal new constraints and opportunities that cause the team to reanalyze and redefine the problem. Team members may be added as needs arise over time and changes in team composition alter the eventual process for completing a project.

The ostensive sequence varies across firms. Figure 6 describes observed variants of the sequencing of problem definition, team formation, and project execution. In QR Consulting and AB Architecture, team formation occurs first and then problem definition follows. Under their market-based structure, a permanent project team takes responsibility for defining the client's problem. In FG Design, problem definition occurs twice. Initially the sales department develops a general definition of the problem through interactions with the client. This initial definition guides project team formation. The project team proceeds to specify the project again in greater detail.

In addition, the whole sequence can be repeated during a project. In LO Computer, for example, problem definition, team formation, and project execution repeats over time with each client. OP Computer adopted an agile software development system that allows teams to break projects into components during software development. Under this agile system, OP Computer develops and delivers pieces of a client's software in weekly iterations rather than all at one time.

Figure 6
Sequences of knowledge combination routines



Learning and Changes in KCRs

Even though KCRs guide problem solving processes, they do not provide uniform solutions for different problems. The senior manager of FG Design described this point:

> So we may employ processes that are consistent, but solutions should never be consistent. They need to gear toward a specific project. Michigan State University may do three, four or five large design projects this year. All of them have a unique problem statement. They have a unique set of circumstances. We have to approach that in such a way that allows us to solve those unique problems. In those circumstances, the design solution may be very different for this project than it is for this one and this one. And that's really where creativity goes about. We can use processes that we have developed…. But those processes can't be cookie cutter solutions. They have a process to get us to the correct solution for that project, which is unrelated to the solution of any other projects.

KCRs lay out a general road map for completing a project rather than specify a solution. These organizational routines are flexible to accommodate varying circumstances (Feldman, 2000). The changes in KCRs come from two sources: individuals and organizations.

First, individual learning can be the source of variations in performed KCRs across projects. Specific actions and contents of the procedure in KCRs vary across projects due to individual agency (Feldman & Pentland, 2003) and improvisation (Miner et al., 2001; Moorman & Miner, 1998b). Project team member brings their own unique personal experiences, subjectivity, and knowledge to a project to provide creativity and uniqueness for each project. Individuals can apply their judgment and perspectives within KCRs. In addition, as noted previously, each problem is unique and provides an opportunity for a PBO to develop a novel solution. The variety of projects presented by clients provides ongoing opportunities for individual learning. Project assignments challenge team members to refine their existing skills and acquire new declarative knowledge (Hackman & Oldham, 1980). Project participants interact with different team members and clients across projects and thereby learn about their characteristics (such as capabilities, working and communication styles, personalities, and preferences).

The different team formation processes also carry implications for learning. As noted previously, project team members in a functional structure have fewer opportunities for repeated collaboration with other team members and clients than in market-based or matrix structures. A history of interactions develops personal relationships among participants that establish trust, norms, and obligations (Nahapiet & Ghoshal, 1998). People who interact frequently with one another are more likely to develop shared understandings and a common language (Carley, 1991). Accordingly, previous collaborative experiences with project team members enhance procedural efficiency when working together (Cohen & Bacdayan, 1994). Furthermore, repeated collaboration with others lets project team members learn which participants have which knowledge, thereby building their transactive memory (Wegner, 1987).

Even though individual learning affects the performance of KCRs, such learning does not change systematically or permanently the nature of KCRs. Learning embedded in individuals carries over to other projects only as the individuals themselves get involved in other projects that apply their knowledge. PBOs can transfer individual learning to the organizational level via "lessons learned" practices that document the experiences of project team members and make them available to others in the organization. Lessons learned, when raised to the organization level, provide opportunities to reflect and modify KCRs. In general, project managers organize and lead lessons learned meetings after completing a project. As described in Table 7, eight firms actively use lessons learned practices. LM Architecture, for example, has a lessons learned committee.

Table 7
Systematic changes of KCRs in lessons learned practices

Lessons Learned Practice	Firms	Example
Constantly	EF Construction	Formal postmortem meeting Documentation and template Lessons learned database Sharing experiences across projects
Constantly	LM Architecture	Formal postmortem meeting Documentation and template Lessons learned database Lessons learned committee Sharing experiences across projects
Constantly	XY Marketing	Formal postmortem meeting Documentation and template Sharing experiences across projects
Constantly	ZA Architecture	Formal postmortem meeting Documentation and template
Occasionally	HI Media	Postmortem meeting
Occasionally	LO Computer	Informal postmortem meeting
Occasionally	VT Furniture	Informal postmortem meeting
Occasionally	AB Architecture	Postmortem meeting
No	FG Design	None
No	JK Construction	None
No	QR Consulting	None
No	MH Furniture	None
No	ST Service	None
No	UV Accounting	None
No	TC Chemicals	None
No	CD Foundry	None

The committee reviews lessons learned documents provided by project managers. The committee decides the value of suggestions and reflects valuable suggestions in their established design process. In addition, EF Construction puts lessons learned documents of every project into its project management software and asks all following projects to consider them. However, ten firms do not gather lessons learned. In these firms, valuable new experiences only remain with individuals. These firms cannot capture learning across projects by revising their KCRs. Instead, learning from experience might reside in only certain teams. It might result in decoupling between KCRs in practice and documented KCRs in documents over time. Furthermore, each project team might conduct projects in different ways and have local its own KCRs. This finding shows that there is divergence between canonical practices and non-canonical practices in KCRs (Brown & Duguid, 1991). For instance, JK Construction developed KCRs for its construction service. They did not capture individual experience at the organizational level. Furthermore, for the last seven years, JK Construction has offered no formal training to introduce new employees to its KCRs. New organizational members have developed practices that differ from established KCRs. Project teams in JK Construction use different templates and systems for managing construction projects.

DISCUSSION

This study examined empirically how firms manage knowledge combination for ongoing novel outcomes in the context of project-based organizations. The evidence from this study characterizes knowledge combination as an organizational routine that generates customized outputs to meet diverse client needs. Knowledge combination routines (KCRs) provide continuity in patterns of action that supports novelty across performances. In a nutshell, stability facilitates novelty (Berger & Luckmann, 1967; Giddens, 1984). Project-based organizations establish stability at a higher level (the KCR) that facilitates change at a lower level (the project) (Zollo & Winter, 2002). Managing the paradoxical combination of continuity and innovation reflected in KCRs are the core capability of project-based organizations.

This study of knowledge combination affirms recent studies describing continuous change within routines (Feldman & Pentland, 2003) and routines as sources of organizational flexibility (Feldman, 2000; Feldman & Pentland, 2003). Extending this line of research, the present study shows that routines enable ongoing innovation. KCRs foster flexibility and enable organizations to deal with novel problems (Farjoun, 2010) rather than determine the specific actions. KCRs offer a shared framework—grounded in prior experience—that guides how firms combine distributed knowledge for novel solutions. KCRs provide structure for setting goals, clarifying roles, and coordinating tasks. Firms that face a continual stream of new projects require an ostensive routine to guide and stimulate new connections among disparate knowledge, new relations among individuals, and new ways of acting individually and collectively. KCRs are not static but change over time by reflecting individual and organizational learning through project experiences. KCRs emerge from the repetitiveness of combining existing knowledge to provide novel solutions. At the same time, organizations develop KCRs while deliberately choosing the practices and components of KCRs. This finding aligns with the argument of organizational routines as effortful accomplishment rather than automatic responses.

This study both describes the phenomenon and builds theory. Analyses of the descriptive details of 16 cases identified key constructs and their sequencing, thereby advancing theoretical understanding of the knowledge combination process. Three subprocesses appear across cases:

problem definition, team formation, and project execution. Furthermore, this study identified key organizational contingencies affecting each subprocess (see Figure 1).

Problem definition sets the scope for knowledge combination. The constraints and opportunities identified through the problem definition guide what knowledge is necessary for problems. It also determines what or how firms are going to combine existing knowledge to fill the requirements of projects. The accuracy and comprehensiveness of problem definition is critical to bounding knowledge combination because the set of possible knowledge combinations increases exponentially with the number of knowledge elements available (Fleming, 2001). Firms not only identify the needs of clients but also interpret and modify clients' understandings. The degree to problem modification is related to the flexibility of PBOs to define the nature of projects. PBOs bring their organizations' expertise into the process of defining the problem through problem modification. Modification of problems is critical to making clients' projects compatible with PBOs' established KCRs. The prospects for problem modification depend on when PBOs get involved in a project and clients' specificity when they initially approach the firm. Furthermore, different dominant actors influence the scope and accuracy of problem definition.

Team formation brings together individuals possessing the range of specialized knowledge relevant to project completion (Grant, 1996a). Team member mobility across projects determines how readily organizations can deploy relevant knowledge to specific projects. Team formation decisions affect the knowledge available for subsequent project execution (Aime et al., 2010; Taylor & Greve, 2006). Furthermore, team composition affects the work process and performance. Hence, how managers identify and recruit members to collaborate on teams is a critical issue (Nair, Tambe, & Marsella, 2003).

The findings of this study show that organization structure is the key contingency influencing the team formation process (as summarized in Table 4). In particular, functional structure and market-based structure have contrasting effects on team member mobility and team stability. A functional structure enhances team member mobility across projects by relying on the temporary project teams and weak association of organization members with specific industries. In contrast, organizations with a market-based structure stimulate team member stability across projects because project teams carry over across time and organization members work for certain clients.

Furthermore, contrasting effects of functional and market-based structure on team formation implies a tension between broad search for team members and deep interaction among team members. A functional structure enables firms to broadly search for people who have relevant knowledge for a project but does not allow a project team to collaborate over multiple projects. In a market-based structure, team members have repeated collaboration opportunities over time, which deepens procedural and transactive knowledge within teams. The downside of repeated collaborations is limited access to the diverse perspectives and expertise distributed across the organization. This contrasting implications of functional and market-based structures imply that team formation can be analyzed with a lens of exploration (search for new team members) and exploitation (repeated collaboration) (Perretti & Negro, 2006).

Project execution unites diverse knowledge. In the execution stage, organizational members apply their specialized knowledge to their assigned tasks to bring about an integrated output. Coordination is a key mechanism for combining disparate knowledge within an organizations (Grant, 1996b) and project managers are central in team coordination. Project managers provide a holistic view for their team members by developing a project plan and they provide continuity as others enter and exit the team over the course of a project. Furthermore, they play a central role in communication among team members and between project teams and clients.

Project managers can be considered as tertius iungens in knowledge combination who actively facilitate coordination between connected individuals (Obstfeld, 2005). Tertius iungens stimulate coordination by establishing a structure. Knowledge workers have substantial discretion about how to implement their assigned tasks; however, their discretion is bounded within a roadmap developed under the project manager. Grant (1996a) argued that discretion for decision-making should be distributed among individuals because they hold various forms of specialized knowledge. However, the findings from this study show that knowledge combination requires some degree of centralized decision making and formal intervention. A comprehensive plan for knowledge combination and centralized communication through a project manager facilitate efficient and effective knowledge combination while allowing team members to exercise personal discretion in task fulfillment. Structure and discretion coexist in knowledge combination. This finding aligns with the importance of *semi-structure* in continuous new product development (Brown & Eisenhardt, 1997). Semi-structure is neither so determined as to control minute details of the knowledge combination process nor so open that the process does not work. The empirical evidence shows that project managers use comprehensive planning, consistent involvement in projects, and centralized communication to develop a semi-structure conducive to knowledge combination.

Artifacts facilitate the knowledge combination process and capture the outcomes. Artifacts serve as boundary objects enabling individuals with different specialized knowledge to coordinate. They help participants see how their tasks relate to others'. Artifacts embed the knowledge of their creators and convey such knowledge between people (Bechky, 2003a; Carlile, 2002). The nature of task interdependence influences how coordination occurs (Thompson, 1967). In particular, task interdependence influences the roles of project managers and artifacts during project execution. Reciprocal tasks that require mutual adjustment among participants for coordination call for more intense involvement by project managers and usage of artifacts than sequential tasks. This implies that problem complexity affects how to combine specialized knowledge and produce integrated outcomes.

Because the unit of analysis of this study is organizations, rather than project teams, this study does not directly explain a relation between KCRs and project performance. However, all three steps that consist of KCRs have critical implications for project success. For instance, without accurate problem definition, firms would deliver outcomes that are deviated from what clients expect from the project. Firms should also identify individuals who have appropriate expertise for the project and bring them together onto a project team. The proper intervention of project managers and the use of artifacts are essential for team members to apply their knowledge in the tasks of project and collectively result in into integrated outputs. Furthermore, this study suggests organization contingencies for each step and these contingencies can be considered as antecedents on the success of each step.

Furthermore, this study identifies that the sequence of KCRs can vary across firms. The observed variants of the sequencing of problem definition, team formation, and project execution imply that organizations share components that consist of KCRs. However, they have different grammar to organize these components and they have different sequences of KCRs (Pentland & Rueter, 1994). The findings of this study extend the previous research that examined the variations of ordered actions within an organization (Pentland, 1992; Pentland & Rueter, 1994) by identifying the common categories of actions and different grammar to organize them across organizations.

This study also contributes to the project management literature. One-off and non-recurring projects appear to provide limited opportunities for systematic repetition (Gann & Salter, 2000) and routinization (Hobday, 2000). Nevertheless, accumulated learning from a stream of projects enables project-based organizations to improve their efficiency and effectiveness (Davies & Brady, 2000). "Lesson learned" practices are intentional ways to carry learning across projects—yet they are not found in all PBOs.

My findings have implications for the practice of project management. This paper shows that PBOs can introduce ongoing new outcomes through the use of KCRs. Project management practices can be a critical component of KCRs and this implies that project management practices can be a source of novel outcomes. PBOs should understand the characteristics of their own project management practices in terms of problem definition, team formation, and project execution. In particular, managers in PBOs need to be aware that each step of their project management practices has unique implications for knowledge combination. Organizational contingencies identified in this study can provide practical guidance for PBOs about how to design their project management practices.

This study has several limitations. First, even though it points out three core events that make up knowledge combination and notes differences in sequencing within and across organizations, it does not fully examine their interrelations. Considering the interdependent nature of these three subprocesses could motivate future research. For instance, how does the complexity of problem definition influence team formation process? This research question might inform which organizational structure is appropriate to respond different problem complexity dimensions such as problem variety (Zollo & Winter, 2002), specification, and decomposability (Nickerson & Zenger, 2004). The findings of this study showed that the team formation process under different organization structure influences the frequency of repeated collaboration among organizational members. Based on the findings, future research might empirically examine how the team formation process affects coordination among team members in project execution.

Second, this study examines KCR from a cross-sectional perspective. Accordingly, it does not examine comprehensively the learning processes and dynamics of KCRs over time. Organization routines are not rigid but flexible and changing (Feldman & Pentland, 2003). The iterative and mutual relation between ostensive and performative aspects of routines suggested by Feldman and Pentland (2003) can be applied to examine the dynamics of KCRs (see chapter 1) but was not explored in the design of this cross-sectional study.

This study identifies knowledge combination routines (KCRs) as how project-based organizations operate. In addition, it builds a process theory of knowledge combination by describing events that make up knowledge combination and their relevant contingencies. It shows that repeated and persistent patterns of action can be the source of novel outcomes.

Chapter 3

TEAM FORMATION, ORGANIZATON STRUCTURE, AND PROJECT ATTRIBUTES

OVERVIEW

How do organization structure and project attributes affect the efficiency of the team formation process in project-based firms? This study considers the effects of two alternative organization structures—functional and team-based—and a set of project attributes on the time required to staff project teams. These features are incorporated into an agent-based model that reflects findings from multiple cases studies of project-based organizations. Analyses of the model indicate that the efficiency of the alternative organization structures depends on the attributes of the projects that the firm faces over time. A functional structure is appropriate for forming project teams when the operating environment is dynamic. In contrast, a team-based structure is optimal for a stable operating environment. In addition, this model highlights transactive memory as a key mechanism for facilitating team formation. This study promotes an understanding of the process of team formation within project-based firms.

INTRODUCTION

Diverse knowledge is distributed across individuals within an organization (Buckley & Carter, 2004; Hayek, 1945) and one of the primary roles of firms is to combine this specialized knowledge (Grant, 1996a; Grant, 1996b; Kogut & Zander, 1992). Teams are critical platforms for accomplishing the collective work of combining knowledge (Guimera et al., 2005; Wuchty et al., 2007). Team formation influences the knowledge brought to bear on projects, as well as the efficiency and effectiveness of teams' collaborative work (Aime et al., 2010; Taylor & Greve, 2006).

Nevertheless, most prior studies have examined the characteristics of already-formed teams rather than the team formation process. The focal unit of analysis in these studies is the team, rather than the organization. Accordingly, our understanding of how organizations form teams is limited (Ruef, Aldrich, & Carter, 2003). The purpose of this paper is to advance the theory of team formation in organizations. The central research question is how do organization structures influence the efficiency of team formation under different project characteristics? To answer this question, this study considers the effects of two different organization structures—functional and team-based—and a set of project attributes through the use of agent-based modeling. The project attributes—distance, size, heterogeneity, decomposability, and ambiguity—are explained in detail below.

The proposed model is based on a set of case studies of project-based firms. I conducted 93 in-depth interviews during 2011 in sixteen firms located in the Midwestern U.S. The field studies motivated the research question raised in this study, as well as key constructs, the chosen organization structures, and the team formation processes considered.

The findings from this study indicate how the relative efficiency of functional and team-based organization structures depends on specific project attributes. A functional structure facilitates efficient team formation when project heterogeneity is high. When each project requires a different combination of knowledge, project managers can efficiently recruit team members with relevant knowledge when the organization has flexible team boundaries within a functional structure.

In contrast, a team-based structure performs efficiently when projects are similar and when demands are difficult to ascertain. In a team-based structure, project teams carry over across time and projects. When projects are similar to each other, an organization with a team-based structure can apply existing teams to new projects with few changes in team composition.

The agent-based model proposed in this study highlights the role of transactive memory in organizing project teams. In particular, it shows how an organization can routinize knowledge combination by developing transactive memory. This study argues that project-based firms achieve ongoing novelty in the combinations of knowledge that they produce, yet they do so by following a patterned process of team formation learned over time.

The next section presents theoretical background and empirical observations on team formation, transactive memory, organization structure, and project attributes. Following this is a specification section—explaining the model's logic and algorithmic details—and a presentation of simulation results and interpretation. The final section discusses implications from the findings of this study for understanding organizational team formation processes.

THEORETICAL AND EMPIRICAL BACKGROUND

Team Formation

A team is a critical interface for accomplishing the collective work of combining knowledge distributed across individuals in an organization (Guimera et al., 2005; Wuchty et al., 2007). Teams connect organizational members to produce outcomes for which they are collectively accountable (Reagans et al., 2004; Sosa & Marle, 2012).

Managers must decide whom to put on project teams (Reagans et al., 2004). Team formation decisions are common and recurrent in project-based organizations, where members regularly move onto new teams across projects (Perretti & Negro, 2006). Staffing decisions affect the knowledge available for subsequent combination during project execution (Aime et al., 2010; Taylor & Greve, 2006). Furthermore, team composition affects the work process and performance. Hence, how managers identify and recruit members to collaborate on teams is a critical issue (Nair et al., 2003).

Few studies have examined the team formation process due to researchers' focus on established teams. Perretti and Negro (2006) suggested team and organizational factors affect team formation. At the team level, they examined the relation between the prestige of team members and the number of newcomers on a project team. Reagans et al. (2004) showed that demographic factors and social networks are key criteria for forming project teams. They suggested that relationships among team members (internal network density) and the external network range of team members influence team performance. Guimera et al. (2005) showed with a simulation model and empirical data that team size, the fraction of newcomers, and the tendency for incumbents to repeat previous collaborations influence team formation. Other factors influencing team formation include gender and ethnicity (Ruef, 2002), functional capability (Reagans et al., 2004; Ruef, 2002), homogeneity of expertise (Taramasco, Cointet, & Roth, 2010), organizational membership (Ruef, 2002), status (Hahn, Moon, & Zhang, 2008;

Perretti & Negro, 2006; Ruef et al., 2003), spatial proximity (Ruef et al., 2003), and previous collaboration experiences (Hahn et al., 2008).

In contrast, there is a lack of attention to the effects of organization structure and processes on team formation. Perretti and Negro (2006) found that the number of hierarchical levels in a firm had U-shaped relationship with the number of newcomers in project teams. My search did not identify any other studies of team formation that consider organizational factors. Furthermore, the current literature has not considered how the external environment affects team formation in organizations. One of the main motivations for forming a project teams is to solve problems arising from sources outside the organization such as the market. In dynamic environments, the problems that an organization faces change continuously over time. Hence, project teams form and re-form in response to a stream of different projects. Due to the lack of attention to project characteristics, prior studies miss considerations relevant to the dynamics of organizing teams. Prior research has focused heavily on the antecedents that influence team composition rather than investigating the process by which organizations form teams. To fill these gaps in the current literature, this study examines how alternative organization structures influence team formation when confronting different kinds of project streams.

Transactive memory is critical to understanding team formation. Transactive memory enables individuals to remember "who knows what" (Wegner, 1987). Through referrals from others, individuals can supplement their own transactive memories by accessing others' transactive knowledge (Wegner et al., 1991). Collaborations with others across projects provide opportunities for project managers and team members to learn which participants have which knowledge, thereby building transactive memory. By building and using transactive memory, project managers can efficiently compose project teams suited to project requirements by inviting organizational members who have relevant knowledge. With few exceptions (e.g., Gaston & desJardins, 2005; Gaston, Simmons, & desJardins, 2004), prior studies have not paid attention to how learning from team experiences guides subsequent team formation. In the model presented below, managers and team participants develop transactive memory while repeatedly working with teams across projects, so patterns emerge in the teams formed.

This study considers project-based organizations (PBOs) as a context for studying team formation. A PBO organizes around performing projects and creates systems to do so (Lundin & Söerholm, 1995; Sydow et al., 2004). PBOs are prevalent in a variety of industries such as film production, professional consulting services, engineering, construction, and manufacturing. PBOs combine knowledge distributed among organizational members to meet clients' ongoing demands for customized solutions (Enberg et al., 2006; Lindkvist, 2005). PBOs should continuously form teams to complete projects (Lundin & Söerholm, 1995; Sydow et al., 2004). By forming teams, PBOs bring together individuals with complementary project-relevant knowledge (Reagans et al., 2004; Sosa & Marle, 2012).

In general, PBOs receive an ongoing stream of projects from their clients. Senior managers (i.e., principals and directors) assign each project to a project manager with relevant experience. Then, the project manager assesses the nature of the project by interacting closely with the client. Based on the resulting understanding of the project, the project manager searches for organizational members who possess the range of knowledge required for executing the project. Project managers rely on several different ways to identify team members. As noted earlier, they draw upon transactive memory to guide the search process. Project experiences give a project manager information about past team members' competencies. In addition, project managers can receive referrals from other organizational members. The possibility that organizational members join a project team is contingent on their availability; they are unavailable if they already serve on another team.

Organization Structure

Case studies of sixteen PBOs indicated that these firms generally structure around functions or teams.

Functional structure. Under this structure, organizational members belong to functional groups. Managers form project teams by pulling people from different functional departments. For instance, in a marketing consulting firm, a typical project team consists of people from client service, operations, planning and engineering, information and technology, and project management. When a client awards new business to the firm, the director of the project management department assigns the project to a project manager. Then the project manager contacts the vice president over each relevant functional department and explains the project requirements to them. The vice presidents in the functional departments ultimately decide who will be involved on the team under the project manager's supervision.

The search for project team members is an extensive process across different functional groups. When forming a team under a functional structure, the mobility of personnel is hindered very little by the boundaries of existing project teams. Because organizational members do not have strong associations with particular clients or industries, firms have flexibility to move people around to different projects. Project teams are temporary in this structure. Teams disband when their projects finish and team members return to their functional groups.

Team-based structure. In this structure, organizational members belong to established project teams that focus on specific industries or clients. For instance, an architectural firm has project teams specializing in healthcare, K-12 schools, transportation, and business development, and each team consists of a project manager, architects, designers, and engineers. When a client brings a new project, the firm assigns the project to a project manager who specializes in the client's market. Then the project manager's specialized project team takes over the project. These specialized project teams carry over members from one project to another, rather than disbanding at project completion (as in a functional structure).

Under a team-based structure, the effort involved in team formation is low because project teams are stable. Team member turnover is low. The search for project-relevant knowledge is usually limited to within the boundary of an existing project team. The search for new team members occurs when the project team recognizes that it lacks particular specialized knowledge for a new project. As such, the team-based structure creates rigid team boundaries as members focus their work together on specific industries or clients. Client and industry focus and team-specific practices limit mobility across project teams.

Project Attributes

To understand the implications of each organization structure on the efficiency of team formation, attributes of the projects that the firm faces over time present important contingencies. PBOs face a stream of projects from clients. Each project presents a unique set of possibilities and constraints. Clients bring their distinct visions, preferences, and expectations. These differences across clients cause variations in projects.

This paper considers five project characteristics: distance, size, heterogeneity, decomposability, and ambiguity: (1) *Distance* reflects how unrelated are the projects that the firm takes on at one time and it captures project dissimilarity across project teams. The more diversified the firm, the more distant the projects undertaken. (2) *Size* refers to the number of tasks that make up a project (Davis, Eisenhardt, & Bingham, 2009). The number of task is one aspect of project complexity (Wood, 1986). (3) *Heterogeneity* indicates to the degree of variability in projects over time (Zollo & Winter, 2002). Environmental dynamism gives rise to project heterogeneity. (4) *Decomposability* decreases with the extent of interactions among project requirements. Borrowing from Simon's (1962) typology of complex systems, Nickerson and Zenger (2004) suggested an analogous typology of projects: decomposable, nondecomposable, and nearly decomposable. Full decomposability indicates that each requirement of a project is independent of the others. Nondecomposability describes a project with fully integrated components that cannot be resolved separately. A project that is nearly decomposable lies between those two extremes but is closer to decomposable than nondecomposable. (5) *Ambiguity* refers to the degree of difficulty organizational members experience in recognizing and articulating the relevant requirements or tasks and their relations in a project (Siemsen et al., 2011; Sommer & Loch, 2004).

Modeling Team Formation

A few studies have adopted agent-based modeling to examine project teams. First, the Virtual Design Team (VDT) model simulates actors working on their assigned tasks and the interactions among actors aimed at resolving interdependent tasks (Fridsma & Thomsen, 1998; Jin & Levitt, 1996; Levitt, Thomsen, Christiansen, Kunz, Jin, & Nass, 1999). The VDT model simulates alternative configurations—such as actor behaviors, interactions among actors, and interdependencies among tasks—to evaluate project team performance. The VDT model assumes that tasks are carried out by pre-assigned actors and examines the coordination of teams rather than the team formation process.

Second, Guimera et al. (2005) developed a model of team formation in a scientific community. They examined the effects of team size, the probability of selecting incumbents who already belong to a scientific community, and the propensity of incumbents to select past collaborators on the structure of the collaboration network. They showed that the team assembly mechanisms influence both the structure of the collaboration network and team performance. In addition, this model demonstrated how project teams evolve into a large network cluster.

Third, R-COM-MTDPs (Roles and Communication in a Markov Team Decision Process) modeled how teams need to evolve to handle external environmental changes (Nair et al., 2003). This study examined the reorganization of a team upon team member failure and the arrival of new tasks.

Lastly, Gaston and desJardins (2005) examined how changes in network structure influence team formation. In their model, an organization receives a stream of projects and the organization forms a team through a decentralized mechanism that relies on agents' local network connectivity. This study considered four types of network structure and nine network structure adaption strategies. This study showed that network structure adaptation influences team formation performance.

The model presented in the next section is distinct from its predecessors because it addresses a unique topic: how organization structure influences the team formation process and efficiency under different project attributes. This section specifies the modeled project attributes, organization structures, and team formation processes.

AGENT-BASED MODEL

Model Specification

Projects

For this model, time is divided into runs, rounds, and periods. *Runs* consist of a series of rounds. A *round* begins by introducing *z* new projects and continues until the organization forms complete teams for all *z* projects. Rounds consist of a series of *periods* in which efforts toward team formation and learning occur.

Each project is an *m*-dimensional vector consisting of zeros and ones. An entry of one indicates that the knowledge associated with that position in the vector is required for completing the project. A zero entry indicates that the project does not require that particular kind of knowledge.

Size. Each project consists of *k* demands among the *m* possible knowledge requirements (i.e., *k* entries of one and *m*-*k* entries of zero). Technological constraints and client preferences determine the *k* demands. Project size is the number of demands (*k*) in a project. The more demands, the greater is the complexity of the project (Wood, 1986).

Distance. The distance between two projects is the number of elements in one project vector that must change to match the other (i.e., Hamming distance). The distance between projects is taken into consideration when establishing the initial set of *z* projects in each run. First, a baseline project is generated by selecting at random *k* demands out of *m* knowledge areas; then *z* projects are generated based on random deviations from the baseline project. Specifically, with probability *l* ($0 \leq l \leq 1$), each demand in the baseline project (i.e., any elements with value 1) is replaced by a zero with probability 0.5. For each demand switched to a zero, a zero element in the baseline project is selected at random to switch to a one in order to maintain *k* nonzero elements per project.[2] When $l = 0$, all projects in the initial round are the same. At the other limit, when $l = 1$, the initial set of z projects are random draws.

Heterogeneity. Whereas distance compares different projects within a round, heterogeneity arises from variation in projects across rounds. With probability h, each demand in a project turns from one to zero with probability 0.5 in the next round. To keep the length of the project (k) consistent, the same number of demands converted from one to zero are converted from zero to one by randomly selecting new demands among those knowledge areas not required in the prior project. As h increases, there is greater variation across projects. At the extreme ($h = 1$), projects are drawn at random each round.

Decomposability. Each project can be decomposed into d subprojects $(1 \leq d \leq k)$. To make d subprojects, first, d of the k demands are selected at random and assigned to distinct subprojects. Then the remaining (k - d) demands are each randomly assigned to the d subprojects. As such, the number of demands can vary across subprojects. The sets of demands making up subprojects are defined at the beginning of a round and remain fixed throughout the round. If $d = k$, the project consists of k independent demands. Under this condition, each demand can be fulfilled individually without considering other project demands (i.e., the project is fully decomposable). At the other extreme, if $d = 1$, the demands that make up a project are not separable from each other; they must be addressed by a single, unified team. In this (nondecomposable) case, each demand is tightly intertwined to other demands and all necessary knowledge for the demands must be available at the same time to complete the project.

Ambiguity. Ambiguity is not solely a property of projects. Ambiguity is perceptual; hence, it is a joint property of project features and the perceptiveness of an agent. Agents bring

[2] If $k > m/2$, it may not be possible to make the appropriate number of switches from zero to one, so k is chosen not to exceed $m/2$.

different background knowledge that allows them to ascertain different project demands. As introduced below, awareness of project demands is an aspect of the knowledge that agents possess. Ambiguity is inversely related to awareness.

Organization

Agents. The organization has *z* managers, so each manager receives one project per round. The other *n* agents in the organization make up a pool of potential team members. An agent is limited to serving on one team in a period. Each potential team member *i* ($i = 1,\ldots, n$) possesses a single kind of knowledge among the *m* possibilities. I chose values for the number of potential team members (*n*) that were divisible by the number of possible knowledge areas (*m*). Each of the *m* agents in a subset possesses a single skill that is unique within that subset. Knowledge *j* can fulfill demand *j* ($j = 1,\ldots, m$).

What distinguishes project managers from other agents is that project managers dedicate their efforts to getting members on their teams and do not complete any project demands themselves (Buckley & Carter, 2004; Hobday, 2000).[3] Project managers must recruit agents with suitable knowledge to fulfill each of their projects' demands. When all *z* project teams are complete, the round ends.

Awareness. Perceived project ambiguity decreases with agent awareness. Any given agent is aware of *a* of the possible *m* demands that make up projects ($1 \leq a \leq m$). An agent is always aware of the demand for which its own skill is suited, plus *a*-1 other demands assigned at random from the *m*-1 remaining demands. Unfamiliarity with some demands blinds the agent to the nature of those facets of a project. Projects are completely unambiguous if $a = m$, and project ambiguity increases as *a* falls below *m*.

[3] To reflect this characteristic, project managers do not have knowledge to meet specific project demands in this model.

Project assignments. Each project manager takes only one project per round. The order in which projects are assigned to project managers is randomized each round. In the initial round, each project is assigned to a randomly chosen project manager. In subsequent rounds, projects are assigned to the available project manager who worked on the most similar project sometime in the past. Hamming distance can be used to measure the dissimilarity of a current project and an earlier project. Hence, when a project comes up for assignment, the available project manager who has the experience with the minimum Hamming distance receives this project. When more than one project manager have the same minimum Hamming distance for a project, the project is assigned to one of these project managers at random.

Transactive memory. Initially, agents have no knowledge of what others know. Experience working together on projects provides opportunities for agents to form transactive memory. Agents have an opportunity to learn what knowledge other agents possess when they work together on the same subteam. A *subteam* is the set of team members assigned to the same subproject in a decomposable project. When projects are nondecomposable(d=1), the subteam is the full team. After working together on a subteam, an agent remembers what each of its subteam members knows with probability p_a ($0 \leq p_a \leq 1$).

A project manager has opportunities to learn who knows what across its entire team. A project manager remembers what any given team member knows with probability p_m ($0 \leq p_m \leq 1$). Because project managers have much less intensive interaction with team members than team members have among themselves (Enberg et al., 2006), the probability of adding to the transactive memory of a project manager never exceeds the learning rate of team members ($p_m \leq$

p_a). All agents recall only the agent stored most frequently in their transactive memory when searching for someone with particular knowledge.

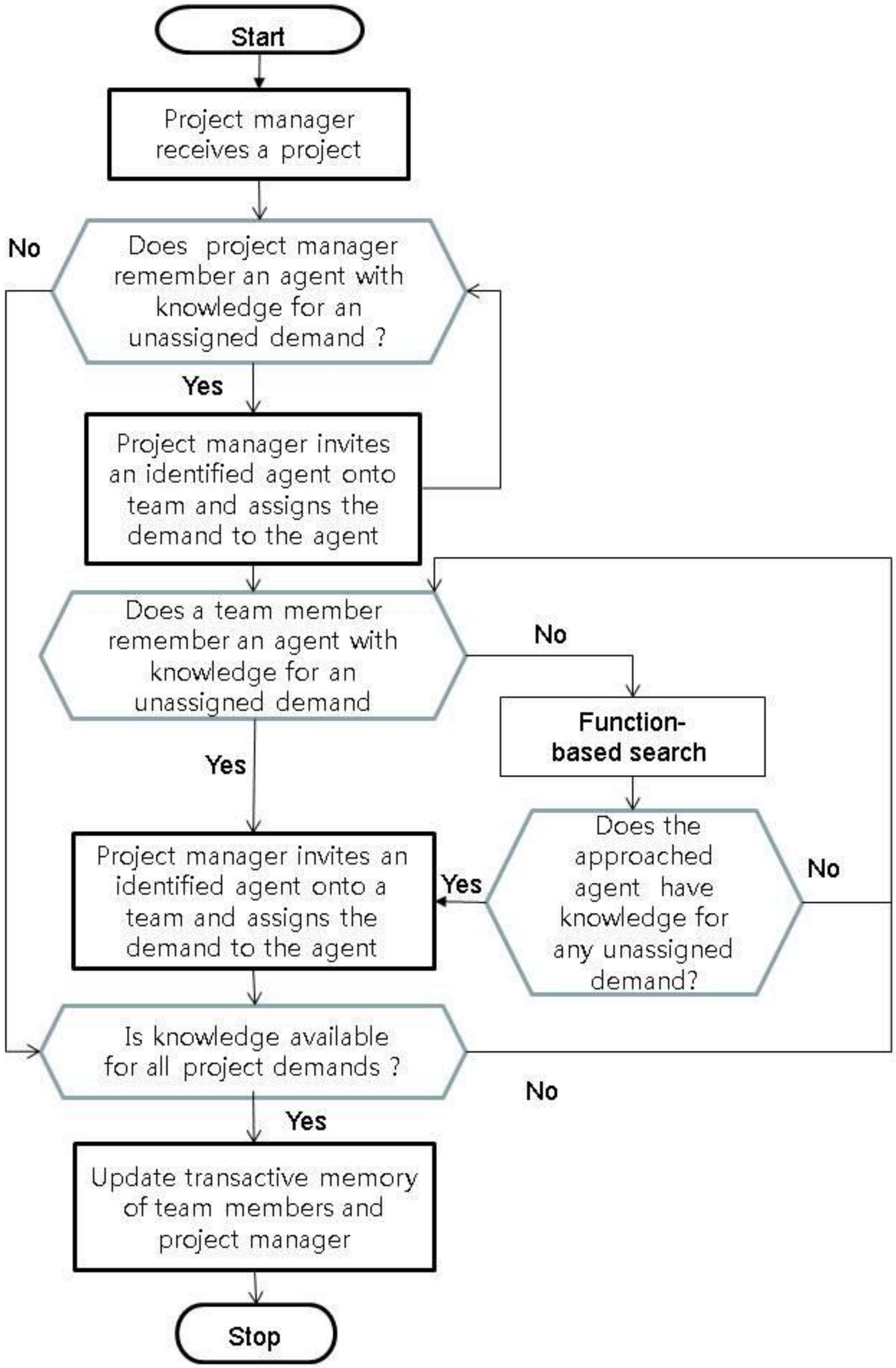
Organization Structures and Search Processes

Functional structure. In a functional structure, potential team members belong to *f* different functional groups ($1 \le f \le m$). The *m* areas of knowledge are randomly assigned to *f* functions, with at least one knowledge area in each function. The knowledge represented within the functions is fixed for all rounds at the beginning of a run. In a functional structure, project managers form project teams by recruiting team members across the *f* functions based on knowing which knowledge areas fall under each function. At the conclusion of a round, project teams dissolve; all agents return to their functional groups and are available for selection to a new project team in the next round.

The search for team members consists of two stages: first, project manager search, then team search. Figure 7 presents the flow of decisions and actions for a project manager's search for suitable agents to form a project team in a functional structure.[4] The project manager works on demands that it can identify (based on its awareness). For each identified demand, the project manager consults its transactive memory to find an agent who has the relevant knowledge. The project manager invites the identified team member onto the project team if the agent is available (i.e., not already working for another project team). It takes one period to try to recruit one agent. If the project manager has relevant transactive knowledge to pursue candidates for other unassigned demands, the project manager moves to another unassigned demand. The same process repeats until the project manager exhausts any relevant transactive knowledge.

[4] To make the flow charts simple, I assume that all demands are unambiguous ($a = m$).

Figure 7
Flow chart for the search process in a functional structure



After a project manager exhausts its knowledge of agents relevant to a project, team search begins.[5] At this stage, search proceeds on the basis of the transactive memories of those agents already recruited. The steps involved in team search are similar to those for project manager search; only the applied transactive memory differs. The order in which each team member examines a project is randomly assigned at the beginning of each period. Figure 7 includes the flow of the team search process.[6] First, a team member identifies an unassigned demand for which it remembers a suitable agent to recruit. The project manager invites one identified agent per period. If the team member does not have any relevant transactive knowledge, the team search process moves to the next member in the search order. The same process repeats until all team members exhaust any relevant transactive memory across all unassigned demands. Once the team's collective transactive memory has been exhausted, the project manager conducts a function-based search to address any remaining unassigned project demands. The project manager approaches the functional group that includes available agents with relevant knowledge for an unassigned demand and contacts one of the agents in the group at random. If the approached agent possesses knowledge relevant for any unassigned demand, the project manager invites the identified agent onto the project team.

If there are ambiguous demands ($a < m$) and a project manager and team members cannot identify an ambiguous demand, a project manager approaches one of the f functional groups at random and contacts an agent in that function at random. An approached agent that has relevant knowledge for any unassigned demand is invited onto the project team. If the

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[5] If a project manager was unable to recruit any agents onto a project team, the project manager moves directly to function-based search.

[6] For simplicity, the team search flow charts (Figures 7 and 8) assume projects are not decomposable ($d = 1$) and all invited agents are available (i.e., not working for another project).

approached agent can specify any ambiguous demands but the agent is unable to perform it, this ambiguous demand becomes unambiguous but remains unassigned. If the approached agent is unable to identify an unassigned demand, the period ends and the function-based search process continues in the next period. After forming a complete project team, the team members and project manager update their transactive memories.

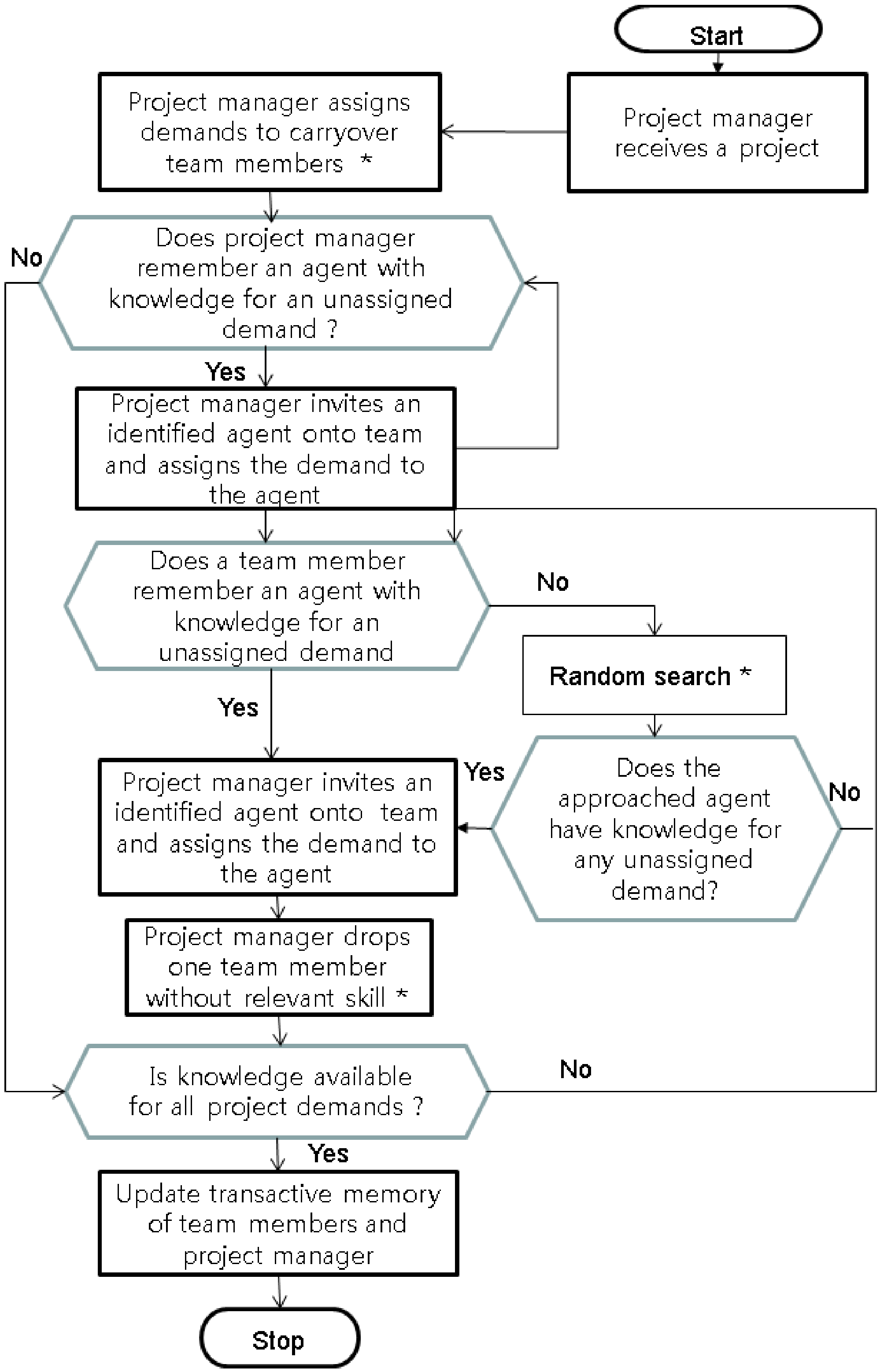
The order in which the *z* project managers and their teams search is randomly assigned in each period. This implies that team formation for the *z* projects proceeds concurrently. The randomized search order avoids getting results that are artifacts of a repeated search order.

Team-based structure. Under a team-based structure, the project teams that formed during the previous round carry over to the next round under the same project managers. A project manager adjusts the composition of its carryover team to the demands of the current project by replacing team members with other members drawn from the organization's pool of unassigned agents (i.e., those not currently involved with project teams). Figure 8 depicts project manager and team search in a team-based structure. The search process in a team-based structure shares many steps with that of a functional structure. Asterisks identify those steps in Figure 8 that distinguish the search process in a team-based structure from that in a functional structure (Figure 7).

The project manager begins by assigning identifiable project demands to carryover team members with suitable knowledge.[7] This invitation process for carryover team members requires just one period. Then the project manager recalls (from its transactive memory) and invites relevant candidates for the remaining unassigned demands. Identifying and inviting each candidate takes one period. Once its relevant transactive memory has been exhausted, team

[7] When a project is decomposed into more than two or more subteams ($d \geq 2$), the team members are treated as one team and are equally available to serve on any subteams for a new project.

Figure 8
Flow chart for the search process in a team-based structure



search is the next step. After inviting each new agent, a project team drops one of the agents that does not have a skill suitable for the current project. Once removed from the project team, the agent becomes available to other projects.

When a project team cannot identify an unassigned demand, the project manager conducts a random search. Unlike the functional structure, agents in a team-based structure do not belong to specialized functional groups; instead, all available agents belong to one large group. In this final stage of the search process, a project manager approaches an available agent chosen at random to find out if it possesses any knowledge needed for the project. This process repeats each period until the project team is fully staffed. Once the team is complete, all agents update their transactive memories.

Cycle time. Cycle time is the number of periods required to organize a project team with agents suited for the k demands of a project. Total cycle time for a given project is the number of periods in which agents are added to the team plus the number of periods of unsuccessful search. Reported cycle times are averages across the z projects in a round. Cycle time is tracked for each round to measure changes in the efficiency of the team formation process over time.

ANALYSES AND RESULTS

I implemented the model using MATLAB 7.12. Table 8 provides a summary of the model parameters, default values, and ranges used in the simulation runs. A model run consists of a series of 100 rounds with z projects per round. All of the results presented in this section are averages based upon 100 runs at each parameter combination.

Table 8
Model parameters

Parameter	**Values***	**Meaning**
m	10, 20, 30	Number of possible demands
k	5, 6,…, 9, 10	Number of demands in a project
a	1, 5, 10, *m*	Number of demands that an agent can identify
n	160, 200, 300	Number of potential team members in the organization
z	5, 6, 7, 8, 9, 10	Number of projects per round and managers in the organization
L	0, 0.1,…, 0.4,…, 1	Probability that a project element varies from the baseline project in the first round
h	0, 0.2,…, 0.8, 1	Probability that each demand varies across rounds
d	1, 2, 3,…, *k*	Number of subprojects per project
p_a	0.2, 0.4, 0.6, 0.8, 1.0	Probability that a team member updates its transactive memory
p_m	0.1, 0.3, 0.5, 0.7, 1.0	Probability that a project managers updates its transactive memory
f	1, 5, 10, 15, *m*	Number of functional groups

* Values underlined are default settings.

Background Parameters

I begin by analyzing the effects of the background parameters for each of the organization structures. These analyses consider the number of team members (n), number of project managers (z), number of functional groups (f), and the learning rates of project managers (p_m) and team members (p_a). The purpose of these analyses is to examine how organization factors except for project attributes influence team formation under two alternative organization structures.

Figures 9a and 9b show how cycle time declines with experience for organizations of different sizes with functional and team-based structures, respectively. Under a functional structure, the organization gains valuable learning in the early rounds. Function-based search enables project managers to focus their efforts on relevant functional groups to find agents who have the knowledge needed for projects. Figure 9a shows that the organization gains efficiency in early rounds as agents learn who knows what. As project managers and team members build transactive memory, the need for function-based search declines and cycle time drops. As organization size increases, the long-run cycle time decreases. The probability that remembered team members will be available for the next project improves as the organization becomes larger.

In a team-based structure, organization size does not affect cycle time. In the initial round, it takes a lot of time for the organization to form project teams (as shown in Figure 9b). Unlike function-based search, random search does not provide project managers any guidance to find relevant agents. However, once project teams form in the initial round, they reform in just one period in next round. Project managers do not compete for recruits due to the continuity of project teams from the end of one round to the beginning of the next.

Figure 9
Number of project team members (*n*)

(a) Functional structure

(b) Team-based structure

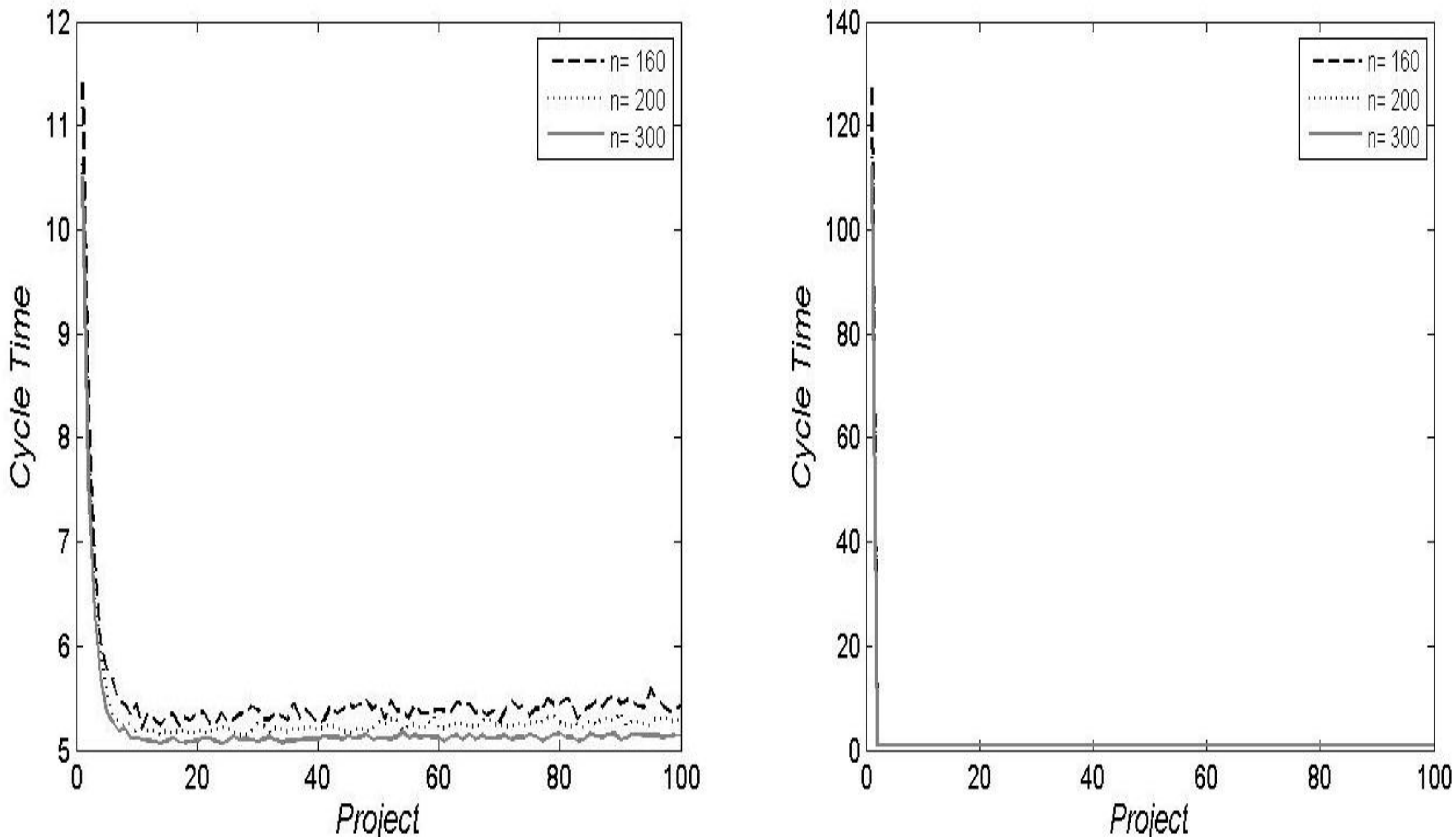


Figure 10 illustrates the relation between the number of projects per round (*z*) and cycle time. Increasing the number of projects raises the long-run cycle time. The greater the number of projects, the higher the utilization of organizational members for projects so project managers are more likely to compete for the same agents. If project managers and team members find that the agent to whom they routinely go for a particular skill is unavailable, they must conduct function-based search to find an alternative agent. In contrast, in a team-based structure, the number of projects does not change cycle time because the same teams carry over across rounds. Figure 11 graphs the relation of the number of functional groups to cycle time. The larger the number of functional groups, the more efficiently an organization conducts function-based search in the early rounds, but after a few rounds the number of functions becomes irrelevant due to reliance on transactive memory. When an organization with a functional structure has one functional group ($f = 1$), the search process and cycle time in the initial round are equivalent to those in a team-based structure.

Figure 10
Number of projects (*z*) in functional structure

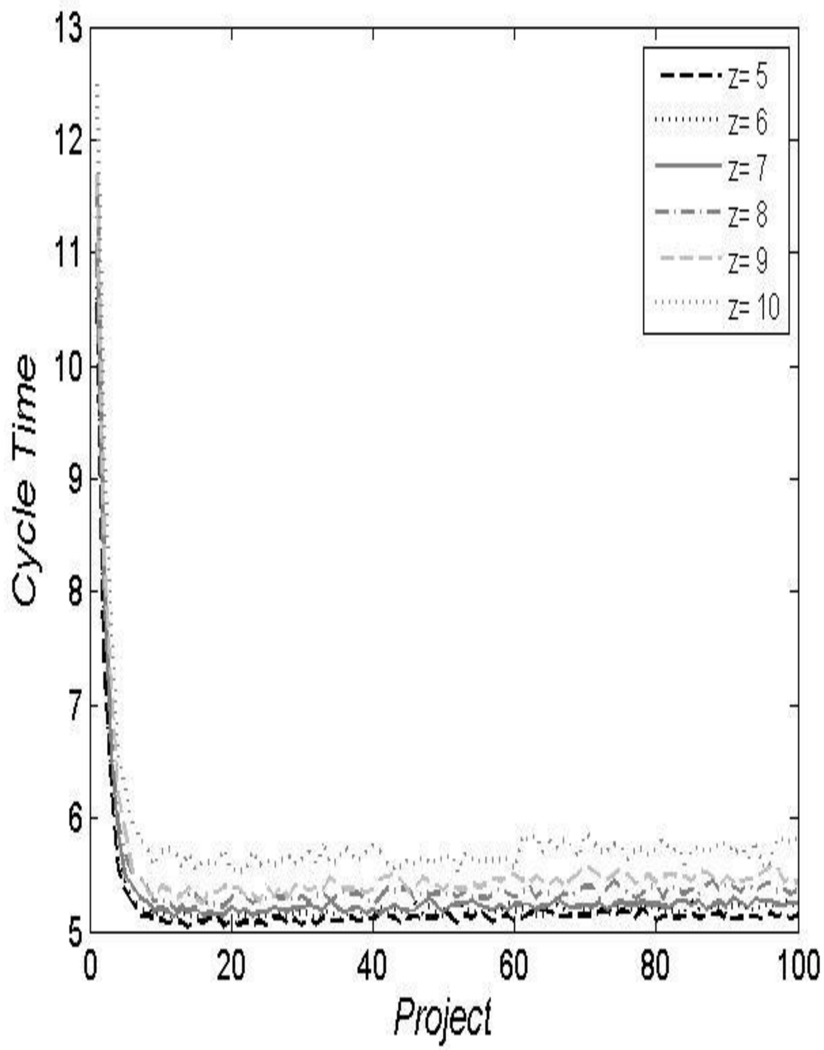


Figure 11
Number of functional groups (*f*) in functional structure

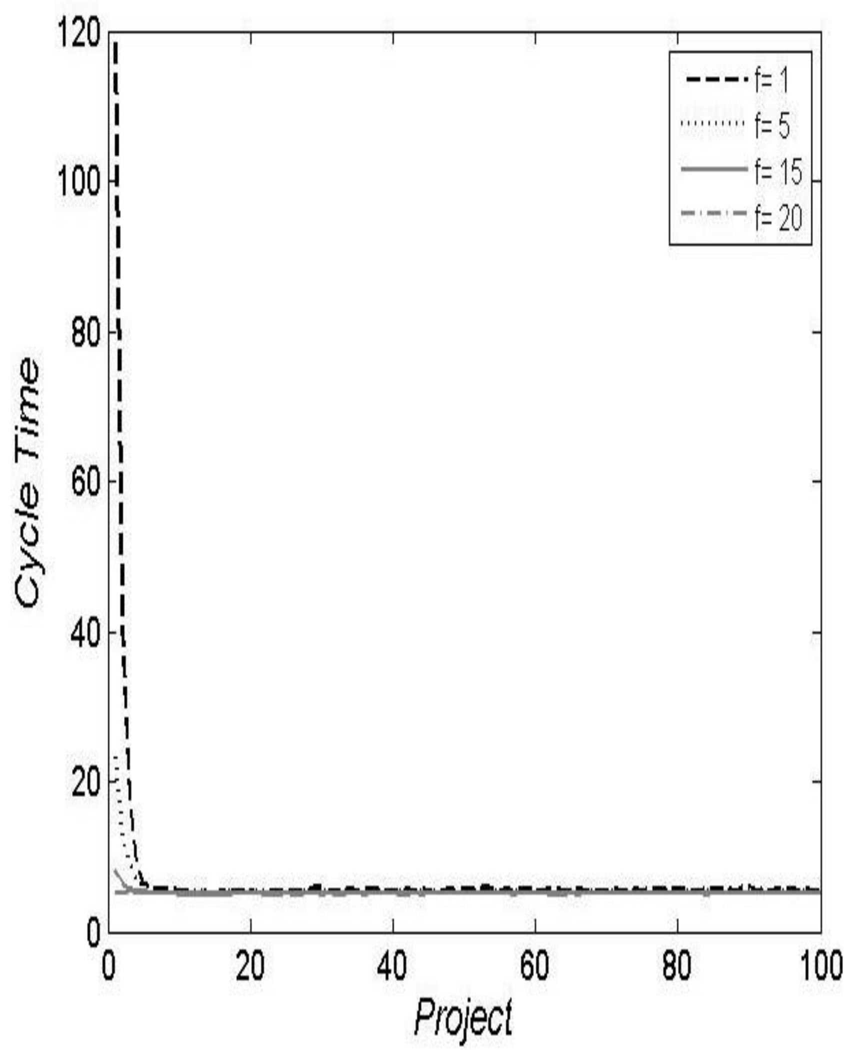
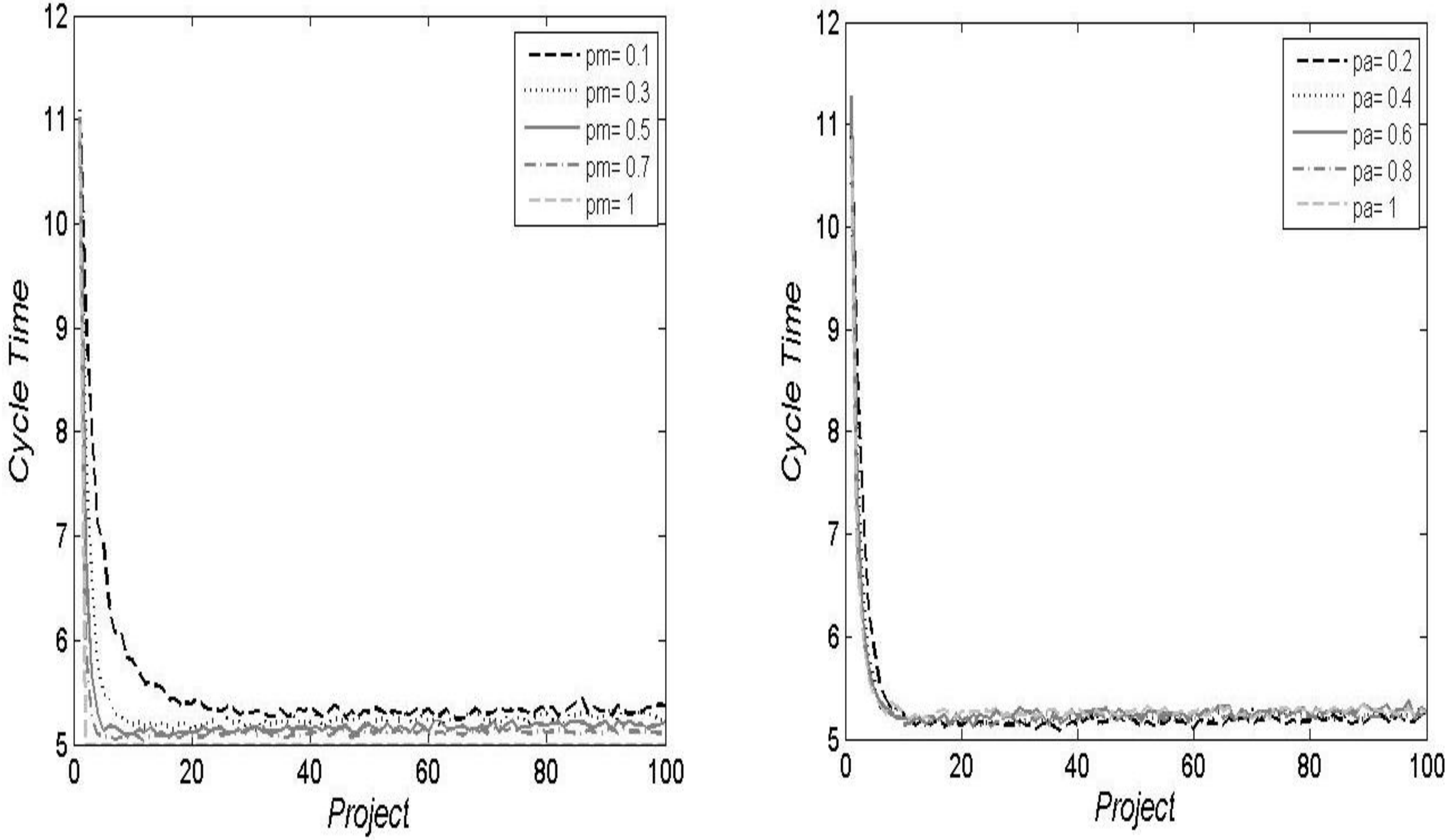


Figure 12 shows the efficiency gains associated with building transactive memory in a functional structure. Increasing the probability of updating project managers' transactive memories (p_m) enables the organization to reach the minimum cycle time more quickly, as shown in Figure 12a. As expected, the more readily project managers remember the skills that others can perform, the earlier they can draw upon this knowledge to invite agents onto project teams. Developing project managers' transactive memory has a much more dramatic effect on team formation efficiency than building team members' transactive memory. Over a wide range of positive values ($0.2 \leq p_a \leq 1$), the probability that team members remember others' skills has little effect on the cycle-time path as shown in Figure 12b. This is because (a) project managers rely first on their own transactive memories and (b) teams pool their transactive knowledge (so deficiencies in a team member's transactive knowledge can be covered by other team members).

In a team-based structure, the carryover of team members leaves no need for transactive memory when projects are consistent across time (h = 0).

Figure 12
Transactive memory in a functional Structure

(a) Project managers (p_m) (b) Team members (p_a)



Project Attributes

In the second set of analyses, I examine how different project characteristics moderate the effects of organization structure on cycle time. These analyses vary project size (k), decomposability (d), ambiguity (a), initial distance (l), and heterogeneity over time (h).

As shown in Figure 13a, increasing the number of demands per project (k) increases cycle time, as one would expect. The more demands in a problem, the more team members are necessary to form a project team. As transactive memory develops, the functional organization reaches its minimum cycle time, which is increasing in k. In contrast, for a team-based structure, altering the number of demands (k) lengthens the cycle time in the initial round, but has no effect thereafter (Figure 13b). As soon as project teams are formed, they remain intact for all subsequent rounds.

Project decomposability (d) lengthens cycle time for forming project teams in a functional structure as shown in Figure 14. As projects are decomposed into more subprojects, team members' transactive memories develop less fully. Decomposability limits learning opportunities only to participants within subteams rather than across all project team members. At the extreme, when a problem is fully decomposable ($d = k$), project team members have no chance to develop transactive memory; only the project manager learns. Furthermore, team members' transactive knowledge is applied only to search for subteam members, not to fill the whole team. In contrast, under a team-based structure, the degree of project decomposability does not affect cycle time. As long as project demands are consistent, team members only learn who knows what within their own subteams, and this knowledge is never applied to team formation.

Figure 13
Project size (k)

(a) Functional structure

(b) Team-based structure

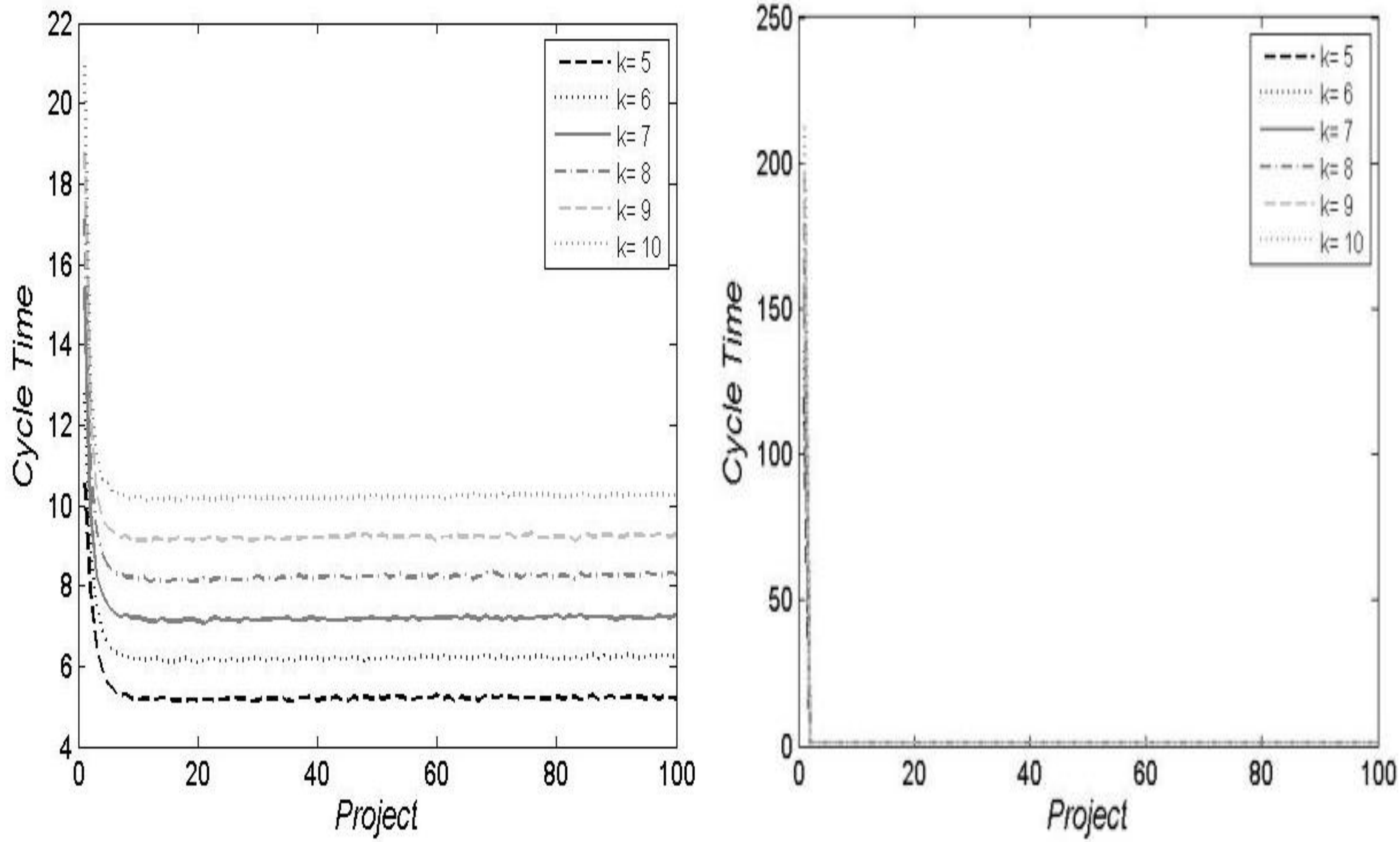


Figure 14
Agent awareness (*a*) in functional structure

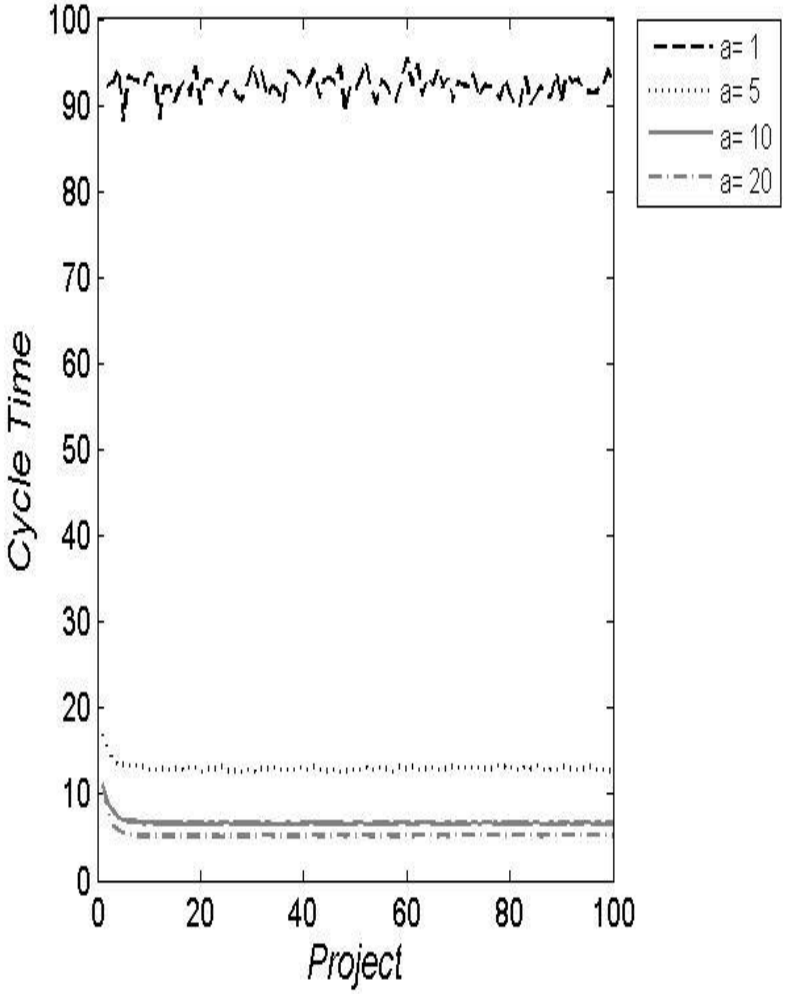


Figure 15
Project decomposability (*d*) in functional structure

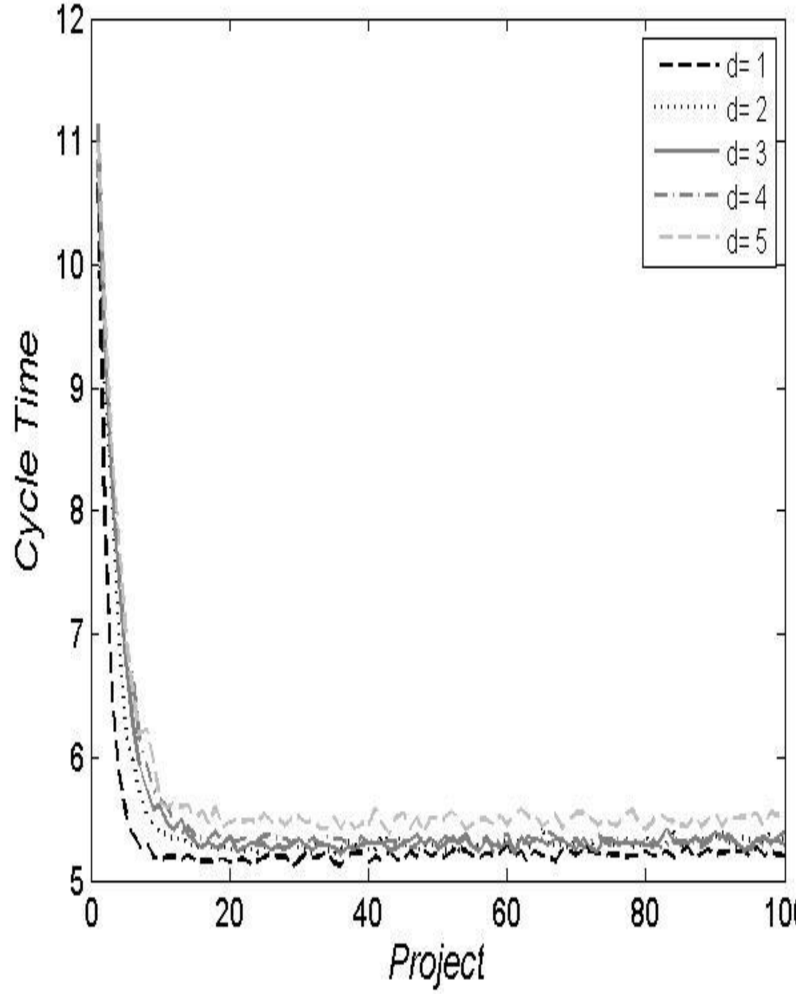
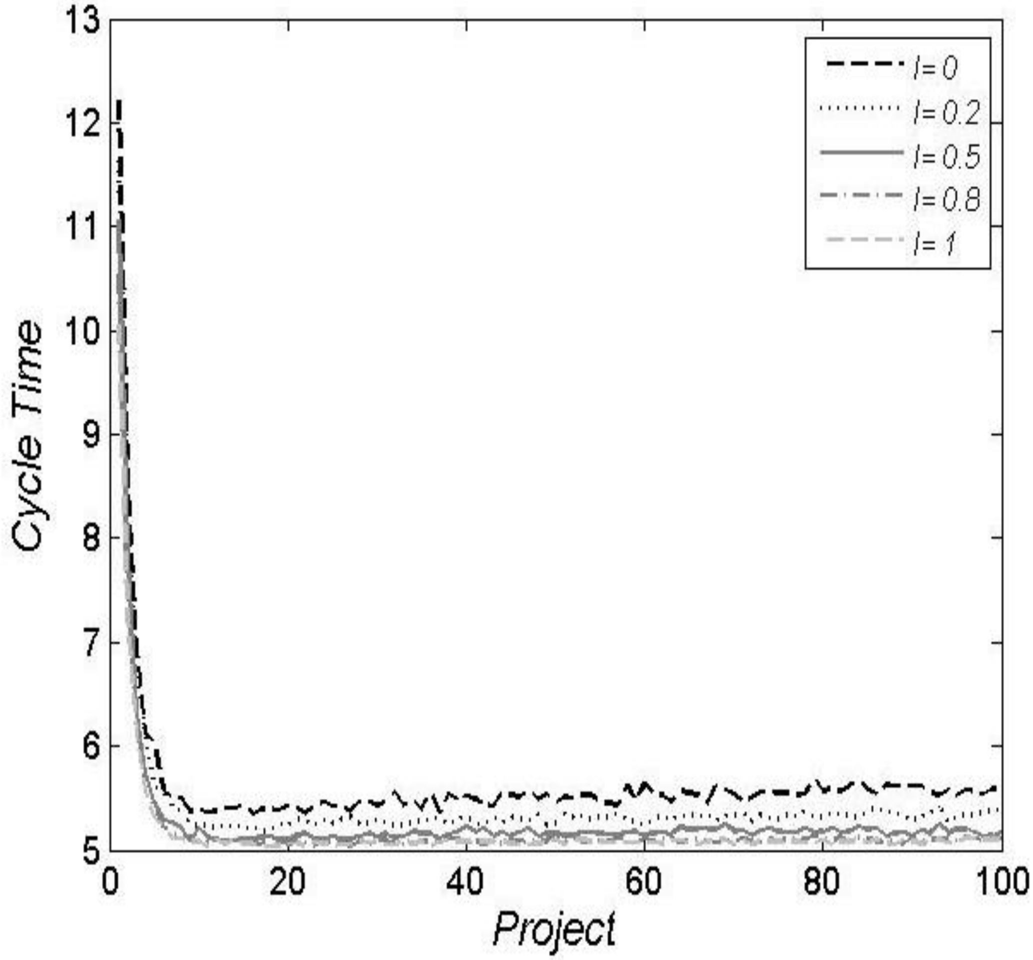


Figure 15 illustrates how project ambiguity affects cycle time under a functional structure by considering the breadth of agent awareness (*a*). Increasing project ambiguity (i.e., decreasing *a*) hinders efficiency gains. Even though transactive memory develops over time, the organization operates inefficiently when agents cannot readily identify project demands (e.g., when *a* is 1 or 5). When project demands are ambiguous, effort goes into searching for agents that understand the projects as well as finding agents that have relevant skills. Project demands must be identified in order to apply developed transactive memory. In contrast, the degree of project ambiguity does not alter the cycle time after the first round in a team-based structure. In a stable operating environment, project team members collectively understand the full nature of their project.

Increasing initial project similarity (*l*) lengthens long-run cycle time in a functional structure as illustrated in Figure 16. The more similar projects are, the more frequently project managers pursue the same agents. Team members from a previous project might not be available for a current project under a low project distance. On the other hand, project distance has little influence on cycle time under a team-based structure due to the stability of team members across rounds.

Lastly, Figure 17 graphs the relation between problem variation and cycle time. Figure 17a shows the implications of altering the probability that demands vary across projects (*h*) in a functional structure. The introduction of new demands extends the search process in the early rounds. However, the variation in demands across projects provides opportunities for agents to work with a diverse set of partners, thereby developing broad and distinctive transactive memories. In the long run, as agents develop transactive memory, the functional organization can reach nearly minimum cycle time (*k*) regardless of the degree of project heterogeneity (*h*).

Figure 16
Project distance (l) in Functional structure

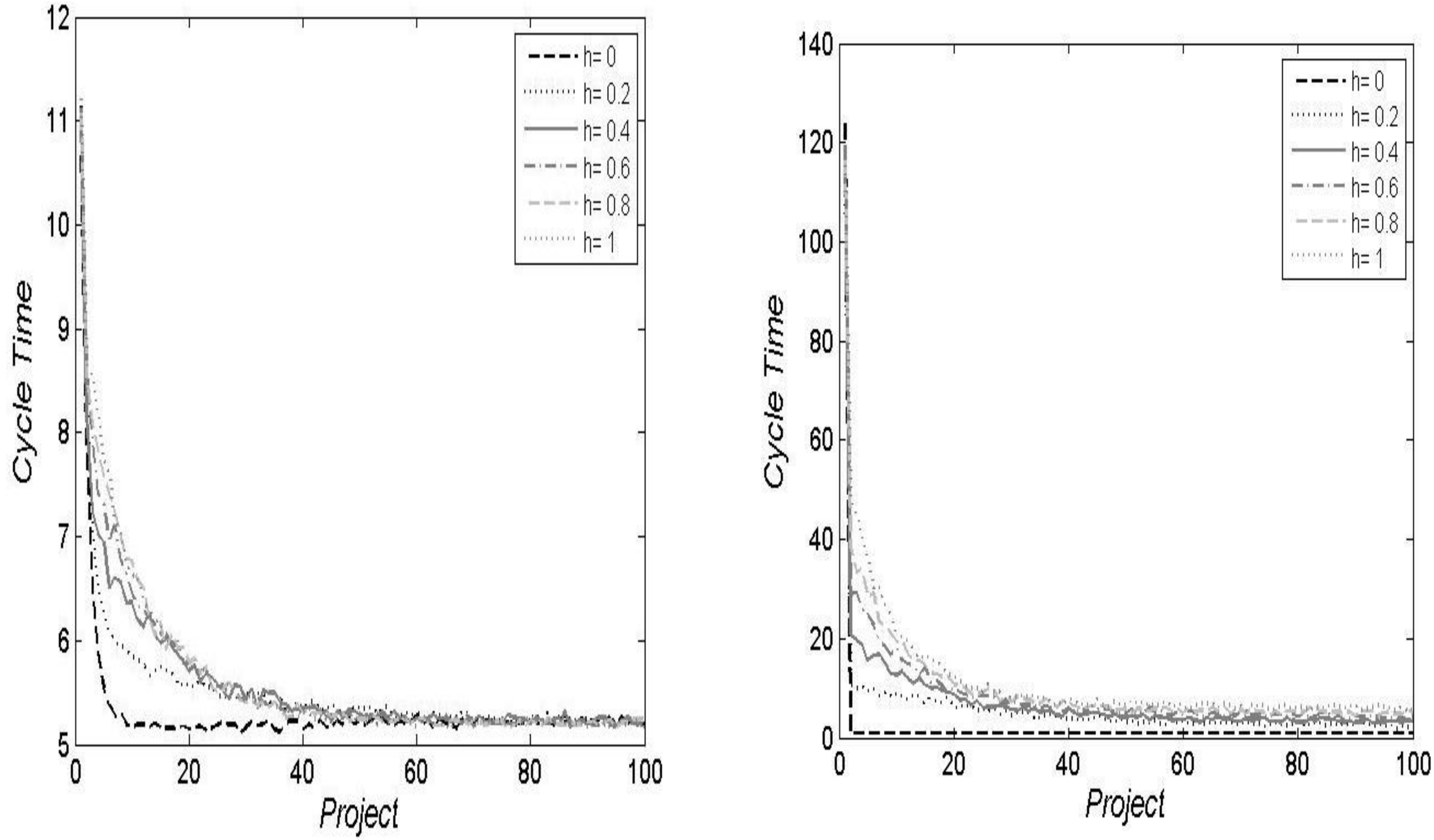


Under project heterogeneity ($h > 0$), an organization with a team-based structure has to adjust the composition of its carryover team to the demands of the current project by replacing team members with other available agents. Search that is unguided by functional designations requires substantial time. The cycle time for the team-based structure is much higher in early

Figure 17
Project heterogeneity (*h*)

(a) Functional Structure

(b) Team-based structure



rounds than it is for the functional structure. For instance, as shown in Figure 17b, even when projects vary moderately (h = 0.2), cycle time lengthens relative to the case of invariant projects (h = 0). This effect is dramatic in the early rounds and, although diminished, remains in the long run. The organization fails to reach the minimum possible cycle time (1) even though agents accumulate transactive memory with experience. Because agents are tied up on teams until appropriate substitutes can be found, the pool of available agents is diminished relative to what it is in the functional structure, hence the search process remains inefficient.

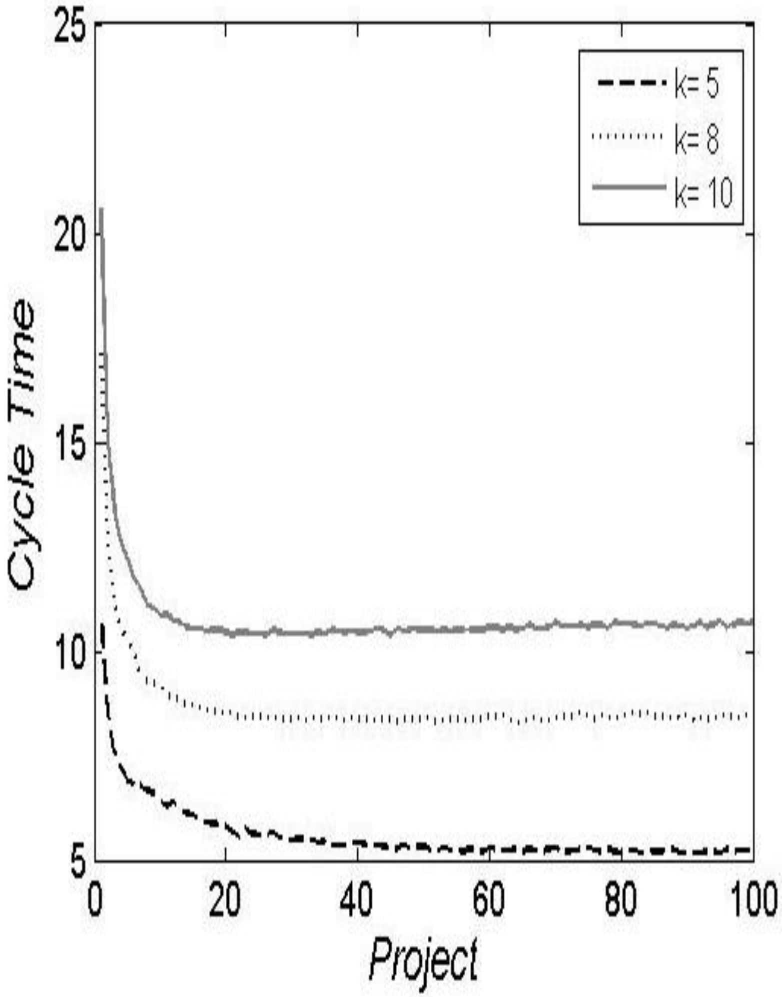
Project Attribute Interactions

Considering that projects come from different clients and situations, investigating project heterogeneity (*h*) together with other project characteristics reflects realistic complications that organizations confront in their st16ream of projects. Accordingly, I vary project heterogeneity (*h*) together with each of the other project characteristics: size (*k*), decomposability (*d*), distance (*l*), and ambiguity (*a*). These analyses retain a fixed level of project heterogeneity, *h* = 0.5, and vary other project attributes one at a time.

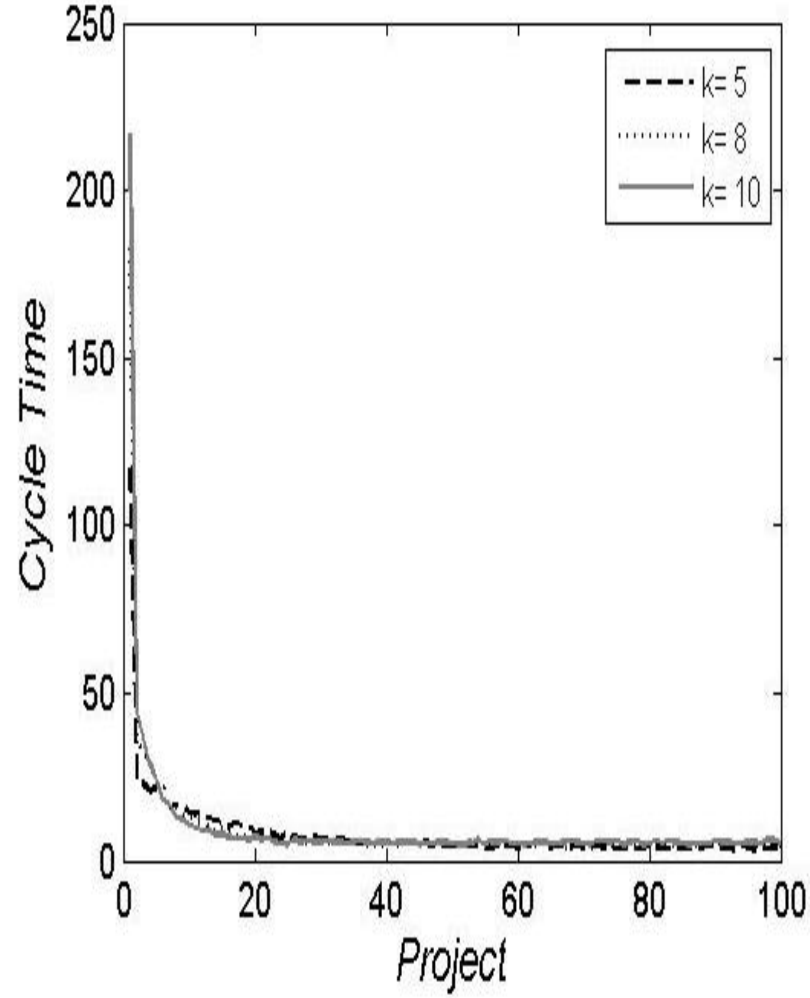
Figure 18 shows the effect of project size on cycle time when project demands vary with probability 0.5. In a functional structure, the relation between project size and cycle time in Figure 18a is quite similar to the relation without problem heterogeneity as shown in in Figure 13a. In contrast, Figure 18b shows that the team-based structure cannot maintain its team formation efficiency when faced with project heterogeneity (cf. Figure 13b). The team-based organization fails to reach the minimum possible cycle time due to inefficient search for suitable agents and the limited pool of available agents as team members turn over within a round.

Figure 18
Project heterogeneity (h=0.5) and project size (k)

(a) Functional Structure



(b)Team based structure



Now consider variations in decomposability under project heterogeneity. Comparing Figure 19a with the earlier Figure 14, we see that the presence of project heterogeneity only delays a functional structure in reaching the minimum cycle time. The results differ for the team-based organization. Figure 19b shows how project decomposability (*d*) alters cycle time under project heterogeneity for a team-based structure. The variation in project demands requires that managers and teams rely on their transactive memory to adjust team composition from one round to the next. Segregation among subteams delays the development of transactive memory among project team members, which has a more detrimental effect on cycle time in a team-based organization than in a functional organization. There is much more variance in cycle times across projects within rounds in a team-based structure than in a functional structure. Based on a comparison of Figures 20a and 15, project heterogeneity (h = 0.5) does not change the relation between project ambiguity and cycle time in a functional structure. However, when project demands change over rounds, carryover teams (in a team-based structure) may not fully identify project demands so they turn to random search to clarify ambiguous demands. Because identifying ambiguous demands is a prerequisite for search informed by agents' transactive memories, the cycle time in a team-based structure is much higher than potential minimum cycle time. Furthermore, it is higher than the cycle time in a functional structure under highly ambiguous projects (a = 5).

Figure 19
Project Heterogeneity (h=0.5) and Project decomposability (d)

(a) Functional Structure

(b) Team-based structure

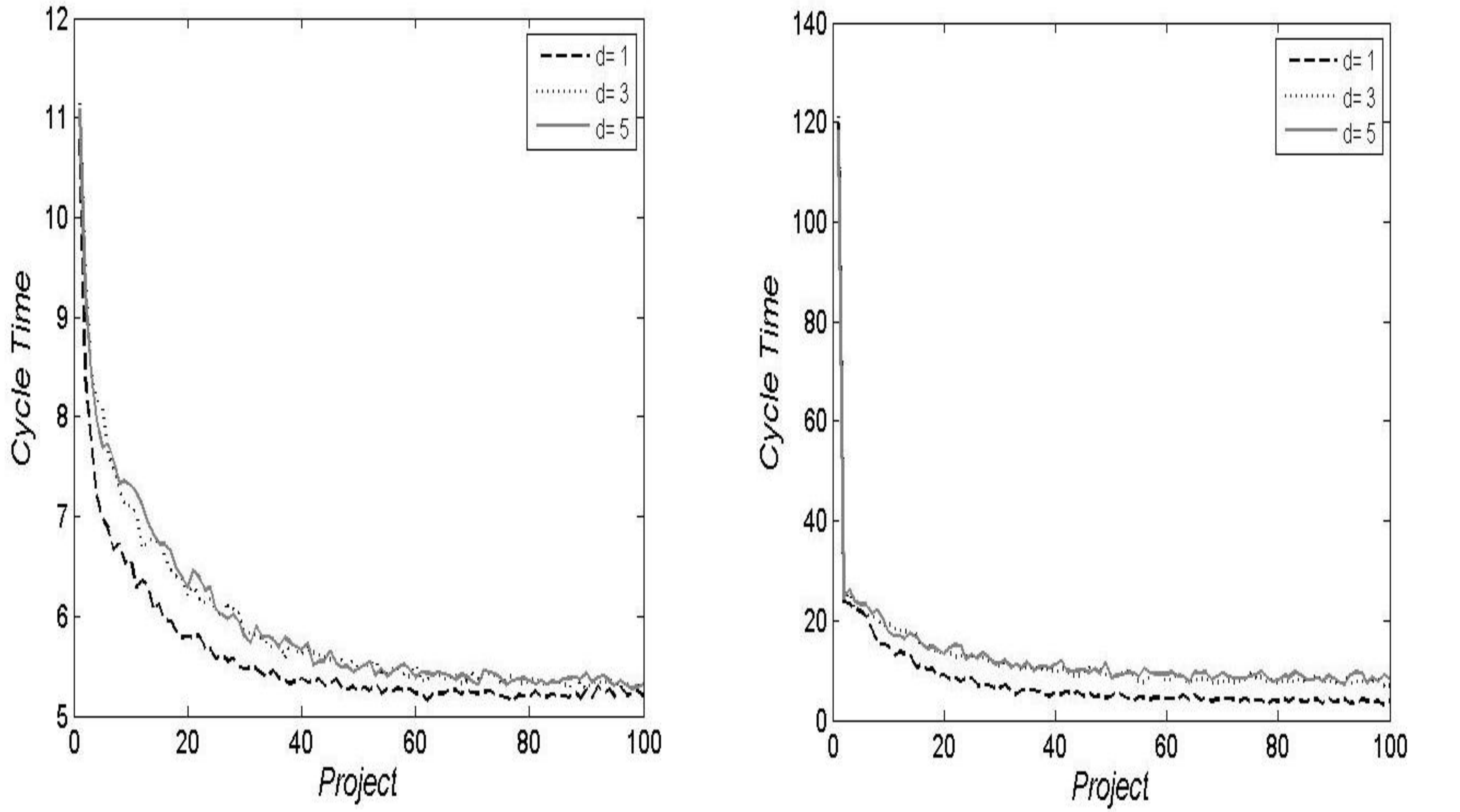


Figure 20
Project heterogeneity (h=0.5) and project ambiguity (a)

(a) Functional Structure

(b) Team-based structure

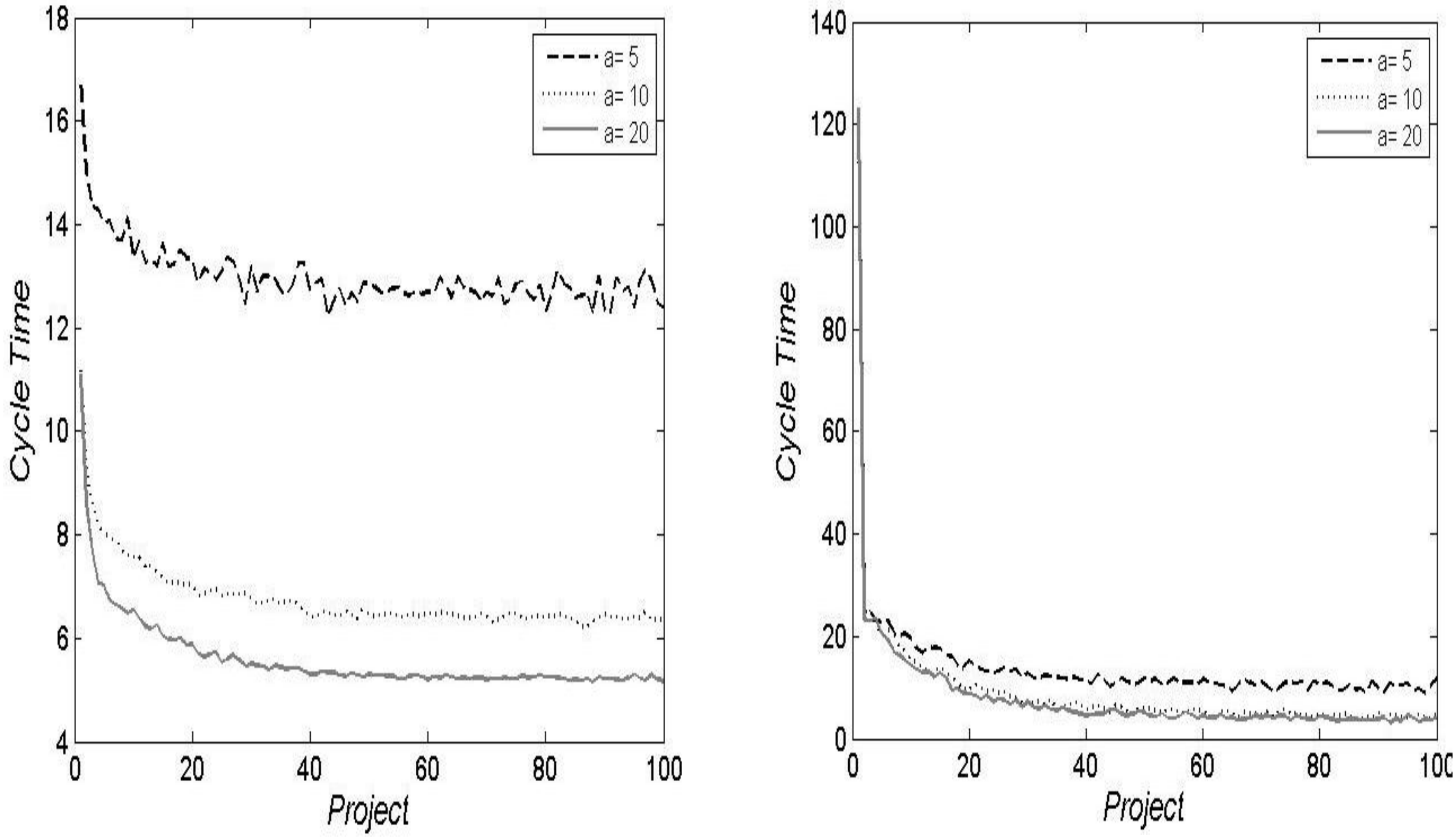
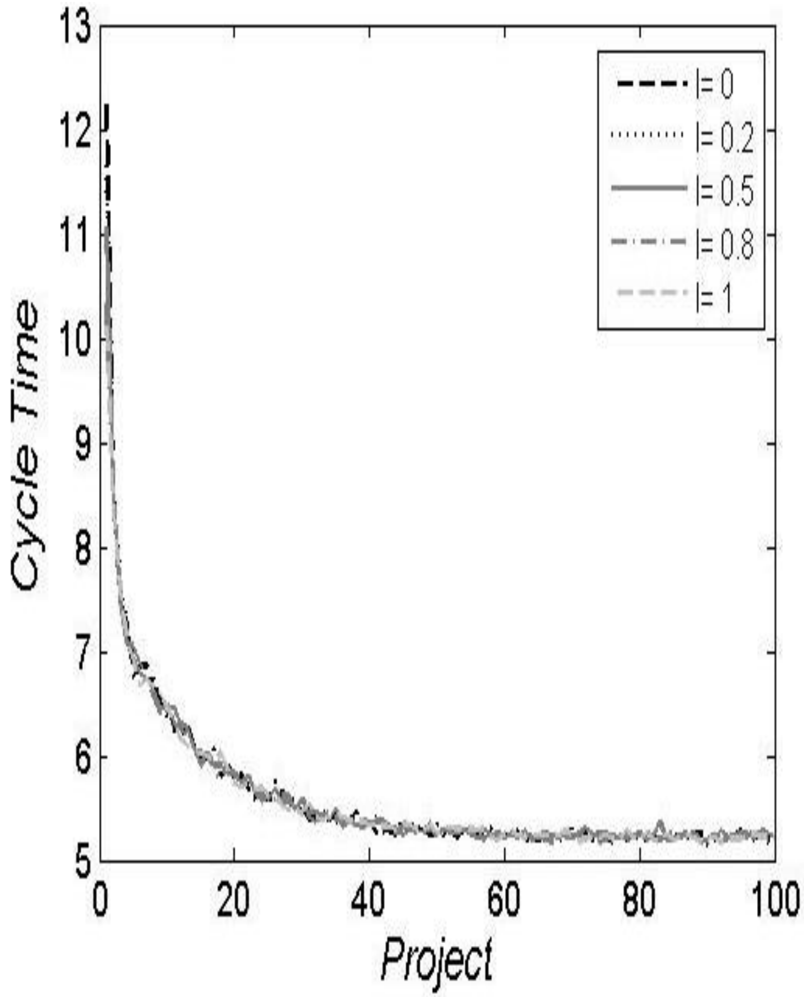
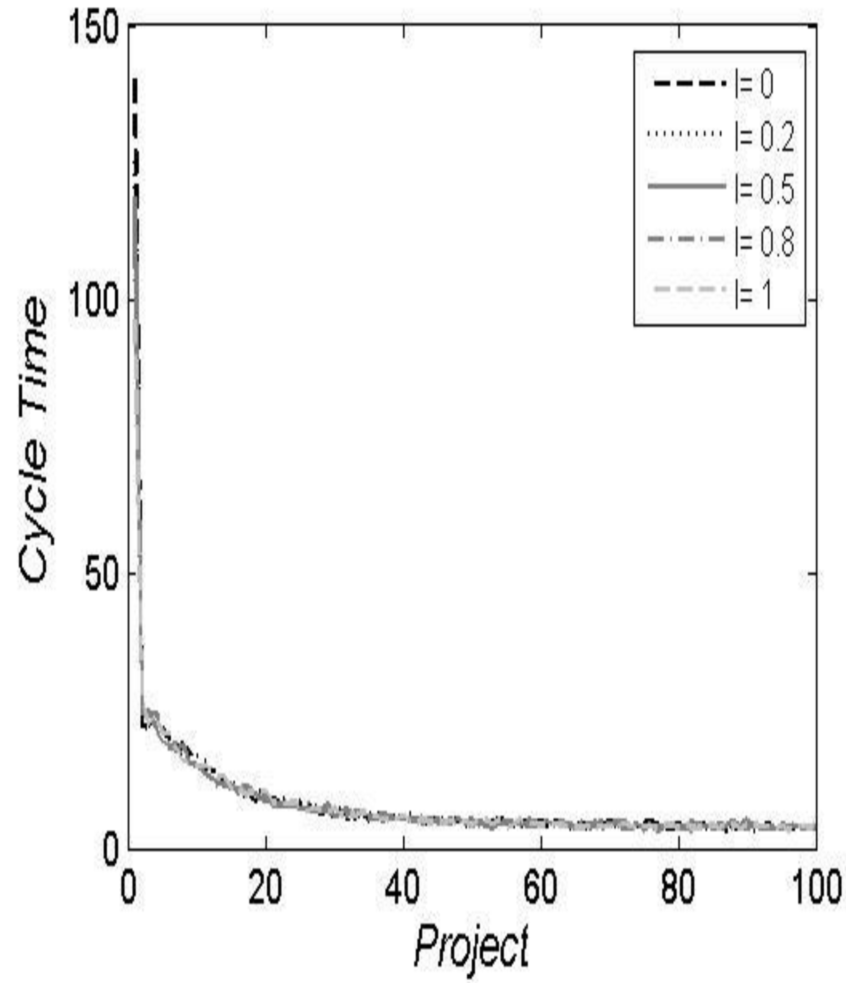


Figure 21
Project Heterogeneity (h=0.5) and Project distance (l)

(a) Functional Structure



(b) Team-based structure



Lastly, Figure 21 shows the relation between initial project distance and cycle time under project heterogeneity for functional and team-based structures. The functional organization exhibits almost no effect due to project distance (*l*). Under high project distance, although agents experience very different projects early in a round, their ongoing experiences expose them to a wide variety of projects and agents. Ongoing changes in project demands limit competition for the same agents within a period. As a result, the degree of initial project distance does not influence cycle times as shown in Figure 21a and 21b.

DISCUSSION

Firms connect distributed knowledge by forming project teams (Guimera et al., 2005; Wuchty et al., 2007). The team formation process affects team composition and, in turn, the work process (Perretti & Negro, 2006) and performance (Reagans et al., 2004). Despite its ramifications, few studies have examined the team formation process due to researchers' focus on established teams. This study provides the basis for a theory of team formation by examining the effects of two alternative organization structures—functional and team-based—and a set of project attributes on the time required to staff project teams.

This study contributes to our understanding of team formation in the following ways. First, this study details the effects of alternative organization structures on team formation. A functional structure is a robust way to facilitate search to compose project teams. Because each potential team member belongs to a functional group that serves to identify its expertise (with varying degrees of precision), search for organizational members with suitable knowledge can be focused. Based on the efficient and focused search for team members, the flow of organizational members across projects and teams is quite fluid in a functional structure. In particular, the model findings show that a functional structure provides an efficient way to form project teams when an organization faces a steam of varying projects from clients (Figure 17a) or when project variation is complicated by other project attributes such as size (Figure 18a), decomposability (Figure 19a), ambiguity (Figure 20a), and distance (Figure 21a). A functional structure affords flexibility to respond to a dynamic operating environment.

In a team-based structure, organizational members belong to a project team that specializes in an industry or a client. Project teams carry over their members across projects. As long as projects are similar and stable over time, a team-based structure can operate efficiently by redeploying established teams. In a stable operating environment, once initial search and learning take place, a team-based organization's performance varies little with other project attributes and organizational factors. The collective understanding among team members helps them efficiently diagnose the ambiguous requirements of new projects.

However, when a team continuously faces new project demands, the stable membership in a team-based structure creates inefficiency in the search for replacement agents (Figure 17b). The search for new team members is less focused in a team-based structure than in a functional structure. Furthermore, members remain on teams until dismissed, even when their knowledge could be useful on other teams. The boundaries between project teams limit member mobility.

Second, this study specifies team formation processes. With few exceptions (e.g., (Guimera et al., 2005; Reagans et al., 2004), prior studies have examined given teams not the way that teams come to be. Few studies (e.g., Gaston & desJardins, 2005) have paid attention to how learning from team experiences guides subsequent team formation.

This study examined team formation as a dynamic, organization-level phenomenon and explored the associated learning by focusing on the development of transactive memory.

Organizational members develop transactive memory while repeatedly participating on teams over time, and patterns of team formation emerge from this learning. Memory reduces the need for search by recording prior successful experiences that guide future action (Paoli & Prencipe, 2003). Through the use of transactive memory, organizations bring together members who possess knowledge relevant to address particular projects. Transactive knowledge maps task requirements to specific individuals who can work together as a team to combine distinct areas of expertise (Brandon & Hollingshead, 2004).

This paper shows that project attributes and organizational factors influence the development of transactive memory. Variation in projects stimulates the accumulation of transactive memory because it leads organizational members to collaborate with different people (Figure 17a). Project decomposability delays the development of transactive memory (Figure 14). The independence of subprojects restricts both learning about others' knowledge and the use of available transactive knowledge. In addition, project ambiguities defer the use of accumulated transactive memory to form project teams (Figure 15). Until organizational members interpret project requirements, they cannot form a project team to respond. Rigorous and accurate project definition must accompany project team formation.

Furthermore, the value of transactive memory turns on the availability of organizational members. Project managers compete for team members when they search simultaneously, which forces them to look beyond their initial choices. In a functional structure, competition for available agents is high when projects are initially similar to each other and vary little over time (Figure 16). The greater the number of concurrent projects (z) relative to the size of the organization, the greater the competition for members among project managers (Figure 10a).

Enlarging the organization (*n*) relieves the competition among project managers by increasing the pool of suitable candidates (Figure 9a).

The transactive memories of project managers and team members carry different implication for team formation. Project managers are gatekeepers for team entry. Because project managers first draw on their own transactive memories before resorting to other bases for search, the transactive memories of project managers take precedence over those of team members. The transactive memories of team members gain potential relevance to the search process only after agents join a team at the invitation of a project manager. Pooling of team members' transactive knowledge makes deficiencies in individual members' learning less important than deficiencies in the project managers' learning (Figure 12a and b). Even though transactive memory is more important in a functional structure than in a team-based structure when projects repeat over time, introducing project heterogeneity makes transactive learning important under both structures.

This study highlights team formation as a core process in the routinization of knowledge combination. A project team is a platform for knowledge combination (Guimera et al., 2005; Wuchty et al., 2007). Through the team formation process, knowledge combination can become "a repetitive, recognizable pattern of interdependent actions, involving multiple actors" (Feldman & Pentland, 2003: 96). The analyses presented here indicate that the development of transactive memory undergirds patterned team formation under a variety of conditions. Regardless of the project attributes and organizational factors, organizations gain efficiency as transactive memory accumulates and eventually reach a stable—sometimes minimal—cycle time. March and Simon (1958: 142) described routines as fixed responses to particular stimuli that enhance efficiency by reducing search. Previous research associated routinization with efficiency gains (Cohen &

Bacdayan, 1994; Cohen et al., 1996; Nelson & Winter, 1982). Although the knowledge combination may be novel, the way to organize people who bring the knowledge together follows routinized patterns. The development of transactive memory produces stable organizational processes (higher-order routines) that alter operational routines (knowledge combinations) to allow firms to adapt to changing environments (Zollo & Winter, 2002).

Third, this study considers project characteristics in team formation. Forming teams is an ongoing response to address a stream of projects. Problem changes call for reorganization of project teams (Nair et al., 2003). By considering a stream of projects, this study adopts a dynamic perspective on organizing and organizations' capacity to form teams efficiently. The findings indicate the unique implications of different project attributes for team formation dynamics.

The findings of this study can provide opportunities for future studies. First, a contingency relation between organization structures and project attributes can be empirically tested by collecting data from PBOs. In these days, most PBOs manage their project with the use of project management software that recorded project attributes, team performance, and team composition across projects. The presence of these archival data makes it possible to test and extend the findings of this study. Second, the model of this study can be extended by considering the role of clients in team formation. As shown in the findings of project ambiguity, accurate problem definition is essential to team formation efficiency. Communication and interaction of project team with clients can reduce project ambiguity. In addition, future research can consider how alternative organization structures influence the development of network structure under different project attributes. Even though transactive memory can be considered as the cognitive side of social network, this study does not adopt formal network structure to analyze the relationships among project participants (e.g., weak ties and strong ties). The analysis of network structure provides the details of how the development of transactive memory forms workflow relations within an organization. Lastly, the mode of this study did not examine the effectiveness of team formation by putting a condition that a project team only invites organization members who have relevant knowledge for the project. The future model might explore how organization structure and project attributes influence the effectiveness of team formation in addition to team formation efficiency

The findings from this study carry practical implications for organizations that staff project teams. Distributing organizational members across projects is a critical issue for most organizations—and for *all* project-based firms. Managers should consider the findings regarding the efficiency implications of alternative structures when designing their organizations and team formation processes. They can evaluate the fit between organization structure and project attributes and design an organization to enhance team formation efficiency. Project-based firms need to structure in ways that produce requisite transactive memory development. They should staff in ways that are cost effective, yet avoid project bottlenecks due to unavailability of individuals with critical knowledge. To minimize the search cost associated with adjusting project team membership, organizations need to conduct rigorous research to understand clients' requirements before assigning projects to managers and establishing project teams.

In conclusion, this study examined how two alternative organization structures and different project characteristics influence team formation efficiency. It suggests that each organization structure has its own advantages and disadvantages for team formation. Hence, we arrive at a contingency view that helps explain the observed variation in structures across project-based firms. Because it facilitates fluid team member mobility, a functional structure is appropriate for a firm facing a dynamic external environment. In contrast, a team-based structure should be considered when the external environment is stable and continuity of team membership serves the organization well across projects. Differences in the team member search process and the resulting formation of transactive memory based on project experiences account for this contingency perspective on structuring organizations.

CONCLUSION

The core purpose of this dissertation was to build a process theory of knowledge combination in organizations. As mentioned throughout this dissertation, knowledge combination remains under-theorized, with most studies employing it as an unobserved explanation rather than exploring the process. Prior research has not examined directly how knowledge combination actually occurs. To address this research gap, this dissertation employs a multi-method approach that combines existing theory (Chapter 1), empirical research (Chapter 2), and agent-based computational modeling (Chapter 3).

Chapter 1 developed a new theoretical framework explaining knowledge combination by drawing on existing literature. In particular, Chapter 1 framed the nature and dynamics of knowledge combination routines in terms of the ostensive and performative aspects of organizational routines (Feldman & Pentland, 2003). Knowledge combination routines (KCRs) are repeated patterns connecting distributed knowledge within an organization, involving multiple actors to generate customized outputs. This chapter identified problem definition, team formation, and project execution as specific actions within knowledge combination routines. Furthermore, it tied these three subprocesses to three types of memory—declarative, transactive, and procedural—that make up the ostensive side of KCRs. Chapter 1 explained that the three subprocesses consisting of the performative side of KCRs contribute differently to organizational learning. This study argues that different types of knowledge have unique implications for KCRs. I argued that the primary learning outcomes from performing KCRs are transactive knowledge and procedural knowledge for interpersonal coordination.

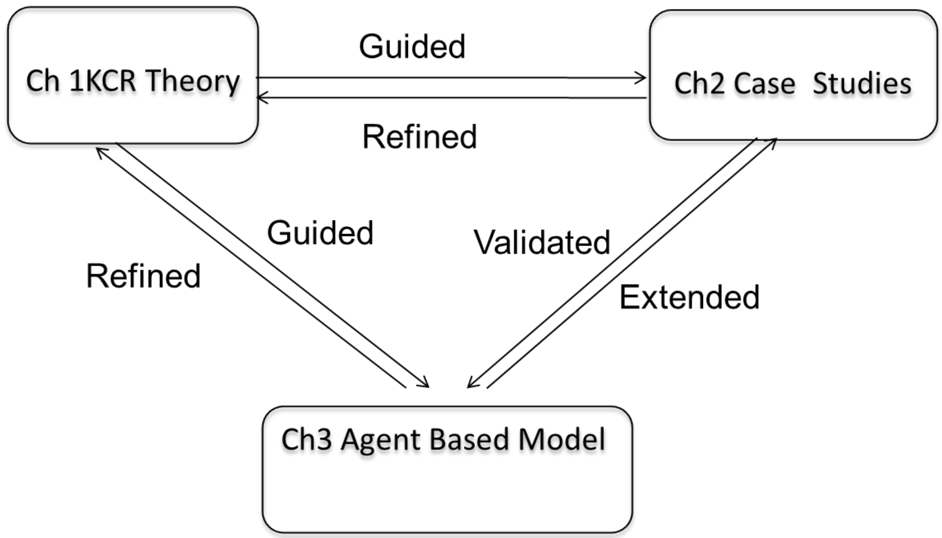
Moving beyond the process of executing a single routine, Chapter 1 analyzed the dynamics of KCRs over the course of repeated projects, in which an iterative mutual relation between the ostensive and performative aspects emerges. The performances of organizational members create, maintain, and modify the ostensive aspect. In turn, the ostensive aspect guides and accounts for particular performances.

Based on the theoretical framework of Chapter 1, Chapter 2 undertook multiple case studies across 16 project-based firms and conducted 96 in-depth interviews. These multiple cases offered a rich context for refining the theoretical framework of Chapter 1 and describing mechanisms underlying KCRs. The findings in Chapter 2 revealed the nature of KCRs and how they generate ongoing novel outcomes. I found that that an organization that continuously provides new customized products and services relied on common and repeated processes called knowledge combination routines (KCRs). KCRs offer a shared framework — grounded in prior experience — that guides how firms combine distributed knowledge to respond to a stream of problems.

Three subprocesses emerge across cases: problem definition, team formation, and project execution. This study also identified key organizational contingencies for each subprocess. Problem definition sets a scope for knowledge combination. The opportunities for problem modification during problem definition depend on when PBOs (project-based organizations) get involved in a project and clients' specificity when they initially approach the firm. Furthermore, different dominant actors influence the scope and accuracy of problem definition. Team formation influences available knowledge and problem execution unites this knowledge. Organization structure is a key factor influencing how project teams are formed. Different types of organization structures affect the search for team members, team member mobility, and team stability. Project execution unites diverse knowledge. In the execution stage, organizational members apply their specialized knowledge to their assigned tasks to bring about an integrated output. Project managers and artifacts play critical roles to facilitate coordination among project team members in project execution. In addition, the prominence of project managers and artifacts depends on the types of tasks required by a project and their interdependence.

Chapter 3 provides the basis for a theory of team formation by examining the effects of two alternative organization structures — functional and team-based — and a set of project attributes on the time required to staff project teams. The findings suggest that each organization structure has its own advantages and disadvantages for team formation. Hence, we arrive at a contingency view that helps explain the observed variation in structures across project-based firms from Chapter 2. Because it facilitates fluid team member mobility, a functional structure is appropriate for a firm facing a dynamic external environment. In contrast, a team-based structure should be considered when the external environment is stable and continuity of team membership serves the organization well across projects. Furthermore, the model presented in Chapter 3 portrays team formation from a dynamic perspective reflecting how teams rely upon transactive memory to form project teams. The model highlights the development of teams for projects by relying on the transactive memory. It shows how an organization can routinize knowledge combination through the development of transactive memory. Chapter 3 argues that combined knowledge might be novel but the process for assembling teams follows patterns learned over time.

Figure 22
Structure of dissertation



Even though each chapter was written independently, the three chapters are complementary to each other and collectively build a process theory of knowledge combination. Figure 22 summarizes these complementary relations. To develop the framework, I drew upon and integrated established concepts in knowledge combination and organizational routines. The theoretical framework in Chapter 1 guided the design of the exploratory empirical and agent-based modeling studies. In return, the empirical findings from exploratory case studies in Chapter 2 can refined the theoretical frameworks of Chapter 1. For instance, Chapter 2 revealed the organizational contingencies and details for each subprocess within KCRs. In addition, the findings from Chapter 2 contributed a grounded computational model in Chapter 3. At the same time, the agent-based model in Chapter 3 advanced the theory of knowledge combination in Chapters 1 and 2 by clarifying theoretical constructs, their relations, and the resulting dynamics of KCRs (Davis, Eisenhardt, & Bingham, 2007; Harrison, Lin, Carroll, & Carley, 2007). Chapter 3 included experiments varying key variables identified in Chapters 1 and 2. For instance, the agent-based model explained the precise relation between transactive memory development and raised team formation as suggested in Chapter 1 and the relation between organization structure and team formation raised in Chapter 2.

This dissertation makes theoretical contributions in several areas. First, this dissertation builds a process theory of knowledge combination. This dissertation characterized knowledge combination as an organizational routine. Central to my framing is a conceptualization of collective knowledge combination as an organizational capability expressed in routines. Based on the complementarity of the three chapters, this dissertation advances the descriptions and explanations of key constructs and their sequencing and dynamics over time in KCRs.

Second, this dissertation advances the organizational routines literature. The analysis of knowledge combination routines affirms recent studies describing continuous change within routines (Feldman & Pentland, 2003; Pentland & Rueter, 1994) and routines as sources of organizational flexibility (Feldman, 2000; Feldman & Pentland, 2003). Extending this line of research, the present study shows that routines enable ongoing innovation. KCRs provide continuity in patterns of action that support novelty across performances.

Third, this dissertation has implications for the innovation literature. To the extent that knowledge combination processes are routinized in organizations, innovations are not merely episodic (i.e., punctuating) but are ongoing. In particular, the ostensive and performative framing of Chapters 1 and 2 explained intra-organizational process and its dynamics for ongoing innovation. Knowledge combination experiences generate learning that changes routines and guides subsequent performances. Ongoing innovation occurs as a direct output of knowledge combination routines and as such, routines themselves undergo change.

Lastly, this dissertation contributes the team formation literature. This study contributes to understanding team formation in following ways. First, this study examined the effects of organization structure on team formation that a topic has received little attention previously. This study shows that different types of organization structures have unique implications for team formation. Second, this study considers project characteristics in team formation. The main motive for forming a project team is to solve a problem and organizations for project teams in response to a stream of projects. The findings from this study show that each different project attribute has unique implications for team formation dynamics. Third, this study specifies the team formation mechanism. With a few exceptions (e.g., Gaston & desJardins, 2005) previous studies have not paid enough attention to how learning occurs in team formation and how it guides future formation. This study indicates that that team participants develop transactive memory while repeatedly forming teams across projects and, as a result, patterns of team formation emerge. Overall, the findings in Chapter 3advance our understanding of the team formation process by systematically examining its key factors and connecting them to the dynamics of team formation.

This dissertation also carries implications for the practice of project management. The findings of this dissertation contribute a framework whereby managers can understand their project management in terms of problem definition, team formation, and project execution. The organizational contingencies of these three stages in Chapter 2 can provide practical guidance for managers to design or evaluate their project management practices. For instance, firms should make efforts to modify the nature of projects to reflect their expertise by interacting with their clients at the early stage of projects. Firms should have qualified and experienced project managers who can develop and manage a coherent plan and promote efficient communication across project teams and clients. However, firms first need to understand their task interdependence in projects to decide whether project managers should be actively involved in the projects. The findings from Chapter 3 offer practical guidance for forming teams efficiently through the choice of structure and design of the team formation processes. Managers can evaluate the fit between organizational structure and project attributes and design an organization to enhance team formation efficiency. Organization structure has implications for team formation efficiency. A functional structure is efficient to the firms, which operate in a dynamic environment. In contrast, firms in stable operating environment would be better to have a team-based structure to form project teams.

Knowledge combination has been treated as a black box in organization theory and strategic management. The purpose of this dissertation was to understand the process of knowledge combination. Knowledge combination does not occur at random; instead, organizations rely on repeated patterns of actions to combine knowledge. This dissertation describes and explains this recognized pattern of knowledge combination and provides a steppingstone for future studies of the knowledge combination process.

APPENDICES

APPENDIX A
Background questionnaire

a) First Name:
b) Last Name:
c) Company Name:
   Department / Unit :
d) Email:
   Phone Number:
e) How long have you worked for this company? ______ years
f) Job title:
g) Job description:
h) On how many project teams have you worked for this company approximately?
i) What are main products or services in your department/unit?
j) Who is your client (customer) for your product and service?
k) What is the typical project team size?
l) How many functional roles are typically represented in a project team and what are their responsibilities in a project team?
m) On average, how long does a project last from start to finish? ___ weeks
n) Who are the main clients (customers) for your project?
o) Does your department (unit) have formal process for project? If you have one, can you please briefly describe it?
p) How much are your products and services customized to your client?
q) How much do projects differ from each other in terms of tasks, durations, or size?

APPENDIX B
Interview protocol

Definition and Planning

1. How do projects (from clients) generally get started?
2. In general, how are the necessary tasks and the scope of a project identified?
    i. What is the role of clients in defining a project?

Team Formation

3. Please tell me how a project team generally is formed.
    i. Who helps to find the needed team members for a project?
    ii. What do you do when your best people are not available for a project?
4. (additional question) Does a project team have subteams? If yes, what are the benefits of subteams in projects?

Execution

5. Please tell me how a project team generally executes (implements) a project.
    i. How is a PMP (project management plan) developed?
    ii. How do project team members coordinate with other team members?
    iii. How is project progress monitored and tracked?

Project changes

6. When do projects get modified or changed?
7. How does a project team manage changes in a project?
    i. What makes a project team flexible?

Repeated collaboration

8. What are some advantages for project execution of having team members who have worked together previously? And disadvantages?
9. What are some advantages from working repeatedly with certain clients? And disadvantages?

Artifacts

10. How do tools, equipment, or technology facilitate project management? [Ask to see these documents.]

Learning

11. How do you repeatedly customize your product and service across different clients?
    i. Where does project creativity and novelty come from?
    ii. How does your firm accommodate customization into the general process?
12. How does your organization capture lessons learned from past projects?

Roles of Participants

13. What is the influence of clients on projects?

14. What are the main responsibilities of a project manager?
15. What are the main responsibilities of executive sponsors?

Project complexity

16. Where does problem (project) complexity come from?
    i. How does project complexity influence project progress?
    (Note: Project complexity refers to the size, unfamiliarity, duration, and ambiguity of projects.)

Evaluation

17. What are the key factors for project success?

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