EXPLORE WITH STRANGERS, EXPLOIT WITH FRIENDS: ORGANIZATIONAL AMBIDEXTERITY AND NETWORKS IN SUCCESSFUL TECHNOLOGY COMMERCIALIZATION

by

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DISSERTATION ABSTRACT

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This dissertation seeks to relieve theoretical tension between organizational ambidexterity and network perspectives by developing a contingent model of firm-level exploration and exploitation. The central proposition of this model is firms need to both effectively explore and exploit to succeed but that inter-organizational network features supporting one of these activities are detrimental to the other. This model indicates firms can resolve this apparent paradox by configuring their networks contingent on the particular goals of these networks. In the context of technology commercialization, I hypothesize firms should benefit by configuring their inter-organizational networks to gather novel information when seeking to discover new technologies but gather redundant information when seeking to bring these new discoveries to market. I test these hypotheses with a unique panel data set of firms active in publishing, patenting, and commercializing technologies in the field of green chemistry. My empirical results largely support these hypothesized relationships.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER I

INTRODUCTION

Exploration and exploitation are fundamental, but often contradictory, activities carried out by organizations (March, 1991; Levinthal & March, 1993). Beginning with Abernathy's (1978) observation of how pursuing efficiency leads to firms' eventual economic decline, researchers and practitioners alike have grappled with resolving the apparent paradox of this "productivity dilemma" (Benner & Tushman, 2003). Conceptually, a common answer is for organizations to balance generating fundamentally new knowledge or "exploration" with utilizing existing knowledge or "exploitation" (March, 1991; Tushman & O'Reilly, 1997; Baum, Li & Usher, 2000).

This "ambidexterity premise" (Raisch & Birkinshaw, 2008, pg. 392) has received some empirical support (Katila & Ahuja, 2002; He & Wong, 2004, Gibson & Birkinshaw, 2004), but research points to multiple hurdles to achieving such balance. These include top management teams' preference for exploitation (Beckman, 2006), the higher degree of uncertainty inherent in exploration (March, 1991), and routine development suppressing exploration (Benner & Tushman, 2002, 2003). Although research on balancing exploration and exploitation tends to focus on exploitation crowding out exploration thereby leading to competency traps (March, 1991; Ahuja & Lampert, 2001) and core rigidities (Leonard-Barton, 1995), organizations can also over focus on exploration leading to an abundance of underdeveloped ideas (March, 1991; Chesbrough & Rosenbloom, 2002; Volberda and Lewin 2003; Simsek, 2009). Furthermore, exploration and exploitation require fundamentally different processes, routines, structures, and incentives, (Nonaka, 1991; Sitkin, 1992; Bradach, 1997;

Christensen, 1998; Adler, Goldoftas & Levine, 1999) which make achieving this balance even more challenging. There is broad agreement that organizations need to both explore and exploit effectively to survive and thrive, but research on how organizations develop such “ambidexterity” (Duncan 1976; Tushman & O’Reilly, 1996; Floyd & Lane, 2000; Gibson & Birkinshaw, 2004) is only now emerging and features few empirical tests (Raisch, Birkinshaw, Probst & Tushman, 2009).

This emerging line of research on organizational ambidexterity uses these challenges as a starting point and offers numerous prescriptions for how organizations can achieve balance among a range of conflicting activities, of which exploration and exploitation are the most common examples (Rasich & Birkinshaw, 2008). One vein of organizational ambidexterity research addresses the temporal ordering of balancing efforts. Specifically, balancing may take place by simultaneously exploring and exploiting (Tushman & O’Reilly, 1997; Benner & Tushman 2003; Gupta, Smith & Shalley, 2006; Raisch & Birkinshaw, 2008) or by cycling between periods of exploration and exploitation (Duncan 1976; Brown & Eisenhart, 1998; Burgelman, 2002; Siggelkow & Levinthal, 2003). A second vein of organizational ambidexterity research addresses structural solutions to this balancing challenge. Here, sub-organizational units focused on exploration and exploitation are structurally (Christensen, 1998) and often physically (Sutcliffe, Sitkin & Browning, 2000) separated, with integration between these units carried out by top management teams (O’Reilly & Tushman, 2004). Alternatively, a third vein of organizational ambidexterity research indicates balance may be possible within a given business unit given proper design, incentives, and leadership (Gibson & Birkinshaw, 2004; Lubatkin, Simsek, Ling & Veiga, 2006). Mirroring this organization-level research, are team-level (Lubatkin et al., 2006, Jansen et al., 2008) and individual-level (Ambile, 1996; Gibson & Birkinshaw, 2004; Smith & Tushman, 2005; Mom, van den Bosch & Volberda, 2007) studies of achieving ambidexterity through balancing exploration and exploitation. These studies reach largely similar conclusions as the organization-level studies; teams or individuals can balance exploration and exploitation by cycling back and forth between these activities over time, setting up dual structures, or incorporating certain managerial techniques.

As insightful as this past research is, it pays minimal attention to a fourth option for achieving ambidexterity. Specifically, *organizations may be able to balance necessary, but often conflicting, activities by using networks of relationships with other organizations*. Not only are such networks increasing common (Mowery, 1988; Gulati, 1995; Powell, Koput & Smith-Doerr, 1996; Ahuja, 2000) but also supplementing organization-level analysis with network-level analysis has helped advance other branches of research such as the Resource-Based View of the firm (Penrose 1959; Barney, 1991; Gulati, Nohria & Zaheer, 2000). Recent research lays a foundation for considering networks as means to ambidexterity by investigating the role of bilateral alliances in exploration and exploitation. For example, Rothaermel & Deeds (2004) find a balance of exploration and exploitation-oriented alliances leads to higher rates of successful drug introductions in the pharmaceutical industry. Similarly, Lavie & Rosenkopf (2006) find that software firms specializing in either exploration or exploitation within domains but maintaining an ambidextrous balance of these activities across domains outperform their competitors. In addition to this empirical work, other researchers have used agent-based simulation to model the effects of network characteristics on ambidexterity (Lazer & Friedman, 2007; Lin, Yang & Demirkan, 2007).

In this dissertation, I extend these efforts to advance ambidexterity research beyond single organizations and organizational dyads. To do this I build on research empirically examining ambidexterity at the organizational-dyad level (e.g. Lavie & Rosenkopf, 2006; Simsek, 2009; Lavie, Stettner & Tushman 2010) and simulation research (e.g. Siggelkow & Levinthal 2003) modeling how certain network characteristics might influence an organization's ability to explore and exploit effectively. Taken together, these lines of research highlight the utility of an empirical study of organizational ambidexterity that incorporates insights from inter-organizational network research. I use this overlap between these two areas of research to develop theoretical propositions relating network characteristics to ambidexterity. In subsequent chapters, I convert these propositions to specific hypotheses that I test using unique data on technology commercialization in the field of green chemistry.

Research Questions

For an organization to successfully explore and exploit, it must harness two different types of information (Levinthal & March, 1993; Siggelkow & Levinthal 2003). Exploration is fueled by information novel to the focal organization (March, 1991; Reagans & Zuckerman, 2001). Such novel information can come from any number of sources, including experimentation and creativity within organizations (Amabile, 1996; Perry-Smith, 2006) or recombination of existing information gleaned from an organization's environment (Kogut & Zander, 1992; Rosenkopf & Nerkar, 2001). It is this novel information that allows a focal organization to design new products, services, and processes to help avoid, or at least stave off, the productivity dilemma (Abernathy, 1978; Benner & Tushman, 2003). In contrast, exploitation requires redundant information to lessen uncertainty regarding how to successfully apply these new products, services, and process (Levinthal & March, 1993; Gilsing, Nooteboom, Vanhaverbeke, Duysters, & van den Oord, 2008) The tension between managing, balancing, and integrating these two disparate types of information is at the core of ambidexterity research (Gupta et al., 2006; Raisch & Birkinshaw, 2009).

As important as these internal efforts undoubtedly are for facilitating exploration and exploitation, the organization-centered approach of past research implicitly discounts the role inter-organizational relationships might play in shaping these processes. Lavie and Rosenkopf (2006) succinctly describe the organization-centered approach of classic organizational ambidexterity research:

> *"Studies such as those cited* [March, 1991; March & Levinthal 1993; Levinthal 1997; Rivkin & Siggelkow, 2003; Tushman & O'Reilly 1997] *have noted that alternative organizational forms, such as decentralized versus centralized structures and organic versus mechanistic ones, are better suited for engaging in either exploration or exploitation within firms' or oganizational boundaries (Brown & Eisenhardt, 1997; Nickerson & Zenger, 2002; Siggelkow & Levinthal, 2003). However, they do not address the question of balance in interfirm relationships."*

The notion that such relationships shape the amount and types of information received by a given organization is more than simply conjecture. Specifically, a central theme in network research explicitly considers connections between organizations as “pipes” through which information flows (Podolny, 2001; Stuart & Shane, 2002; Borgatti & Foster, 2003). Investigating how the configurations and sources of these “pipes” affect organizational ambidexterity is the core research question I seek to answer in this dissertation:

> RQ1: *How do network characteristics affect an organizational ability to explore and exploit?*

Under the umbrella of this broad research question, I examine four specific sub-questions, summarized in Table 1. The first two questions focus on ego-level network characteristics and their affect on exploration and exploitation respectively. An organization’s ego network is the group of organizations to which a focal organization has direct connections (Nohria & Eccles, 1992). Drawing on previous network research, I explore how the composition (what types of organizations make up a given firm’s ego network) and structure (how these organizations are connected to one another) of a focal firm’s ego network influences its ability to both explore and exploit by answering the following sub-questions:

> RQ1a: *How does ego network composition and structure affect an organization’s ability to explore?*
>
> RQ1b: *How does ego network composition and structure affect an organization’s ability to exploit?*

In this dissertation's second set of research questions, I investigate the influence of beyond ego-level network characteristics on exploration and exploitation. For these questions, I focus on the role of centrality in shaping information flows within a network. Although measured in a number different ways, centrality calculations always (with the exception of degree centrality) include data from beyond an organization's ego network (Nohria & Eccles, 1992). Such centrality measures are consistent with using organizations as the unit of analysis. However, since their values depend on the characteristics of a network as a whole, they can help account for the influence of network characteristics and organizations beyond a focal organization's ego network. In considering beyond ego-level network effects, I address the following research questions:

RQ1c: *How does network centrality affect an organization's ability to explore?*

RQ1d: *How does network centrality affect an organization's ability to exploit?*

Table 1. Research questions

	Exploration	Exploitation
Ego Network Level	RQ1a	RQ1b
Beyond Network Level	RQ1c	RQ1d

My second broad research question in this dissertation examines how the link between network characteristics and ambidexterity plays out over time. My motivation for "taking time seriously" (Mitchell & James, 2001) in this context is two fold. First, ambidexterity research contains an explicitly temporal element, as both exploration and exploitation are activities organizations carry out over time (Tushman & O'Reilly, 1997;

Stuart, 2000; Burgelman, 2002). For example, inherently ambidextrous processes such as technology commercialization take place in temporal sequences (Rothaermel & Deeds, 2004), although not necessarily linear ones (Nelson, 2005). Second, the value of information flowing in a given network is time, context, and task dependent (Levin & Cross, 2004; Obstfeld, 2005; Reagans & McEvily 2003), so occupying a certain network position at time X may affect ambidexterity differently than occupying that same position at time Y. Although such temporal dynamics are notoriously hard to capture and examine, this dissertation utilizes a unique data set that helps to overcome many of these difficulties. This unique empirical setting helps me explore long-run versions of RQ1-d under the umbrella of the following broad research question:

> RQ2: *How do network characteristic in RQ1 affect an organization's long-term ability to explore and exploit?*

Study Objectives

My primary objective in this dissertation is to extend organizational ambidexterity research by incorporating key insights from social network research. This extension contributes to the underlying theory of organizational ambidexterity both by assessing if its fundamental tenants apply at the network level of analysis, and if so, how might organizations shape their respective networks to achieve ambidexterity. This first objective makes an original contribution to management research. However, I hope this theory building and testing exercise has consequences outside of its immediate contribution to academic literature. For example, the network-informed ambidexterity theory I develop here may help us better understand what Adner (2006) calls "innovation ecosystems”. Since innovation is increasing carried out across numerous diverse organizations interacting in complex ways (Powell et al., 1996; Ahuja, 2000; Hagadoorn, 2002) and requires both discovery of new means-end relationships and the application of these discoveries, theory that accounts for both inter-organizational relationships and ambidexterity is especially well suited to studying such phenomena.

Past research shows that successful technology commercialization is critical to a diverse set of outcomes including economic growth (Romer, 1994; Nelson, 1993), firm competiveness (Zahra & Nielsen, 2002), lessening the environmental impact of economic activity (Hart & Dowell, 2011), and empowering traditionally underprivileged groups (Prahalad & Hart, 2002). By developing and testing theory that combines both exploration and exploitation in the context of technology commercialization, I hope future extensions of this dissertation will generate new insights on innovation ecosystems, in addition to its contributions to ambidexterity research. Of course, the “causal path” by which these insights might affect policy at the organizational or political level is long, uncertain, and non-linear. Still, the innovation ecosystem’s central role in solving economic, social, and environmental problems means that even an incremental increase in our understanding is worthwhile pursuing.

Key Definitions

In this dissertation, I bring together research on organizational ambidexterity, networks, and technology commercialization. As is common in differing areas of academic research, each of these areas has its own specialized terminology, some of which may not be familiar to those with expertise in other areas. Additionally, researchers in these areas have not necessarily settled on specific terms to describe key constructs. As a result, there are multiple terms used for the same underlying constructs both across within these research domains. In an effort to maintain conceptual clarity in this dissertation, I use this section to provide upfront definitions of the key constructs I use in theory building. Although definitions are not necessary a settled matter in any of these areas of research, the definitions I rely on here are well established in their respective literatures. Table 2 summarizes these definitions.

Table 2. Definitions

Area	Construct	Definition	Source(s)
Organizational Ambidexterity	Ambidexterity	The ability of an organization to perform seeming incompatible tasks well	Duncan 1976; Tushman & O'Reilly, 1996
Organizational Ambidexterity	Exploration	"The pursuit of new knowledge, of things that might come to be known"	Levinthal & March, 1993
Organizational Ambidexterity	Exploitation	"The use and development of things already known"	Levinthal & March, 1993
Networks	Node	An actor in a network	Wasserman & Faust, 1994
Networks	Tie	Something that connects nodes	Wasserman & Faust, 1994
Networks	Diversity	Measure of either differing tie or node types	Campbell, Mardsen, & Hurlbert, 1986
Networks	Closure	The ratio of observed to possible links within a node's ego network	Coleman, 1988
Networks	Centrality	Various measures of a node's importance in an overall network.	Borgatti, 2005
Technology Commercialization	Technology	Design for instrumental action that reduces the uncertainly in the cause-effect relationship involved in achieving a desired outcome	Rogers, 1995
Technology Commercialization	Invention	The process by which a new idea is discovered or created.	Rogers, 1995
Technology Commercialization	Innovation	An idea, practice, or object that is perceived as new by an individual or other unit of adoption	Rogers, 1995
Technology Commercialization	Commercialization	The process of acquiring ideas, augmenting them with complementary knowledge, developing and manufacturing saleable goods, and selling goods in a market	Mitchell and Singh, 1996

Research Setting and Results Summary

Organizational ambidexterity and networks are both data-intensive research domains. Empirical studies of ambidexterity require two outcome variables rather than the customary one, because such studies need to explain both exploration and exploitation (Hess & Rothaermel, 2011; Rothaermel & Deeds, 2004). Furthermore these variables must, at least plausibly, capture similar discoveries at differing points in their development from the "new possibilities" generated by exploration to the "old certainties" of exploitation (March, 1991; Levinthal & March, 1993). Empirical studies of networks are perhaps even more data intensive. In these studies, researchers must both have a credible way of linking organizations to create a network and capture the entirety of a given network to investigate anything beyond simple ego-level network characteristics (Wasserman & Faust, 1994).

Green Chemistry

To meet these challenges, I use the field of *green chemistry* as my research setting for this dissertation. Put simply, green chemistry is the design of chemical products and processes that reduce or eliminate the use or generation of hazardous substances. Green chemistry is a reasonably new field of chemistry research, coalescing in the 1990s around 12 technical principles, launching a peer-reviewed academic journal in 1999, and becoming a recognized division within the American Chemical Society and Britain's Royal Chemical Society in 2001 and 1998, respectively. Although green chemistry is a recognized scientific field, there is also a reasonably high level of firm involvement in green chemistry research. For example, many firms, especially in the bulk chemical and pharmaceutical industries, have their own green chemistry research programs.

As with many scientific fields, green chemistry leaves a robust set of paper trails for researchers to analyze. These include peer-reviewed academic publications reporting new scientific discoveries and patents detailing potentially valuable inventions. Information contained in these documents also provides a credible way to observe links between collaborating organizations. Specifically, multiple organizations can be associated with a single document, either through co-authorship of articles or co-assignment of patents. In addition, by focusing on a single modestly-sized scientific field, building complete networks for both co-publication and co-patenting becomes a more manageable, but still data intensive, task.

The paper trails provided by publications and patents are a reasonable justification for exploring this dissertation's research questions in the broad context of science-based technology commercialization. However, these empirical artifacts are not unique to any particular scientific field, including green chemistry. What makes green chemistry an advantageous setting for this dissertation are some unique empirical outcroppings in this particular scientific field, which help satisfy ambidexterity research's requirement for two outcome variables. For the first of these variables, I follow voluminous past research in using patent data to measure inventiveness. For the second variable, I take advantage of nomination documents for a prestigious award given to firms for developing green chemistry technologies with demonstrated positive financial and environmental outcomes. These award nominations, unique to the field of green chemistry, provide the last source of data needed to test my proposed network-level extension of organizational ambidexterity.

Results Summary

In this dissertation, I develop and test three ambidexterity-related models using concepts and measures drawn from network research as the central explanatory variables. For all of these models I take a number of precautions to help guard against identifying spurious correlations and to ensure I report robust results. For example, I use panels of data for all models allowing the use of a fixed-effects statistical approach (Kennedy, 2008; Cameron & Trivedi, 1986) that controls for the inevitable unobserved heterogeneity amongst the firms active in green chemistry. I also include a number of control variables and develop context-specific lag structures to provide some evidence of causality.

In my first model, I seek to explain firm-level exploration outcomes as a function of participation in a network formed by the coauthoring of academic publications by firm-based researchers. In this model, I develop and test hypotheses predicting network characteristics that facilitate a firm's timely access to novel information will lead to increased exploration outcomes. With one exception, my results largely support these hypotheses.

In my second model, I seek to explain firm-level exploitation outcomes as a function of participation in a network formed by co-assignment of patents to firms. The hypotheses I develop for this model predict network characteristics that provide redundant information to the focal firm and slow information flow to competing firms will lead to increased exploitation outcomes. For this model, my results follow a similar pattern to the exploration model, with the exception of one hypothesis that ultimately proved untestable.

In summary, I use the setting of technology commercialization in the field of green chemistry, and its attendant unique empirical outcroppings, to test the extension of organizational ambidexterity research I develop in this dissertation. In this extension, I hypothesize how various network characteristics should affect ambidexterity's constituent processes of exploration and exploitation. At least in the context of green chemistry, I find broad support for these hypotheses. Although my findings are not definitive, they do provide some reasonably strong evidence that insights from past research on inter-organizational networks can extend organizational ambidexterity theory in a meaningful way. Furthermore, my findings suggest a number of ways organizations can potentially design their networks to help facilitate, the exploration for new ideas, the exploitation of existing ones, and ideally both.

Overview of the Dissertation

To answer the research questions posed in this dissertation, I build directly on the foundation created by dyadic and simulation-based ambidexterity research to develop models of exploration and exploitation through inter-organizational networks. Specifically, I extend this research by looking beyond counts and categorizations of dyadic alliances (e.g. Rothaermel & Deeds, 2004) to empirically test the effect of specific network characteristics on organizational ambidexterity. Each of these network characteristics has well-established consequences for information flow within a network

(Borgatti & Foster 2003; Kilduff & Brass, 2010) and therefore has conceptually clear consequences for exploration and exploitation, respectively.

I divide the balance of this dissertation into four parts. In Chapter II, I review past research on organizational ambidexterity, organization-level networks, and technology commercialization. This review shows that including a network perspective is a natural extension of organizational ambidexterity research and that technology commercialization is a useful setting for studying this extension. In Chapter III, I integrate specific aspects of network and ambidexterity research into theoretical propositions concerning exploration and exploitation in technology commercialization. These propositions reflect past research in showing effective exploration and exploitation require different types of information, but also implies firms seeking these types information through inter-organizational networks face a paradox. Specifically, networks designed to gather novel information should support exploration but harm exploitation, whereas networks designed to gather redundant information should do the opposite.

Prescriptions from past research for achieving ambidexterity appear unlikely to resolve this paradox, so I propose a novel configurational solution developed from network theory. In Chapter IV, I convert these propositions into specific hypotheses, describe my research methodology, and introduce a unique data set of scientific papers, patents, and successfully commercialized technologies from the field of green chemistry. In Chapter V, I use these unique data sources to empirically test my hypotheses linking organizational ambidexterity and networks. Finally, in Chapter VI, I discuss these results and their consequences for the ambidexterity literature, managers, and policymakers.

CHAPTER II

LITERATURE REVIEW

As highlighted in the introduction, organizations often face the need to balance conflicting activities (March, 1991; Levinthal & March, 1993; Tushman & O'Reilly, 1997), a common example of which is balancing the exploration for new ideas with exploitation of existing ones. Failure to strike such a balance can either choke off needed innovation and subsequent renewal (March, 1991; Leonard-Barton, 1995; Ahuja & Lampert, 2001) or generate a glut of underdeveloped ideas (March, 1991; Chesbrough & Rosenbloom, 2002; Volberda & Lewin 2003; Simsek, 2009). Although striking such a balance within an organization is undoubtedly important, activities critical to achieving such a balance are increasing taking place across networks of interconnect organizations (Mowery, 1988; Gulati, 1995; Powell et al., 1996; Ahuja, 2000). With organizations increasing competing as groups of interconnected organizations or ecosystems (Adner, 2006; Adner & Kapoor, 2010) rather than in isolation, understanding ambidexterity at this new level of analysis calls for new theorizing that reaches beyond single organizations.

This chapter reviews the two main bodies of research that this dissertation draws on: organizational ambidexterity and organizational networks. These two literatures provide the theoretical underpinning for this dissertation. Although these streams of research have evolved largely in isolation from one another, they tend to address similar questions, feature similar mechanisms, and are otherwise largely compatible. Historically, the major difference between these two perspectives seems to have been a focus on different levels of analysis. However, the extension of ambidexterity research to organizational dyads (e.g. Homqvist, 2004; Rothaermel & Deeds, 2004; Lavie & Rosenkopf, 2006) has brought these two areas of research closer together.

I organize this chapter into three main parts. First, I review past research on organizational ambidexterity, followed by selected research organization-level networks. Next, I highlight the parallels between ambidexterity and network research and suggest how each might usefully inform the other. I focus on organizational-level research from each of these research areas because this forms the direct theoretical underpinnings of this dissertation. In addition, reviewing the entirety of each of these literatures would simply be too lengthy for a single study (for broader reviews see Lavie et al., 2010; Borgatti & Foster 2003; Kilduff & Brass, 2008).

Organizational Ambidexterity

The fundamental premise of organizational ambidexterity research is that organizations' success depends on balancing and integrating conflicting, activities, structures, and demands (March, 1991; Levinthal & March, 1993). The most common application of organizational ambidexterity is in balancing "exploration of new possibilities and exploitation of old certainties" (March, 1991; Levinthal & March, 1993). If organizations over-focus on exploiting their current advantages, competitors will eventually overtake them as these advantages become obsolete (Leonard-Barton, 1992; Ahuja & Lampert, 2001). In contrast, if organizations over-focus on exploring, they may produce an abundance of new ideas but fail to capitalize on this novelty (Volberda & Lewin 2003). Although some early studies regard this tradeoff as insurmountable, recent research argues ambidexterity can attenuate this trade off (Miller & Friesen, 1986; Levinthal & March, 1993; Burgelman, 2002; Benner & Tushman 2003; Gupta et al., 2006; Raisch & Birkinshaw, 2008). Accordingly, conceptual and simulation research predicts organizational ambidexterity will lead to improved firm performance (March, 1991; Levinthal & March, 1993; Tushman & O'Reilly; 1996, Lazer & Friedman, 2007). These predictions have received some empirical support with studies linking organizational ambidexterity to organizational performance (e.g. Gibson & Birkinshaw, 2004; He & Wong, 2004; Tiwana, 2008), but such studies are rare (Raisch & Birkinshaw, 2008).

Although many organizational ambidexterity studies follow March's (1991) seminal paper in investigating organizations' balancing of exploration and exploitation, organizational ambidexterity studies also examine balancing numerous other seemingly contradictory concepts. Examples include implementing organic versus mechanistic structures (Burns & Stalker 1961; Adler et al., 1999; Sheramata, 2000) and pursuing incremental versus radical innovation (Tushman & O'Reilly, 1996). Consistent with past research, I treat exploration and exploitation as specific activities carried out by organizations, while organizational ambidexterity is the organization-level theoretical construct explaining how these divergent activities are balanced and why this balance should result in improved organizational performance (He & Wong, 2004; Simsek, 2009).

Structural Solutions

One stream of research focuses on achieving ambidexterity through structural separation of sub-organizational units pursuing incompatible tasks such as exploration and exploitation (Duncan 1976; Tushman & O'Reilly, 1996; Christenson, 1998; Raisch et al., 2009). Here, organizations insulate units responsible for each task from one another and allow these units to have different internal structures, incentives, metrics, and cultures (Christensen, 1990; Benner & Tushman 2003; Gilbert, 2005). This research recognizes that organizations must ultimately integrate these activities to create value (Eisenhardt & Martin, 2000; Tushman & O'Reilly, 2008), but assigns responsibility for such integration to top management teams supervising these separate units (Smith & Tushman, 2005). A competing line of research focuses on how organizations can achieve ambidexterity within a given unit. Here, the proper organizational design (Gibson & Birkinshaw, 2004) and leadership (Lubatkin et al., 2006) can lead to ambidexterity without structural separation.

Critics of the first approach regard structural separation as insufficient for achieving ambidexterity (Gilbert, 2006). Critics of the second question the wisdom of requiring individuals with shared skills, values, and "thought worlds" (Dougherty, 1991) to switch between radically different tasks (Inkpen & Tsang, 2005) . Efforts to resolve this "differentiation versus integration" tension (Raisch et al., 2009), include creating parallel structures for individuals to occupy (Adler et al., 1999) and managing the relative mix of activities according to there salience for a particular time period or initiative (Gulati & Puranam, 2009).

Temporal Solutions

A complementary line of research examines how organizations achieve ambidexterity by cycling between incompatible activities. Although most organizational ambidexterity examines the simultaneous pursuit of conflicting activities (Raisch et al., 2009), a considerable number of studies consider asynchronous ambidexterity as a solution to the productivity dilemma (Brown & Eisenhardt, 1998; Benner & Tushman, 2003). Siggelkow & Levinthal (2003) use agent-based simulation to model temporal cycling between centralized (associated with exploitation) and decentralized structures (associated with exploration). Their simulation finds cycling between these structures is more effective than either structure in isolation because it allows for periods of exploration followed by periods of refinement and coordination. Similarly, Nickerson & Zenger (2002) argue that modulating between governance modes enhances efficiency under conditions of imperfect mode-environment fit and reasonable mode-switching costs.

Although empirical research in this branch of organizational ambidexterity is rare, there is some evidence of organizations using temporal cycling. For example, Nickerson & Zenger (2002) point to past research describing oscillating patterns of structural change over time (Eccles & Nohria, 1992; Cummings, 1995), and Gulati & Puranam (2009) offer a case study of reorganization at Cisco Systems describing how this project's focus switched cyclically between formal and informal portions of the organization.

Although some researchers do not consider such asynchronous cycling true ambidexterity, others point out that differentiating between cyclical and simultaneous activities can be a largely false dichotomy (Raisch & Birkinshaw, 2008). Specifically, as cycles become temporally closer together, cyclical activities become functionally equivalent to (and difficult to empirically distinguish from) simultaneous activities. For example, cycles may be as short as minutes or hours at the individual level, although probably longer at the organization level (Raisch et al., 2008).

Furthermore, empirical work in this area emphasizes that some important organizational activities are inherently cyclical. For example, Rothaermel & Deeds (2004) argue that in the context of technology commercialization, exploration necessarily precedes exploitation, since organizations cannot exploit technologies before their invention. This same study finds empirical support for this cyclical pattern in new product introductions in the pharmaceutical industry. Similarly, Lavie & Rosenkopf (2006) use data on exploration and exploitation-oriented alliances in software development to show firms adjust the balance of these alliance types in their alliance portfolios over time. More generally, recent reviews of organizational ambidexterity research point to cyclical ambidexterity as a promising, yet underdeveloped, area of organizational ambidexterity research (Simsek, Heavey, Veiga & Souder 2009).

Inter-Organizational Solutions

Although most organizational ambidexterity research focuses on the organizational level and below (Raisch & Birkinshaw, 2008; Simsek et al., 2009), an emerging stream of research examines how organizations use inter-organizational relationships to pursue ambidexterity. This line of research suggests organizations can address needing to perform incompatible activities by collaborating with other organizations (Raisch et al., 2009). Some organizational ambidexterity scholars express concern over difficulties inherent in such arrangements, such as coordination and integration across organizations, (e.g. Benner & Tushman, 2003), but others point out these issues simply mirror those identified in organizational ambidexterity research at the business unit, team, and individual levels (Gupta et al., 2006). Inter-organizational solutions to balancing exploration and exploitation also draw support from other areas of research. Specifically, multiple studies show the importance of acquiring knowledge from outside of the organization to stave off obsolescence and increase performance (e.g. Eisenhardt & Martin, 2000, Rosenkopf & Nerkar, 2001).

Related research also emphasizes the benefits of combining knowledge from both inside and outside of a given organization (Kogut & Zander, 1992; Henderson & Cockburn, 1994). It is important to note this line of research does not claim organizations must specialize in either exploration or exploitation, rather that organizations may achieve a better balance of these activities in collaboration than in isolation. This argument is consistent with research on absorptive capacity showing how organizations need a certain level of internal knowledge to effectively absorb external knowledge (Cohen & Levinthal, 1990; Lane & Lubatikin, 1998). Similarly, organizations may need to engage in a certain level of exploration (exploitation) to effectively collaborate with another organization more focused exploitation (exploration).

Despite this promising theoretical backdrop, there are few empirical studies of achieving ambidexterity through inter-organizational relationships. Studies on searching outside of organizational boundaries (e.g. Rosenkopf & Nerkar, 2001) focus on "knowledge landscapes" rather than direct partnerships with other organizations. As useful as this research is, it is also important to explicitly examine pursuing organizational ambidexterity through inter-organizational relationships (Lavie & Rosenkopf, 2006; Simsek, 2009; Lavie et al., 2010) as organizations' environments mostly consists of other organizations (Levitt and March, 1988). What studies there are tend to either be single-firm case studies or focus on achieving organizational ambidexterity through dyadic alliances (e.g. Rothaermel & Deeds, 2004; Lavie & Rosenkopf, 2006). In an example of the former, Holmqvist (2004) uses a case study of a Scandinavian software company to show how inter-organizational exploration and exploitation helped shape intra-organizational exploration and exploitation. In an example of the latter, Rothaermel & Deeds (2004) code alliances of pharmaceutical companies as either exploratory or exploitive and assume a balanced ratio of these as an indicator of ambidexterity. Consistent with calls for incorporating dynamic elements into organizational ambidexterity research (Raisch et al., 2009), Roathermel & Deeds (2004) also demonstrate firms tend to focus more on exploitation as they increase in size. Extending this line of research, Lavie & Rosenkopf (2006) demonstrate how software firms balance exploration and exploitation both over time and across "domains" such as functions, structures, and attributes.

These studies trace out some of the ways a firm's dyadic inter-organizational relationships can affect ambidexterity, however network research demonstrates the importance of looking beyond such dyads to characteristics of organizations' partners' partners (Auhja, 2000; Christakis & Fowler, 2007, 2008) and overall network structure (Powell et al., 1996). A small number studies attempt to integrate organizational ambidexterity with elements of research on networks. For example, Tiwana (2008) used cross-sectional survey data to show how a large service conglomerate combined bridging and strong network ties to achieve alliance ambidexterity. The author measures alliance ambidexterity as a product of questionnaire responses regarding alliance-objective alignment and alliances' adaptability to change. Results from this survey support the author's hypotheses that strong ties and the interaction between strong and bridging ties lead to increased alliance ambidexterity.

In another effort to merge insights from organizational ambidexterity and network, Lin & colleagues (2007) use alliance data from 95 randomly selected firms in five industries. The authors find an overall negative relationship between ambidextrous alliance formations and firm financial performance, however with more nuanced analysis the authors show a positive relationship between alliance ambidexterity and firm financial performance in uncertain environments. The authors supplement these empirical findings with a simulation designed to "test" hypotheses regarding network structure, ambidexterity, and performance. These simulations indicate positive interactions between firm centrality and alliance ambidexterity, but negative interactions between firms occupying structural holes and ambidexterity, using firm performance as the dependent variable. The authors claim these mixed results as evidence for a contingent relationship between ambidexterity and performance.

Ambidexterity and Outcomes

In extending March's (1991) foundational insights on the value of balancing exploration and exploitation, Tushman & O'Reilly (1996) developed the "ambidexterity premise." This premise suggests organizations that can both explore and exploit effectively will outperform organizations specializing in either activity. The underlying logic of this premise is organizations overly focused on exploring may never gain from the knowledge they create (Levinthal & March, 1993), as follow-on exploitation never occurs at an adequate level to replace the resources invested in exploration (Volberda &

Lewin, 2003). This results in a downward cycle of exploration without exploitation leading to yet more exploration, resulting in organizations never consolidating potential gains from new discoveries. Conversely, organizations that overly focus on exploitation may perform well in the short-term, but this performance is not sustainable (Abernathy, 1978; Van Looy, Martens & Debackere, 2005; Probst & Raisch, 2005) as obsolescence (Levinthal & March, 1993), core rigidities (Leonard-Barton, 1992), and similar "organizational pathologies"(Ahuja & Lampert, 2001) flourish in the absence of new ideas. These results imply the eventual withering of organizations' new product, service, business model, or production technique pipelines. Conceptually, the ambidexterity premise predicts both the renewal (Barr, Stimpert & Huff, 1992) inherent in exploration and the "apropriability" (Teece, 1986) inherent in exploitation are necessary for sustained organizational performance and survival.

Despite the recent surge in organizational ambidexterity research more generally, empirical tests of the ambidexterity premise remain rare (Raisch & Birkinshaw, 2008, Raisch et al., 2009, Sasson & Minoja, 2010). Anecdotal evidence in support of the ambidexterity premise includes, Adler and colleagues' (1999) case study of balanced exploration and exploitation at Toyota, and Ahuja & Katila's (2002) findings of a positive interaction between local and distal knowledge search. Gibson and Birkinshaw (2004) test the closely related concepts of alignment and adaptability in a sample of business units, and find balancing these concepts positively related to financial performance. Researchers have also found positive relationships between ambidexterity and intermediate outputs linked to firm performance, such as new product introductions (Prieto, Revilla & Rodriguez, 2007).

He & Wong (2004) directly test the ambidexterity premise in a sample of manufacturing firms and found empirical support for a positive relationship between organizational ambidexterity and sales growth. Similarly, Lubatkin & colleagues (2006) found support for the ambidexterity premise in a survey-based study of small and medium sized firms. Although, this limited research provides some support for the ambidexterity premise, other studies show no (Venkatraman, Lee & Iyer, 2007) or negative relationships (e.g. Atuahene-Gima, 2005) between ambidexterity and performance.

One possible reason for these mixed results is the mismatch between the conceptualization of time in organizational ambidexterity theory and the operationalization of time in empirical organizational ambidexterity research (Sasson & Minoja, 2010). Specifically, organizational ambidexterity does not predict ambidextrous organizations will out perform others at all points in time, in fact performance might be lower than that of comparable organizations focusing on exploitation at any given point in time or over the short-term (Thornhill & White, 2007; Van Looy et al., 2005). Instead, organizational ambidexterity predicts ambidextrous firms will out perform others and be more likely to survive in the long-term (March, 1991; Cottrell & Nualt, 2004; Probst & Raisch, 2005), as exploration-oriented organizations struggle to capitalize on their discoveries and exploitation-oriented organizations' innovation pipelines run dry and current offerings, techniques, and business models become obsolete.

Organizational ambidexterity's theoretical focus on the long-term requires time series data to adequately test the ambidexterity premise, however existing empirical tests tend to either use cross-sectional data (e.g. Lubatkin et al., 2006), feature a narrow timeframe (e.g. He & Wong, 2004), and/or rely self reports of performance and ambidexterity (e.g. He & Wong, 2004; Gibson & Birkinshaw, 2004). In general, reliance on cross sectional data is problematic for determining causality, but this concern is particularly acute when assessing the long-term performance predictions embedded in organizational ambidexterity theory (Raisch & Birkinshaw, 2008; Sasson & Minoja, 2010). For example, in industries such as pharmaceuticals, new products take up to 15 years to move from discovery to market introduction (Rothaermel & Deeds, 2004). Therefore, a study seeking to test the ambidexterity premise using a cross-section (or narrow timeframe) of data could find a positive, negative, or no relationship between organizational ambidexterity and successful introduction of pharmaceutical products based simply on when the sample was gathered. Calls for increased use of longitudinal data are common in organizational research, but this call is even more urgent for organizational ambidexterity and other theories that take time seriously by incorporating temporal dynamics at their cores (Ancona, Goodman, Lawrence & Tushman, 2001).

Although studies merging insights from organizational ambidexterity and networks remain rare, recent reviews of organizational ambidexterity research point to this intersection as a critical direction for future inquiry (Raisch et al., 2009; Lavie et al., 2010). The network literature is likely larger and more diverse than that of organizational ambidexterity, as a result I focus the next section on reviewing specific themes in network research most likely to matter for firms trying to achieve ambidexterity through inter-organizational relationships.

Organization-Level Networks

Tracing its roots back to sociometry (Moreno 1934, 1953), network research has achieved visibility across a diverse group of disciplines (Kilduff & Brass, 2010). For the purposes of this dissertation, I focus on reviewing a specific slice of the broader network literature. Specifically, I review research on organization-level networks that addresses issues of network structure and the relationship between these structures and organizational outcomes (For a thorough review of the broader body of network research see Borgatti & Foster, 2003).

Motivation for studying networks of organizations comes from at least two places. First is the empirical observation that organizations often and increasing operate as networks rather than in isolation (Powell et al., 1996; Hagedorn, 2002). Explanations for this trend include resource sharing, complementarily assets, and knowledge pooling (Galaskiewicz, 1985; Gulati, Noria, & Zaheer, 2000; Rothermel, 2001; Hagedorn & Duysters, 2002). Research showing myriad interconnected organizations engaging in complex problem solving, such as the discovery, refinement, and application of new technologies in industries including biotechnology (Powell et al., 1996; Baum et al., 2000), semi-conductors (Stuart, 1998, 2000) and chemicals (Ahuja, 2000) also supports this proposition.

The second motivation for studying organization-level networks is the growing awareness that network-level properties transcend the mere summation of network members' attributes. Similar to the rationale for studying teams, groups, and firms, networks of organizations are more than the sum of their parts. As a result, considering network-level concepts is important both in its own right and for providing control variables for organization level studies (Wellman, 1988; Coleman, 1988; Burt, 1992; Provan, Fish & Sydow, 2007) . The latter is especially important because isolating the effect of a concept at one level of analysis often requires controlling for variables at other levels of analysis and doing so effectively is the only way to avoid identifying spurious relationships (Nerkar & Shane, 2007).

Network Structure

The basic premise of the structural branch of network research is patterns of "connectivity and cleavage" both enable and constrain actors (Wellman, 1988). This approach is largely unique in that it considers both the presences *and absence* of relationships in explaining outcomes (Kilduff & Brass, 2010). This branch of network research tends to focus on the informational consequences of an organization's position in broader network (Gulati, 1998). Early research in the network paradigm was largely descriptive, including a wide range of settings from bank wiring rooms to entire towns (Warner & Lunt 1941; Davis, Gardner & Gardner, 1941; Scott, 2005). As a natural extension of this work, later research explores how these structures affect outcomes. At the organization level, research shows network structure influences innovation (Ahuja, 2000), firm performance (Powell et al., 1996; Mehra, Kilduff & Brass, 2001), and other key outcomes. Although past research describes numerous structural characteristics, for the purpose of this dissertation I focus on three of the most common and likely to affect organizational ambidexterity (Tiwana, 2008; Lin et al., 2007; Simsek, 2009). Specifically, I consider the effects of network closure, network diversity, and centrality on exploration and exploitation.

Network Closure

The costs and benefits of network closure have been extensively explored in the structural holes versus closure debate in sociology (e.g. Coleman, 1988, 1990; Burt,1992, 2000). Networks provide informational benefits in at least two ways (Granovetter, 1992; Gulati,1998). A pro-closure perspective, argues that dense networks of redundantly interconnected ties leads to network members holding more common knowledge, diminishes uncertainty, and promotes trust between network remembers (Coleman, 1988; Podolny, 1994; Gulati, 1995a). In contrast, a positional perspective argues for the informational advantages of less than closed networks allowing for "weak" or non-redundant ties (Granovetter, 1973, 1983) and brokering relationships between otherwise unconnected actors by bridging a "structural hole" (Burt, 1992, 2000). Such positional perspectives suggests that only in more open networks can actors find such beneficial positions from which to connect otherwise disconnected actors.

Past research shows networks can confer benefits on a focal organization if interconnected ties create a "closed" network with numerous redundant source of information (Coleman, 1988, 1990). The advantages of such closed networks include stability (Podolny & Baron, 1997), trust (Coleman, 1990), and longevity (Soda, Usai & Zaheer, 2004). These features tend to lower coordination and integration costs, since they lessen the need for monitoring (Gulati & Singh, 1998), facilitate knowledge transfer (Reagans & McEvily 2003; McElvily & Marcus, 2005), and limit opportunistic behavior (Williamson, 1991; Walker, Kogut & Shan, 1997). Although the theorized mechanisms in these past studies vary somewhat, they all support the notion of closed networks leading to superior organizational outcomes. Furthermore, meta-analysis shows a positive relationship between network density (a network level equivalent to closure) and organizational-level outcomes (Balkundi & Harrison, 2006).

The weak ties argument for accessing novel information is well established and intuitive, however the logic underpinning structural holes is perhaps less immediately obvious. Organizations occupy a structural hole when they can act as brokers between two or more otherwise disconnected organizations (Burt, 1992). Organizations occupying such structural holes benefit in at least three ways. First, they receive non-redundant information from their contacts, providing benefits by similar logic as the weak ties argument. Second, they can act as brokers channeling information or resources between otherwise unconnected parties (Burt, 1992; Ahuja, 2000). Third, occupying a structural hole may help organizations transfer a well-known solution from one part of a network to solve a problem in another part of the network (Hargadon & Sutton, 1997). These advantages are time dependent and transitory (Burt, 2002; Soda et al., 2004), but meta analyses at both the organization and individual level find support for occupying structural holes being advantageous for a given focal actor (Kilduff & Brass, 2010).

Network Diversity

Another factor influencing the availability and flow of novel information is the diversity of nodes in given network. Nodes of different types and with different experience are likely to be sources of novel, and therefore potentially beneficial, information for a focal actor in a network. For example, Beckman and Haunschild (2002) use diversity of network partners to predict premiums paid during corporate acquisitions and stock performance of acquiring firms. They find that firms tied to a heterogonous set of partners pay less of a premium for acquisitions and have better subsequent stock price performance than firms tied to a less heterogeneous group of partners.

Similar to node diversity, the logic underlying tie diversity is straightforward. Specifically, different types of ties transmit different types of information (Powell et al., 1996) and presumably signal different things to outside observers. An organization with a wider diversity of ties benefit by accessing more varied information (Powell et al., 1996). This diversity holds both for having different ties with different organizations and multiple or "multiplex" ties to the same organization (Beckman & Haunschild, 2002). As tie diversity increases, an organization has access to a broader range of information in the forms of new perspectives, knowledge, and ideas (Reagans & Zuckerman, 2001). The accessibility of this diverse information increases the chances of solving complex problems or developing novel products and services (Ahuja, 2000; Tiwana, 2008). The importance of tie diversity is consistent with research on recombinant innovation, which shows many organizations innovate through novel arrangements of preexisting, rather than newly invented, components (Hargadon, 2002).

Networks and Outcomes

Although these three network features have plausible theoretical and empirical links to organizational outcomes, these links are neither unchallenged nor necessarily linear. For example, very high levels of network tie diversity could create problems for communication, knowledge integration, and goal alignment (Dougherty, 1992, Spender & Grant, 1996; Reagans & McElviy, 2003). Perhaps due to the contentious debate in sociology (e.g. Burt, 1992, 2002; Coleman, 1988, 1990), the downsides of both structural holes and closed networks are well known. Organizations occupying structural holes enjoy only transitory benefits (Soda et al., 2004) and risk being cutout of a brokerage position if otherwise disconnected organizations find a way to connect (Gulati, 1995). Furthermore, occupying structural holes does not generate trust and other positive externalities associated with long-term stable relationships. On the other hand, closed networks can suffer from a lack of novel information possibly leading to obsolescence (Brass, Galaskiewicz, Greve & Tsai, 2004).

Scholars assessing this mixed bag of evidence for the network – organizational outcome linkage argue for developing a contingent perspective detailing specific conditions under which each network feature is likely to lead to a specific outcome of interest (Kilduff & Brass, 2010). Such a contingent model could help unravel these conflicting empirical findings and leverage the observation that these network features are not mutually exclusive across networks (Tiwana, 2008) and their relationships to organizational outcomes may well be time, task, and context dependent (Levin & Cross, 2004; Obstfeld, 2005; Reagans & McEvily 2003).

Differing Networks for Differing Purposes

In a recent meta-review of research on inter-organizational relationships, Parmigiani & Rivera-Santos (2011) argue that all inter-organizational relationships can be usefully categorized as either exploratory or exploitative in orientation. Firms entering exploration-oriented relationships endeavor to create new knowledge either through joint production of new knowledge or through novel combinations of existing knowledge held by the partnering organizations (Lubatkin at al., 2001; Hoang & Rothaermel, 2010). In contrast, firms enter exploitation-oriented relationships in an effort to covert previously discovered knowledge into marketable products (Bresser, Heuskel, & Nixon, 2000).

The notion that properties and consequences of inter-organizational relationships may vary according to the purpose of these relationships is largely absent from research on both strategic alliances and networks more broadly (Nohria & Eccles, 1992; Hoang & Rothaermel, 2010; Kilduff & Brass, 2010). With few exceptions (e.g. Rothaermel, 2001; Baum et al., 2000; Lavie & Rosenkopf, 2006), research on alliances and other types of inter-organizational relationships tends to aggregate all of these relationships into a single measure. This is problematic since such relationships often have divergent goals (Koza & Lewin, 1998; Hoang & Rothaermel, 2010). Of course, the other extreme, where relationships become incomparable because their respective goals are not identical, is equally problematic. In an effort to avoid both of these extremes, I build on Parmigiani and River-Santos' (2011) categorization of inter-organizational relationships as either exploratory or exploitative in orientation.

Recent research highlights the importance of distinguishing between different types of inter-organizational relationships for understanding variations in organization-level outcomes. For example, Hess & Rothaermel (2011) investigate the consequences of star-scientist involvement and strategic alliances at differing points in the value chain in the pharmaceutical industry. The authors show star scientists and strategic alliance are substitutes in the upstream exploration-oriented portion of the pharmaceutical value chain but are complements if star scientists are employed upstream and alliances in the downstream exploitation-oriented portion of this same value chain. The authors argue that this pattern emerges because star scientists' social networks and firms' alliance portfolios generate redundant information when leveraged at the same point the value chain. Had the authors not made a distinction between these two types of relationships, their results could be interpreted as star scientists and strategic alliance being harmful for performance since their simultaneous upstream presence was associated with lower levels of innovation and new product development (pg. 904).

Distinguishing between exploration and exploitation oriented relationships has conceptually clear, but empirically underexplored, consequences for merging organizational ambidexterity and network perspectives. Specifically, a natural extension of categorizing dyadic relationships, such as alliances, as exploratory or exploitative in orientation is to conceptualize networks aggregating these dyadic relationships with the same framework. Paralleling past research on dyadic relationships, I conceptualize firms' participation in exploration-oriented networks as an effort to develop fundamentally new knowledge and firms' participation in exploitation-oriented networks as an effort to convert this new knowledge into a marketable product or service.

Extending Organizational Ambidexterity with a Network Perspective

The preceding literature review frames the new ground I hope to tread in this dissertation. Organizational ambidexterity research continues to address ever more macro levels of analysis. Recent empirical research examines ambidexterity at the level of organizational dyads and recent conceptual research hints at the value of ramping the level of analysis up to the network level. Meanwhile organization-level network research has begun to consider the time, task, and context dependent nature of certain network characteristics, including those reviewed here. The trajectories of these two compatible, but largely separate, areas of research frame the value of a study examining organizational ambidexterity at the network level. Of course a single study cannot possibly fully integrate two large and growing bodies of research, however I believe investigating a few clear points of intersection can make meaningful contributions to both areas of research.

CHAPTER III

THEORETICAL PROPOSITIONS

In this chapter, I build on the literature reviewed previously to develop theoretical propositions linking network characteristics to organizational ambidexterity. I later convert these propositions to specific hypotheses that I bring to an empirical test in the context of green chemistry. Before developing these propositions, I first introduce technology commercialization as an advantageous context for exploring the intersections of organizational ambidexterity and organization-level networks. Although I describe this dissertation's specific empirical context in detail later, introducing a high-level overview of the technology commercialization process helps me develop propositions that are more specific. In addition, I hope including a tangible context at this point allows the reader to follow the theory development section more efficiently and effectively.

Connecting Ambidexterity and Networks using Technology Commercialization

Part of the challenge in integrating organizational ambidexterity and network perspectives is finding a setting where researchers can observe organizations both balancing exploration and exploitation and forming inter-organizational networks (Lin et al., 2007). Although past research shows both are common phenomena, each suffers from particular empirical challenges. For organizational ambidexterity, researchers have difficulty directly measuring exploration and exploitation, and distinguishing between the two (Lavie et al., 2010). As a result, researchers have either relied on proxies such as categorizing types of inter-organizational agreements (e.g. Rothaermel & Deeds, 2004; Russo & Vurro, 2010) or engaged in detailed case studies of single organizations (e.g. Holmqvist, 2004). For networks, researchers need to capture full populations of organizations to perform network analysis, since sampling may miss organizations occupying key network positions (Wassermann & Faust, 1994).

One setting that both addresses these empirical challenges, and has received considerable attention in its own right, is technology commercialization. Technology commercialization is an inherently ambidextrous activity as new technologies must be discovered through exploration before they are commercialized through exploitation (Rothaermel & Deeds, 2004). As such, technology commercialization, defined by Mitchell and Singh (1996) as "The process of acquiring ideas, augmenting them with complementary knowledge, developing and manufacturing saleable goods, and selling the goods in a market", fits squarely with foundational definitions of ambidexterity (e.g. March, 1991; Tushman & O'Reilly, 1997).

Increasingly, networks of organizations, rather than single organizations in isolation, carry out technology commercialization (Powell et al., 1996; Ahuja, 2000; Hagadoorn, 2002). Furthermore, these networks often feature considerable diversity of participants including firms, universities, private research organizations, and government agencies (Powell et al., 1996; Owen-Smith 2003). Technology commercialization also closely correlates with organizations' financial performance (Mitchell & Singh, 1996, Zahra & Nielson, 2002; Katila, 2002) and is a performance goal unto itself for many organizations (Markman, Siegel & Wright, 2008; Nerkar & Shane, 2007). As a result, technology commercialization offers an advantageous context for testing the relationships between organizational ambidexterity and network characteristics I propose in this dissertation.

Linking Ambidexterity and Networks

Although organizational ambidexterity and organizational-level networks research come from largely distinct theoretical traditions, they examine many of the same themes and phenomena. Examples include learning (e.g. March, 1991; Powell et al., 1996; Beckman & Haunschild, 2002), innovation (e.g. Rothaermel & Deeds, 2004; Ahuja, 2000) and performance (e.g. Lee, Lee & Pennings, 2001; He & Wong, 2004). Another parallel between these research streams is a focus on the access, production, and use of novel and redundant information as central mechanisms linking theoretical constructs to tangible outcomes (Granovetter, 1973; Podolny, 2001). Finally, both literatures feature highly equivocal and inconsistent empirical results when attempting to predict outcomes. For example, researchers have found positive, negative, and no correlation between organizational ambidexterity and various measures of organizational performance (Lavie et al., 2008; Raisch & Birkinshaw, 2008). Similarly, network researchers have found inconsistent correlations between occupying theoretically advantageous network positions and similar measures of performance (Kilduff & Brass, 2010).

Despite addressing similar phenomena and considering similar mechanisms, organizational ambidexterity and network research has evolved largely in isolation from one another, with the exceptions of a handful of recent studies (e.g. Lin et al., 2007; Atuahene-Gima, 2008; Tiwana, 2008; Simsek, 2009). Perhaps part of the reason for this isolation is organizational ambidexterity and network traditionally focus on different levels of analysis. For example, most organizational ambidexterity research focuses on units of analysis from the organization level downward and often prescribes dividing conflicting activities (e.g. exploring and exploiting) between lower levels of analysis, such as business units (Tushman & O'Reilly, 1996; Christensen, 1998; Raisch & Birkinshaw, 2008). In contrast, network research focuses on units of analysis from the organization-level upwards to examine both dyadic relationships between organizations (Ahuja, 2000; Beckman, Haunschild & Phillips, 2004) and the overall structure of networks formed by aggregating such relationships (Coleman, 1988; Burt, 1992; Powell et al., 1996; Provan et al., 2007).

As a result, much of organizational ambidexterity and network research does not overlap simply because it addresses different levels of analysis. However, there are branches of research from each area that should theoretically intersect. Specifically, the nascent branch of research examining inter-organizational relationships as a tool for achieving ambidexterity (e.g. Rothaermel & Deeds, 2004; Lavie & Rosenkopf, 2006; Lin et al., 2007; Tiwana, 2008) and the branch of network research investigating how networks generate utility for participating organizations (e.g. Coleman, 1988; Burt, 1992, 2004; Powell et al., 1996). In the following section, I investigate these intersections in more detail.

Tension Between Ambidexterity and Network Perspectives

Despite research showing benefits of ambidexterity in areas as diverse as innovation (Benner & Tushman, 2003), knowledge search (Katila & Ahuja, 2002), and alliances (Rothaermel & Deeds, 2004; Lavie & Rosenkopf, 2006), firms attempting to achieve ambidexterity through networks of inter-organizational relationships face a paradox. Specifically, participating in a more open network featuring a diverse group organizations should provide firms with novel information and exposure to a broad swath of “new alternatives”, which is the “essence of exploration” (March, 1991; Reagans & Zuckerman, 2001; Burt, 1992). However, these same network features increase coordination costs and discourage the type of long-term, trusting, and stable relationships needed to “refine and apply existing information”, which is the essence of exploitation (March, 1991; Rothaermel & Deeds, 2004; Soda et al., 2004).

Conversely, participating in a closed network with homogeneous membership should provide firms with the redundant information needed to lower coordination costs, maintain stable relationships, and a lower likelihood of opportunism by partners (Coleman, 1988; Uzzi, 1997; Ahuja, 2000; Baum & Ingram, 2002) all of which past research highlights as critical to exploitation. However, these network features reduce firms' exposure to novel information and thus reduce access to “new alternatives” necessary for exploration (Burt, 1992; Baum & Ingram, 2002; March, 1991). Table 1 summarizes this paradox.

Table 3. Ambidexterity – network paradox

Network Characteristic (Information Type)	High Closure (Redundant)	Low Closure (Novel)	High Diversity (Novel)	Low Diversity (Redundant)
Exploration	-	+	+	-
Exploitation	+	-	-	+

This paradox at the network level mirrors observations from past ambidexterity research in that tensions between exploration and exploitation are at the heart of the organizational ambidexterity research paradigm (Gupta et al., 2006; Raisch &

Birkinshaw, 2009). However, common prescriptions for pursing ambidexterity from past research become problematic when applied at the network level.

Organizations can achieve ambidexterity by creating structurally separate subunits specializing in either exploration or exploitation as long as these organizations' top management teams can effectively integrate the outputs of these units (Tushman & O'Reilly, 1996; Benner & Tushman 2003; Smith & Tushman, 2005). However, in the context of inter-organizational relationships, there is no overarching top management team to facilitate such integration. Furthermore, research on absorptive capacity casts doubt on specialization as a tactic for achieving ambidexterity across organizations, because effectively integrating external knowledge requires a focal organization to also be generating knowledge in this same area (Cohen & Levinthal, 1990; Rothaermel & Alexandre, 2009).

Another prescription from past organizational ambidexterity research is to alternate between periods of exploration and exploitation (Nickerson & Zenger, 2002; Siggelkow & Levinthal 2003). This is also problematic in the context of inter-organizational relationships since many of these, such as alliances or joint R&D projects, have pre determined timeframes (Reuer & Zollo, 2005), and appropriate transition points between exploration and exploitation are often emergent and difficult to predict in advance (Raisch & Birkinshaw, 2008). Therefore, whereas managers within an organization can adjust the timing and length of these cycles as new information emerges, in the inter-organizational context such adjustments may involve extensive renegotiation and reorientation of the entire relationship.

A third option identified in past research is to construct “parallel structures” to allow for exploration and exploitation within a single unit (Gibson & Birkinshaw, 2004; Lubatkin et al., 2006). However, this approach is also problematic when applied to pursuing ambidexterity via inter-organizational relationships because key network structures, such as structural holes and closed networks, are mutually exclusive (Walker et al., 1997; Ahuja, 2000). In other words, structural holes generate benefits explicitly because of the lack of connections between a focal organization’s partners, whereas closed networks generate benefits by precisely the opposite logic. Any attempt by an organization to pursue both types of network structures simultaneously would lead to a zero-sum game between effective exploration and exploitation.

Ambidexterity Through Inter-Organizational Networks

Since none of these prescriptions identified in past research resolve the ambidexterity-network paradox, it creates opportunity to develop new theory addressing how organizations might resolve this seemingly intractable problem. The key to the theory I develop in this dissertation is disaggregating a firm’s various types of inter-organizational relationships into either exploratory or exploitative in orientation (Parmigiani & Rivera-Santos, 2011). After a firm’s inter-organizational relationships have been disaggregated, the firm should be able to resolve the network-ambidexterity paradox by creating an low closure, high diversity network with its exploration-orientated relationships, and a high-closure, low diversity network with its exploitation relationships. The balance of this section develops specific propositions regarding how network characteristics in these two differing types of networks relate to exploration and exploitation. I describe these propositions in both text and graphical form. In these graphical representations, node shape indicates organization type, the differing dashing in ties indicates exploration and exploitation oriented relationships, and the focal firm is either at the center (for ego-level measure) or the solid-filled node (for beyond ego measures).

Exploration and Network Characteristics

The hallmark of exploration is “the pursuit of new knowledge, of things that might come to be known” (Levinthal & March, 1993). In the context of technology commercialization, this often involves the discovery of some new means-ends relationship, often advancing basic science in the process (Rosenkopf & Nerkar, 2001). Exploration is unpredictable, uncertain, and emergent, making it difficult for firms to distinguish useful information before actually engaging in the exploration process. For example, pharmaceutical firms screen approximately 2,000 chemical compounds to identify one candidate for human drug trials. From there, approximately 20% of these compounds pass all three phases of FDA trials. This implies an ex ante probability of any given compound becoming a marketable end product of 1 in 10,000 or 0.01% (Giovanetti & Morrison, 2000, Rothaermel & Deeds, 2004). Screening is a costly process, however these firms simply have no way of discovering the efficacy and side effects of these compounds without engaging in such testing. Although the nature of exploration faced by pharmaceutical firms maybe an extreme case, it illustrates the uncertainty inherent in the exploration process.

Since ex ante determination of a given technology’s value is difficult, if not impossible, firms should benefit from casting a wide net (Baum & Ingram, 2002; Hoang

& Rothaermel, 2010). In terms of inter-organizational relationships, this implies firms can benefit from occupying network positions that afford access to novel sources of information (Burt, 1992; Hargadon & Sutton, 1997). Past research indicates firms can do this through two distinct, but complementary, approaches. First, a firm can participate in a less closed network, where it has opportunities to bridge otherwise unconnected partners (Burt, 1992). Although research on the ultimate performance consequences of participating in networks that are more open has generated mixed results (e.g. Burt, 1997; Ahuja, 2000), the notion that occupying such a network position affords access to non-redundant information is widely accepted (Borgatti & Foster 2003). It is this non-redundant information that fuels the exploration process (Baum & Ingram, 2002; Gilsing et al., 2008).

In contrast, one of the most well established mechanisms linking network closure to outcomes is closure providing focal organizations with redundant information (Coleman, 1990; Walker et al., 1997). As useful as this type of information is for certain purposes, such as building stable and trusting relationships (Gulati, 1995; Uzzi, 1997), it should not be particularly useful for exploring. This is because variation (and even deviancy) fuels the exploration process, whereas closed networks tend to discourage variation through developing shared norms (March, 1991; Coleman, 1988; Walker et al., 1997; Rowley, Behrens & Krackhardt, 2000). Returning to the example of pharmaceutical firms exploring for compounds to screen in hopes of finding drug trial candidates, if a firm's partner organizations all have the same compounds available for screening, this redundant information would have little value for exploration.

Like Abernathy's (1978) observation of efficiency efforts first positively, then negatively affecting organizational performance, the consequences of network closure should follow a similar temporal pattern. Specifically, network closure should ultimately have a negative effect on exploration because it means a focal firm is drawing on a smaller pool of novel information than a focal firm with a more open network (Granovetter, 1973; Ahuja, 2000). However, such a closed network might benefit a firm's exploration efforts in the short term, since it encourages shared norms, knowledge sharing routines, and problem solving (Uzzi, 1997; Gulati 199 Walker et al. 1997); effectively allowing a focal firm to more efficiently tap this smaller pool of information. In contrast, a less closed network might feature a wide variety of, possibly conflicting, norms, routines, and problem solving approaches; effectively hampering a focal firm's access to this larger pool of information. Ahuja (2000) identifies these contradictory effects of network closure on innovation, but sets these up as competing hypotheses rather than using time to adjudicate when each effect will be most pronounced. As a result, I propose the negative effect of closure will be noticeable in the long-term, but may be unrelated or even positively associated with exploration in the short-term. This consideration of the temporal dynamics of network closure leads to my first two propositions:

P1: The greater the level of closure in a firm's exploration-oriented ego network the more likely it is to invent new technologies in the short-term

P2: The greater the level of closure in a firm's exploration-oriented ego network the less likely it is to invent new technologies in the long-term

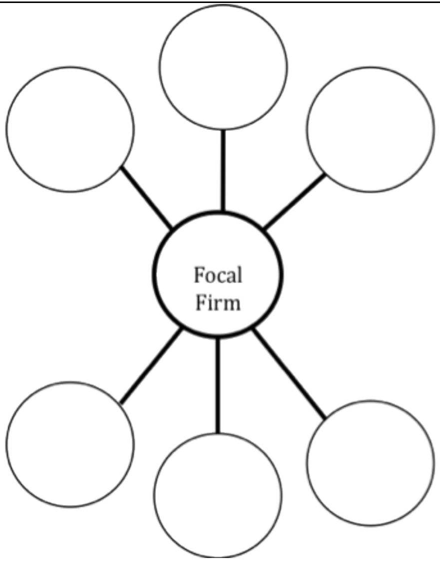
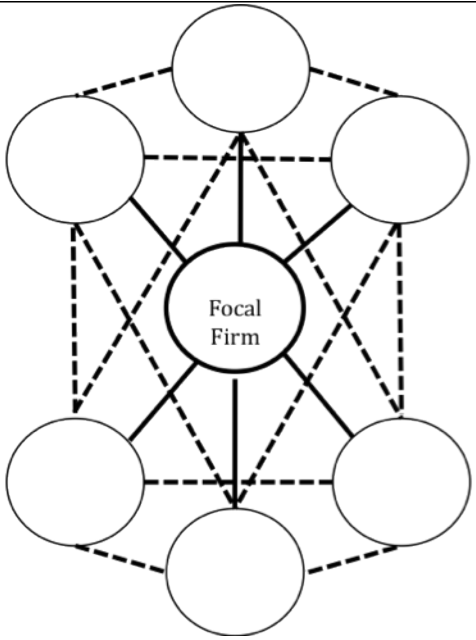
Archetype: Low Closure Proposed Effect: -/+ in Short/Long-term	Archetype: High Closure Proposed Effect: +/- in Short/Long-term
	

Figure 1. Ego network closure and exploration

A second factor shaping the relative novelty of information in a firm's ego network is the diversity of organizations with which it collaborates. In the context of technology commercialization, firms commonly collaborate with universities, government agencies, and non-profit research foundations as well as other firms (Shan, Walker & Kogut, 1994; Powell et al., 1996; Owen-Smith 2003). Regardless of whether or not these organizations are themselves connected to one another, they tend to pursue different research agendas leading to a diversity of discoveries (Mora-Valentine, Montoro-Sachez & Guerra-Martin, 2004). For example, universities tend to focus on basic scientific discoveries whereas large science-based firms tend to focus on breakthrough innovations with direct commercial applications (Hoang & Rothaermel, 2010). Both types of organization make fundamentally new discoveries but do so in different ways. As a result, a firm that collaborates with a more diverse set of organizations in an exploration-oriented network should be better able to invent new technologies with commercial potential, leading to my second proposition:

P3: The more diverse a firm's exploration-oriented ego network, the more likely it is to invent new technologies

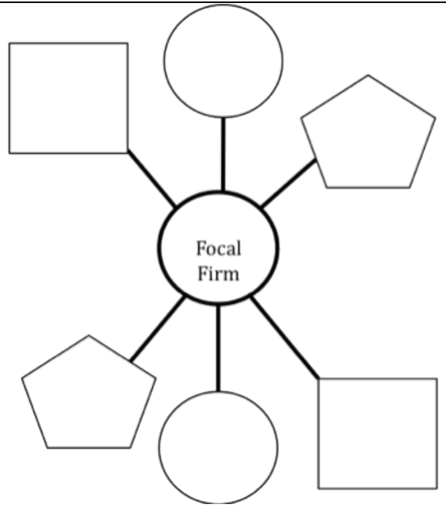
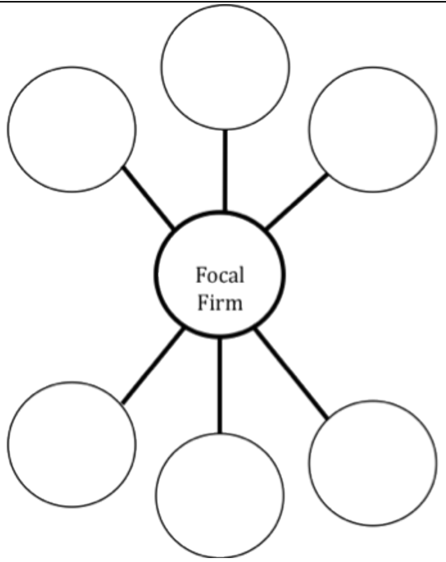
Archetype: High Diversity Proposed Effect: + in Short/Long-term	Archetype: Low Diversity Proposed Effect: - in Short/Long-term
	

Figure 2. Ego network diversity and exploration

Amongst the most common network characteristics used to explain organizational outcomes are various measures of an organization's centrality within a network. (Provan et al., 2007). Of this group of measures, I focus on closeness centrality in this dissertation. Closeness centrality measures a firm's access assets such as knowledge or information that resides in other organizations in a given network (Freeman 1979; Provan et, 2007). Network members with low closeness centrality tend to receive information sooner, given this information originates from all other network members with equal probability as long as that information travels along the shortest path (Borgatti, 2005). Closeness centrality is also particularly well suited to the context of innovation because "organizations with low closeness in an R&D technology-sharing network are able to develop products sooner than others" (Borgatti, 2005).

As a result, a firm that is closer to other network members (i.e. has a lower closeness centrality score) is "in a favorable position to see a more complete picture of all the alternatives available in the network" (Lin et al., 2007; Perry-Smith & Shalley, 2003). This advantage would likely be temporary in a network generating little novel information, since after these discoveries diffused throughout the network all firms would have access to the same information until a subsequent discovery. However, in a network characterized by constant discoveries, such as a network of firms developing science-based innovations, rapid access to the latest discoveries should be advantageous to a firm's exploration efforts. The notion that centrality benefits innovation more broadly is consistent with past research (e.g. Ahuja, 2000; Tsai, 2001; Schilling & Phelps, 2007), but these studies do not specifically address its potential differential affect on exploration and exploitation. As result, I start my investigation of closeness centrality and ambidexterity, by proposing the following:

P4: The lower a firm's closeness centrality in an exploration-oriented network, the more likely it is to invent new technologies

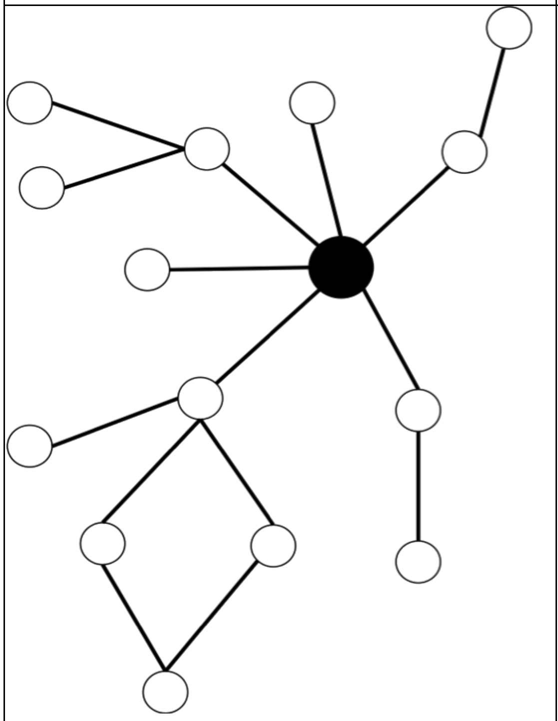
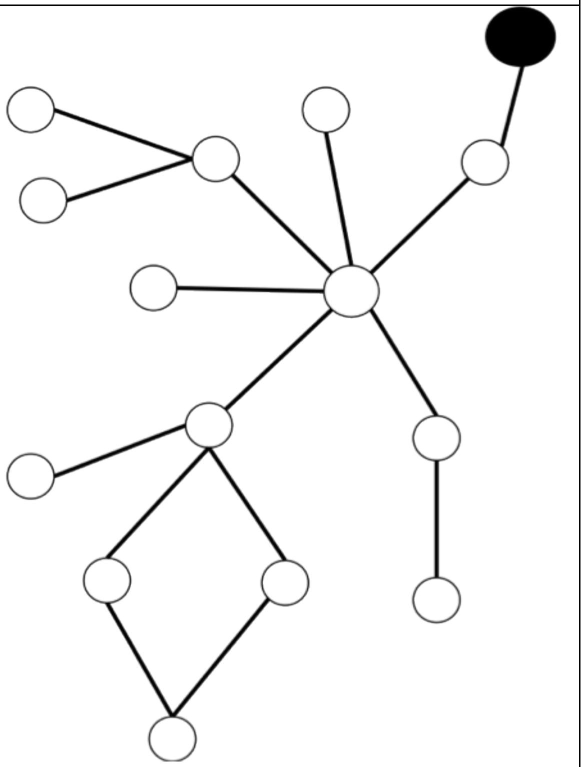
Archetype: Low Closeness Centrality Proposed Effect: + in Short/Long-term	Archetype: High Closeness Centrality Proposed Effect: - in Short/Long-term
	

Figure 3. Network closeness centrality and exploration

Taken together these propositions predict firms occupying positions and choosing partners in exploration-oriented networks that increase access to non-redundant information will be more successful in inventing technologies with commercial potential. However, such invention through exploration is not a guarantee a firm will realize the commercial potential of these technologies. Firms that explore to the exclusion of exploitation generate large numbers of inventions but fail to capitalize on these discoveries by converting these inventions into viable products. For example, Chesbrough and Rosenbloom (2002) analyze Xerox Corporation's repeated failure to capitalize on its inventions such as graphical user interfaces, word processing, the mouse, and the first personal computer. Despite Xerox being the first to invent these technologies, other firms captured their value by successfully commercializing what Xerox had originally invented. To avoid the fate of Xerox, firms must also exploit the newly invented technologies identified in the exploration process. However, in attempting to exploit such new discoveries, the network structures investigated in this dissertation should have very different consequences for the focal firm than they do for exploration.

Exploitation and Network Characteristics

In contrast to exploration, the hallmark of exploitation is "the use and development of things already known" (Levinthal & March, 1993). In the context of technology commercialization, such things are often products or processes that have been refined and tested to the point where they demonstrate at least plausible market value. Exploitation is relatively predictable when compared to exploration as firms know with a reasonable degree of certainty what needs to done at this stage in a technology's development (March, 1991; Gilsing et al., 2008). In the example of a new pharmaceutical product, a firm may not know which of the 10,000 compounds will yield a viable drug, but it can know what it needs to successfully test, manufacture, market, and distribute this drug no matter which chemical compound it is ultimately based on. This is not to claim that exploitation is easy, rather it requires a different type of information than exploration. Specifically, it requires redundant information leading to higher degrees of certainty, routine development, and the lessening of information asymmetries endemic to the technology commercialization process (Pisano, 1997; Hoang & Rothaermel, 2010). As a result, in exploitation-oriented networks, occupying positions that provide redundant information should improve firms' chance of successful commercialization of known technologies.

When a firm has a more open network, its otherwise unconnected partner organizations cannot monitor one another for opportunistic behavior (Coleman, 1988; Walker et al., 1997). Furthermore, since less closed networks are inherently unstable (Soda et al., 2004), they should be unlikely to generate the kind of certainty, routine development, and integration needed to effectively exploit a nascent technology. In contrast, past research shows closed networks, featuring redundant and often repeated ties, generate considerable trust, help curb opportunism, lead to reciprocity, and improve problem solving (Uzzi, 1997; Walker at al., 1997; Gulati, 1999; Rowley et al., 2000). . This implies a high degree of closure in an exploitation-oriented network will have the opposite effect on firms as it does in an exploration-oriented network. As in the case of exploration, I propose this effect will manifest in the long-term, with the short-term showing the opposite:

P5: The greater the level of closure in a firm's exploration-oriented ego network the less likely it is to successfully commercialize a known technology in the short-term

P6: The greater the level of closure in a firm's exploration-oriented ego network the more likely it is to successfully commercialize a known technology in the long-term

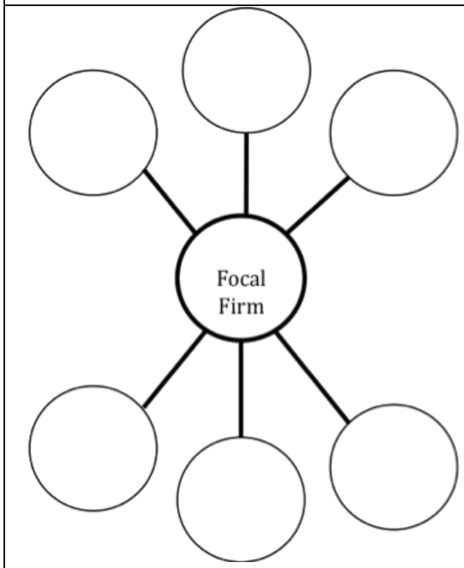
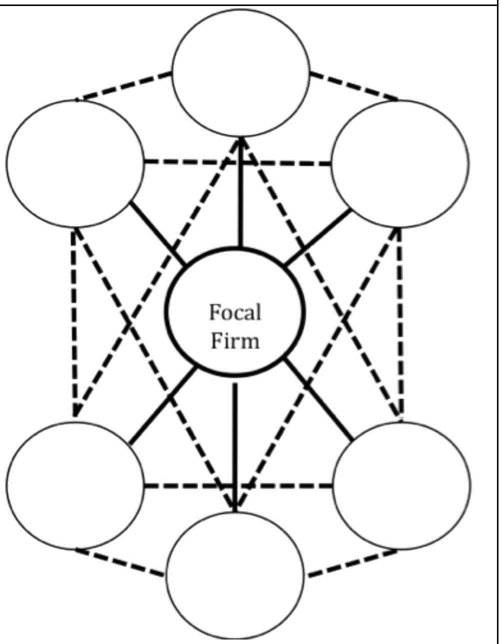
Archetype: Low Closure Proposed Effect: +/- in Short/Long-term	Archetype: High Closure Proposed Effect: -/+ in Short/Long-term
	

Figure 4. Ego network closure and exploitation

Whereas collaborating with a diverse set of organizations should benefit a firm in terms identifying promising new technologies, this diversity should become a liability when trying to bring a known technology to market. This is because organizations often involved in technology commercialization, such as universities, government agencies, and firms, tend to have different cultures, incentive systems, and norms (Mora-Valentine et al., 2004). As a result, transferring and refining knowledge between these diverse organizations is difficult and costly (Lane & Lubatkin, 1998; Simonin, 1999; Rothaermel & Deeds, 2004). Furthermore, these diverse organizations may have different goals leading to difficulty in agreeing on exactly how they should go about commercializing a given technology (Lambert 2003; Wright, Birley & Mosey, 2004).

It is important to note that this negative effect of organization type diversity does not seem to apply to diversity within a given category of organizations. For example, Rothaermel & Deeds (2004) find that collaboration between different types of firms, in the forms of large established pharmaceutical firms and small innovative biotechnology companies, led to more successful technology commercialization due to complementary assets. However, this example highlights the benefit of *within* organization-type diversity, rather than the *across* organization-type diversity I examine in this dissertation. Based on this difficulty in aligning goals and coordinating knowledge transfer between different types of organizations, I propose:

P7: The higher the level of diversity in a firm's exploitation-oriented ego network, the less likely it is to successfully commercialize a known technology

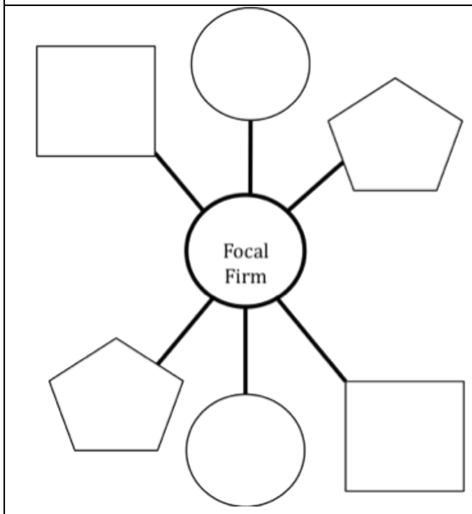
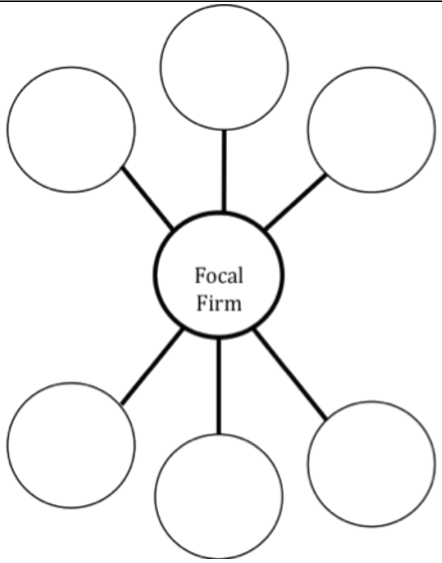
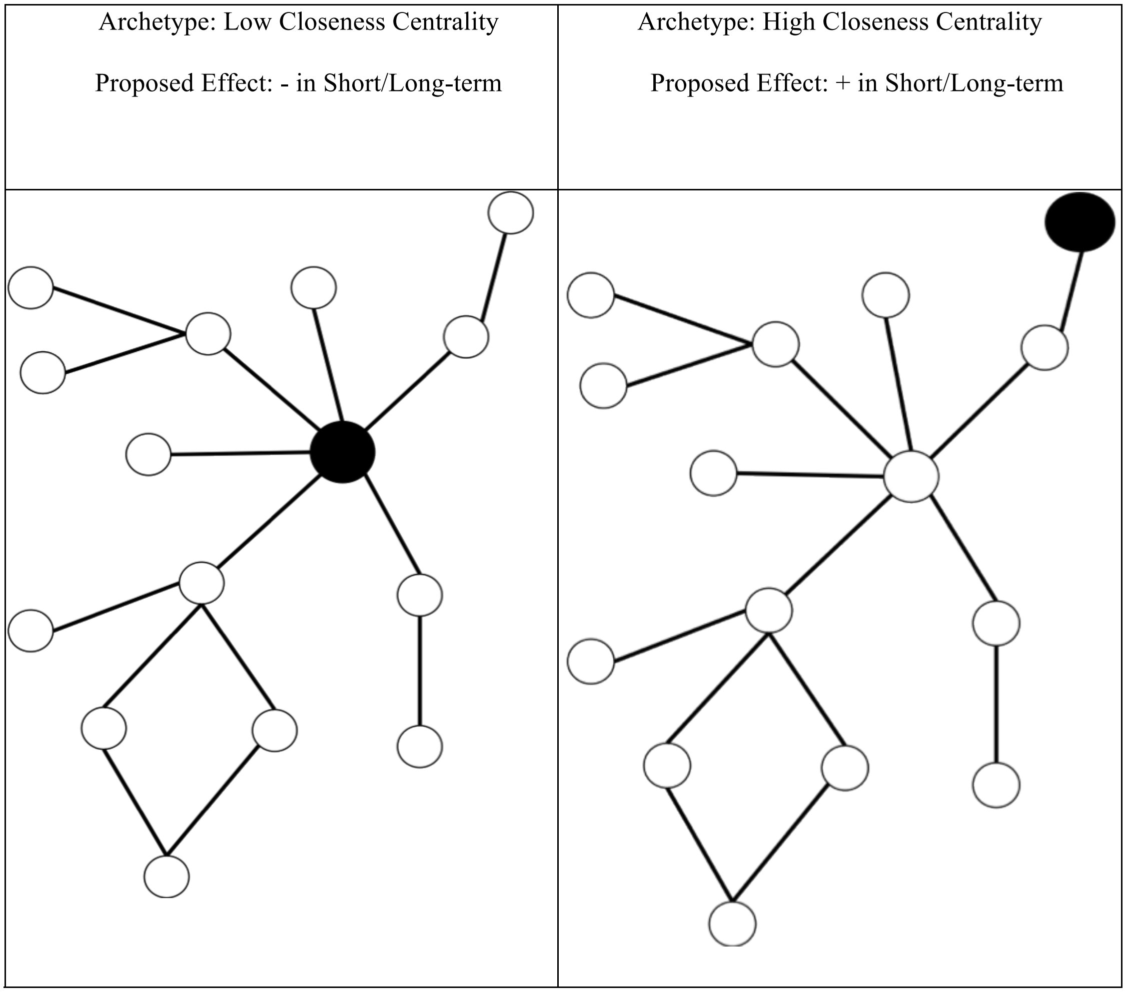
Archetype: High Diversity Proposed Effect: - in Short/Long-term	Archetype: Low Diversity Proposed Effect: + in Short/Long-term
	

Figure 5. Ego network diversity and exploitation

Proposition three highlights the informational advantage of low closeness centrality for exploration when beneficial information appears with equal probability throughout a network (Borgatti, 2005). The case of exploration approximates this condition, since firms know so little ex ante about where in a network the next promising invention may come from. As a result, a focal firm's access to information from other network members ought to be advantageous for exploration. In contrast, when a firm is trying to commercialize a known technology, competitors aware of these efforts may try to copy, preempt, or invent around this technology (Gilbert & Newbery 1982; Mansfield, 1985; Ziedonis, 2004) . Although more central firms may be "in a favorable position to see a more complete picture of all the alternatives available in the network" (Lin et al., 2007; Perry-Smith & Shalley 2003), this also implies the activities' of such firms will be more readily observable to other network members. In this scenario, I predict limiting network members' access to information from a focal firm will benefit exploitation. Stated another way, firms that can hide in the far reaches of a network should have an advantage when exploiting information already known to their competitors, leading to:

> *P8: The higher a firm's closeness centrality in an exploration-oriented network, the more likely it is to successfully commercialize a known technology*



Archetype: Low Closeness Centrality

Proposed Effect: - in Short/Long-term

Archetype: High Closeness Centrality

Proposed Effect: + in Short/Long-term

Figure 6. Network closeness centrality and exploitation

Network Configurations and Ambidexterity

If firms were limited to participating in a single network (or if researchers aggregate all of their network ties into a single measure) balancing exploration and exploitation would simply be a direct tradeoff. If a given firm chose to have a more open network or collaborate with a diverse set of organizations, it should be more likely to invent new technologies but have difficulty capitalizing on these inventions. Conversely, if a given firm chose to participate in a closed network or collaborate with a homogeneous set of organizations, it would be less likely to invent new technologies despite having an enhanced ability to successfully bring such technologies to market.

Such a tradeoff is consistent with my earlier description of the network-ambidexterity paradox and with conceptualizations of exploration and exploitation as poles of a continuum (e.g. Ebben & Johnson, 2005; Lavie & Rosenkopf, 2006; Lin et al., 2007). However, this tradeoff functionally ignores that firms can participate in multiple types networks simultaneously. Although network research conventionally collapses many tie types into one, recent reviews point to this convention as one of the serious weak points in this area of research (Kilduff & Brass, 2010). In fact, organizations participate in many networks simultaneously, with each having unique purposes, dynamics, and challenges (Nohria & Eccles, 1992; Gulati, 1999). For example, firms can maintain multiple sets of alliances, with each set designed to carry out different tasks (Rothaermel & Deeds, 2004, Lavie & Rosenkopf, 2006).

In the case of exploration and exploitation oriented networks, this implies organizations could benefit from configuring these respective networks differently. Such configurational approaches to analyzing organizations are part of a well-established research tradition (e.g. Miles & Snow, 1978; Meyer, Tsui & Hinings, 1993), but to my knowledge have not been widely applied in either organizational ambidexterity or network research outside of simulation-based studies (e.g. Lazer & Friedman, 2007; Lin et al., 2007).

It is important to note that differentiating between network types does not require a focal firm to collaborate with a distinct set of other organizations in a given network. Rather, it requires categorizing a focal firm's inter-organizational relationships as either exploratory or exploitative in orientation (Parmigiani & Rivera-Santos, 2011). Stated another way, it is the types of links that change between exploration and exploitation networks; the nodes may be the same, as with case of "multiplex ties" (Beckman & Haunschild, 2002), or different. Figure 7 demonstrates an extreme case where the same focal firm in a (stylized) network with identical actors has low closure, high diversity, and low closeness centrality in its exploration-oriented relationships and high closure, low diversity, and high closeness centrality in its exploitation-oriented relationships.

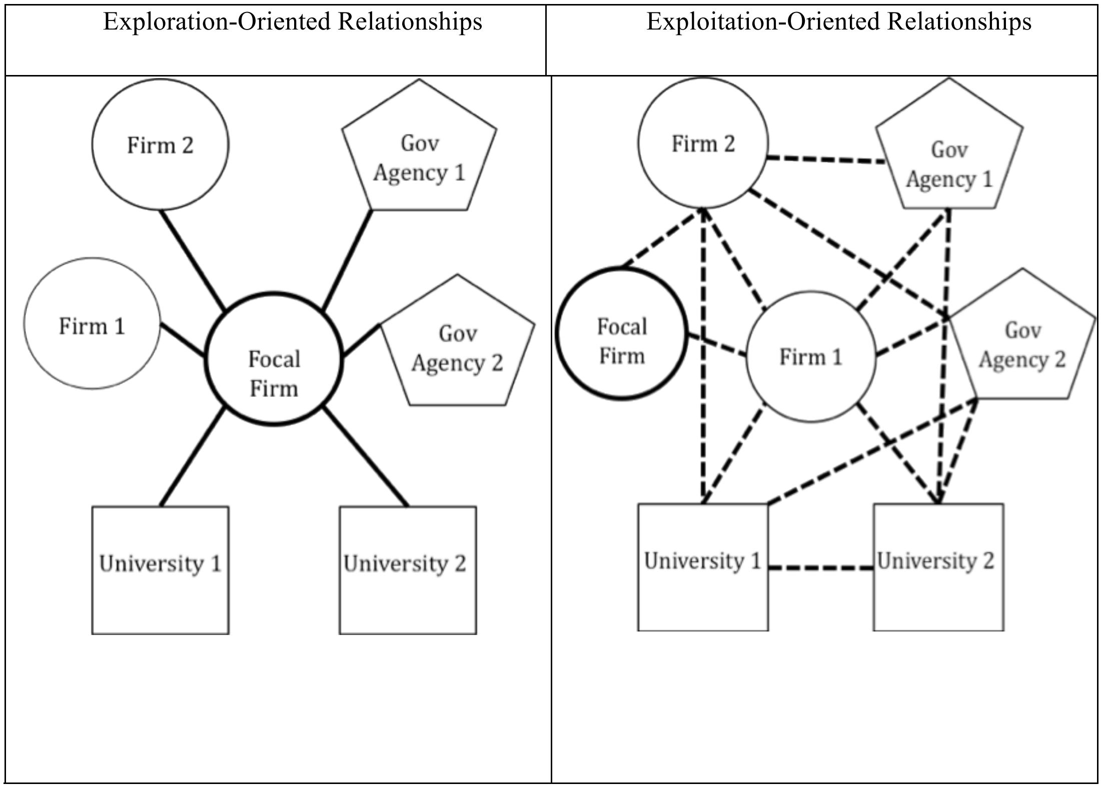


Figure 7. Stylized Exploration and Exploitation Networks

Specific to this dissertation, all else equal, firms should tend to succeed at technology commercialization by configuring their inter-organizational relationships to have low closure, high diversity, and low closeness centrality in exploration-oriented networks, and high closure, low diversity, high closeness centrality in exploitation oriented-networks. Such a network configuration is truly ambidextrous because not only are the two “hands” performing different tasks, but are also performing different tasks in differing ways. In other words, a person would not be truly ambidextrous if they could use both hands but each always had to make the same motions as the other. Rather, true ambidexterity is when each hand can operate independently, making the correct motions for its assigned task. Figures 8, 9, and 10 visually contrasts such ambidextrous network configurations to the establish network archetypes of closure, diversity and centrality. This ambidextrous network configuration leads to three additional propositions:

> *P9a: The lower the level of closure in a firm's exploration-oriented ego network and the higher the level of closure in a firm's exploitation-oriented ego network, the more successful it will be in commercializing technologies*

Exploration-Oriented Relationships Archetype: Low Closure Proposed Effect: + in Long-term	Exploitation-Oriented Relationships Archetype: High Closure Proposed Effect: + in Long-term

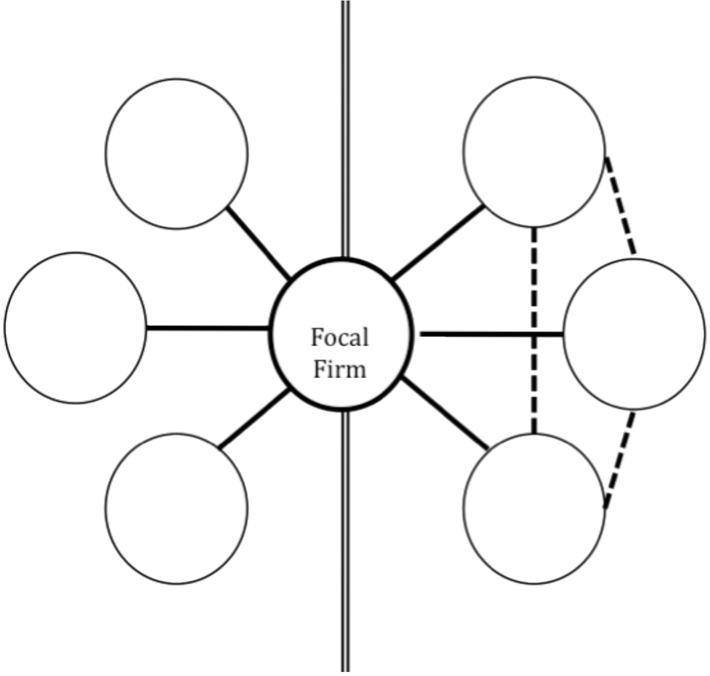


Figure 8. Ego network closure and ambidexterity

P9b: The higher the level of diversity in a firm's exploration-oriented ego network and the lower the level of diversity in a firm's exploitation-oriented ego network, the more successful it will be in commercializing technologies

Exploration-Oriented Relationships Archetype: High Diversity Proposed Effect: +	Exploitation-Oriented Relationships Archetype: Low Diversity Proposed Effect: +

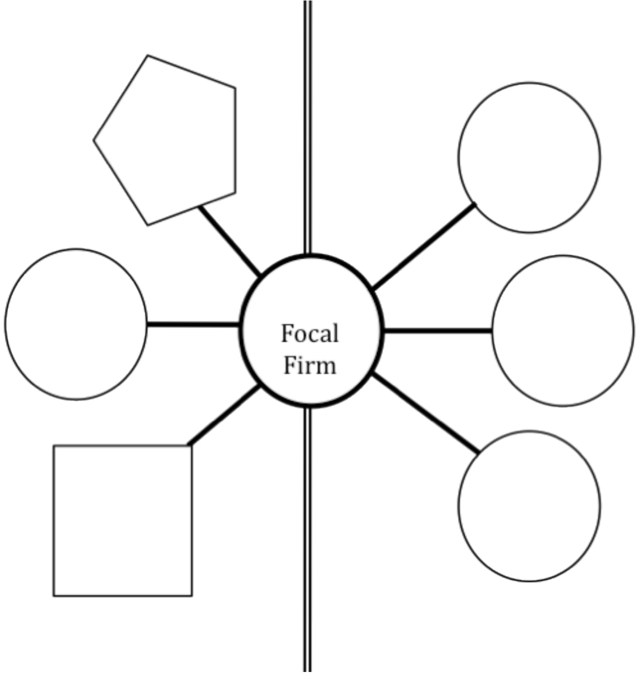


Figure 9. Ego network diversity and ambidexterity

P9c: The lower a firm's closeness centrality in its exploration-oriented network and the higher a firm's closeness centrality in its exploitation-oriented network, the more successful it will be in commercializing technologies

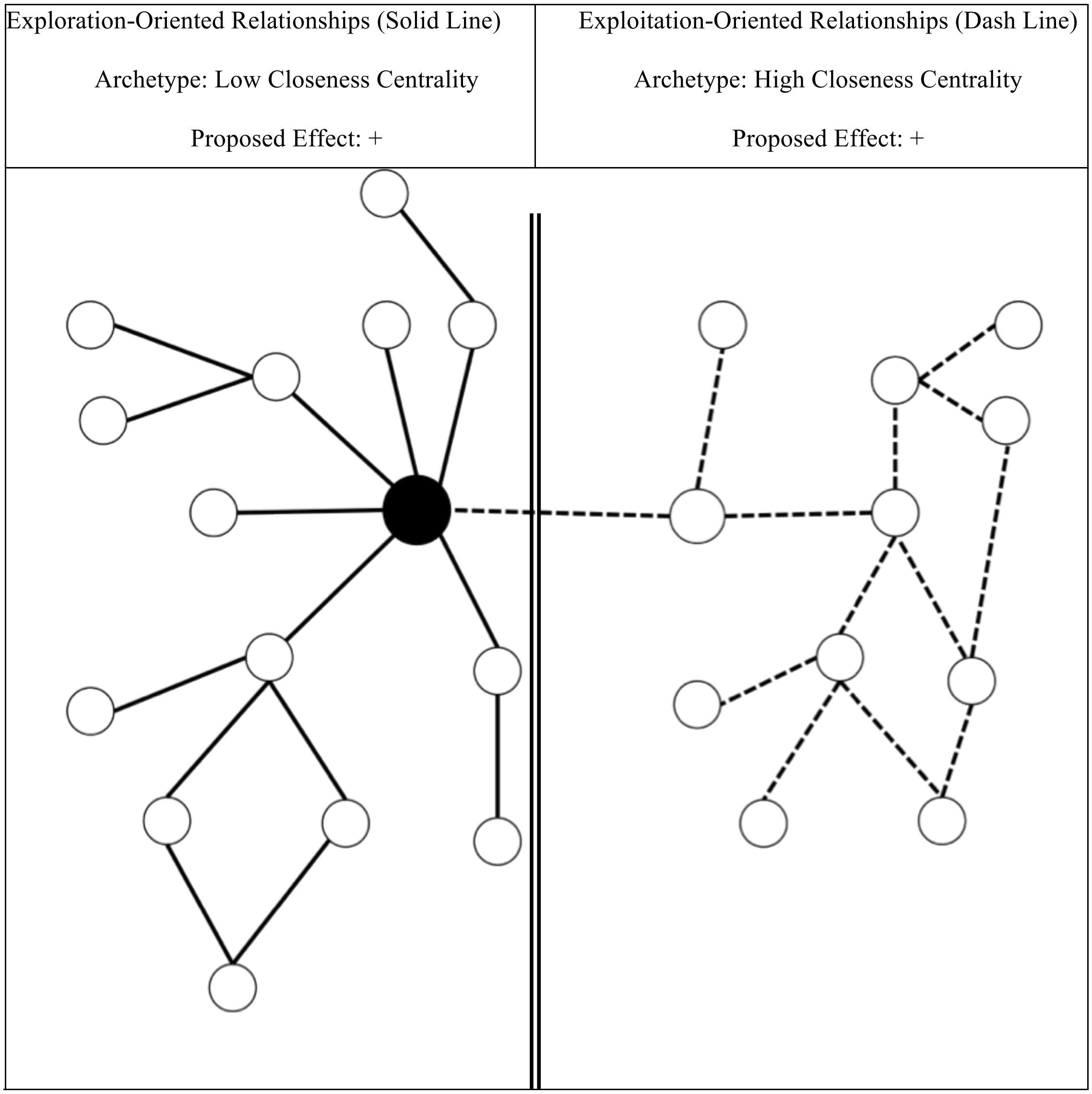


Figure 10. Closeness centrality and ambidexterity

Figures 8-10 show archetypes of ambidextrous configurations for each of three types of network characteristics I consider in this dissertation. Each of these network characteristics affect the information reaching a focal firm, but past research offers no reason to believe they are mutually exclusive. As a result, a firm could conceivably adopt all three configurations simultaneously. Figure 11 offers a graphical depiction of a focal firm with all three types of ambidextrous network configurations. Although, the theory I develop in this section implies firms with such a network configurations would out perform rivals in both exploration and exploitation, I do not formally propose this linkage because such a six-way interaction term is too difficult to test and interpret in the statistical models I employ in subsequent chapters.

Exploration-Oriented Relationships (Solid Line) Archetypes: Low Closure (+), High Diversity (+), and Low Closeness Centrality (+)	Exploitation-Oriented Relationships (Dash Line) Archetypes: High Closure (+), Low Diversity (+), and High Closeness Centrality (+)

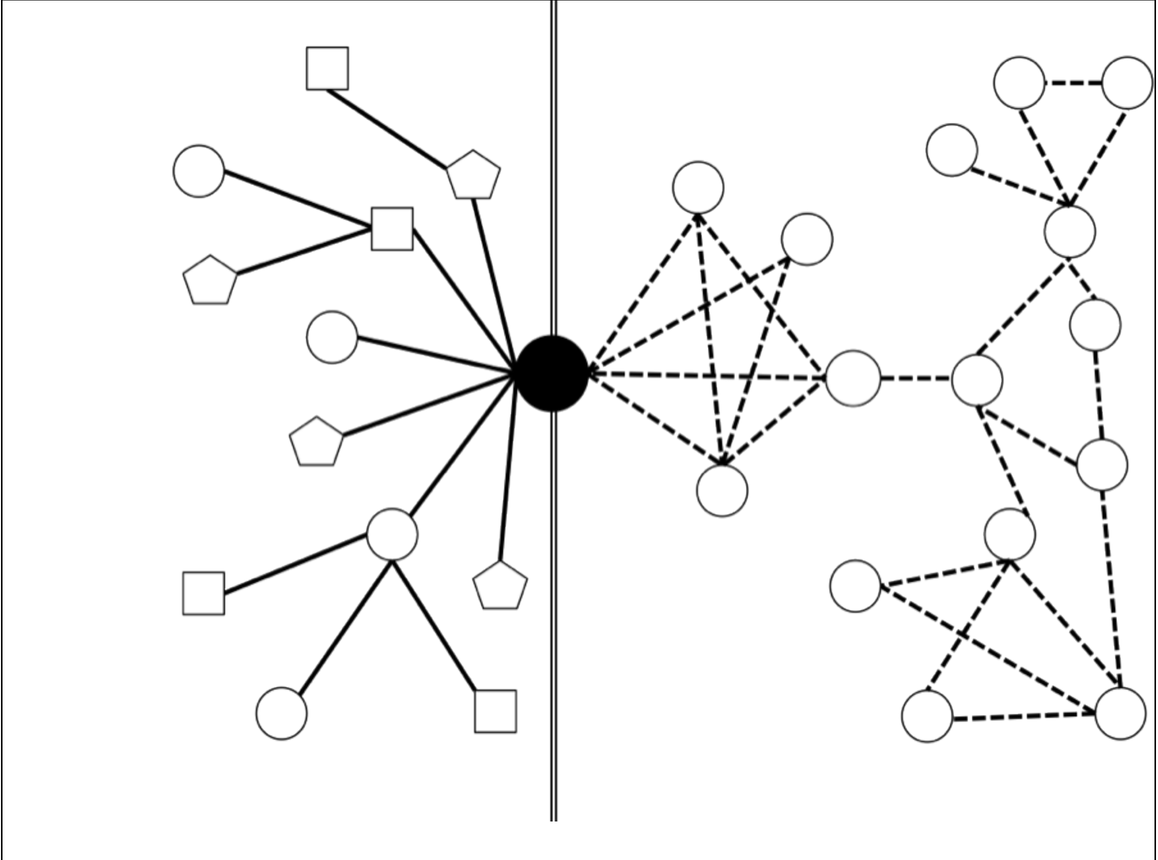


Figure 11. Closure, diversity, closeness centrality, and ambidexterity

Figures 12, 13, and 14 summarize the propositions I developed in this chapter and foreshadow the three statistical models I use in chapter IV. Figure 11 shows my “exploration model” relating networks characteristics to firm discovery of “that which might become known” (March & Levinthal, 1993). Figure 12, my “exploitation model”, uses this same set of network characteristics to predict how firms convert “that which is known” (March & Levinthal, 1993) into useful products, processes, and services. Figure 13 shows my novel “combined model” which breaks with past research (e.g. Hess & Rothaermel, 2011; Rothaermel & Deeds, 2004) that model exploration and exploitation in isolation, by combining these activities over time in a single dependent variable.

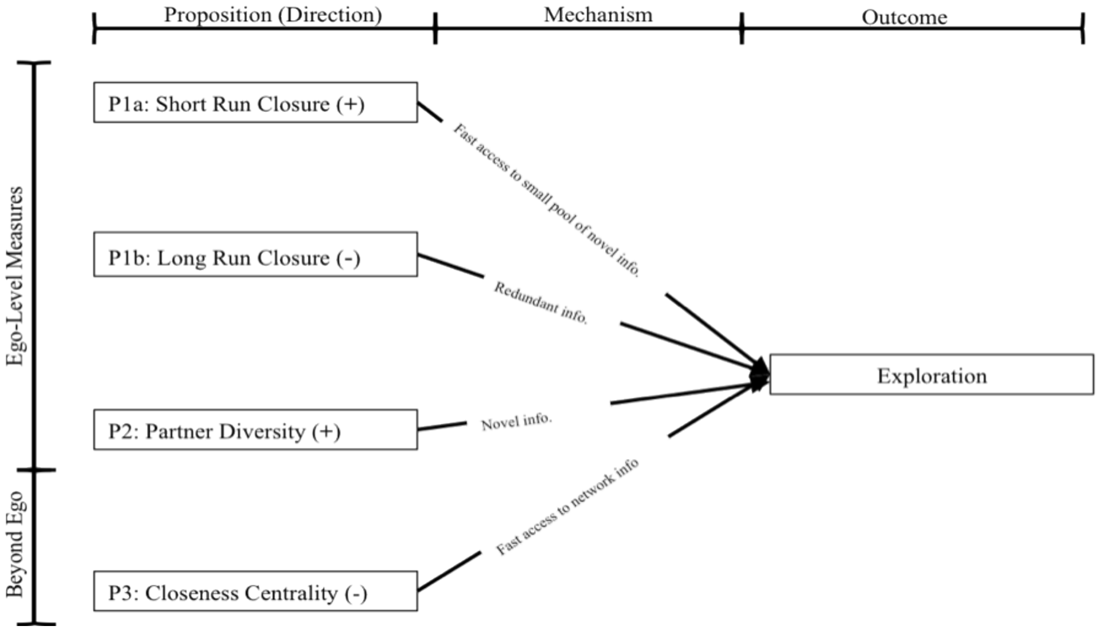


Figure 12. Exploration model

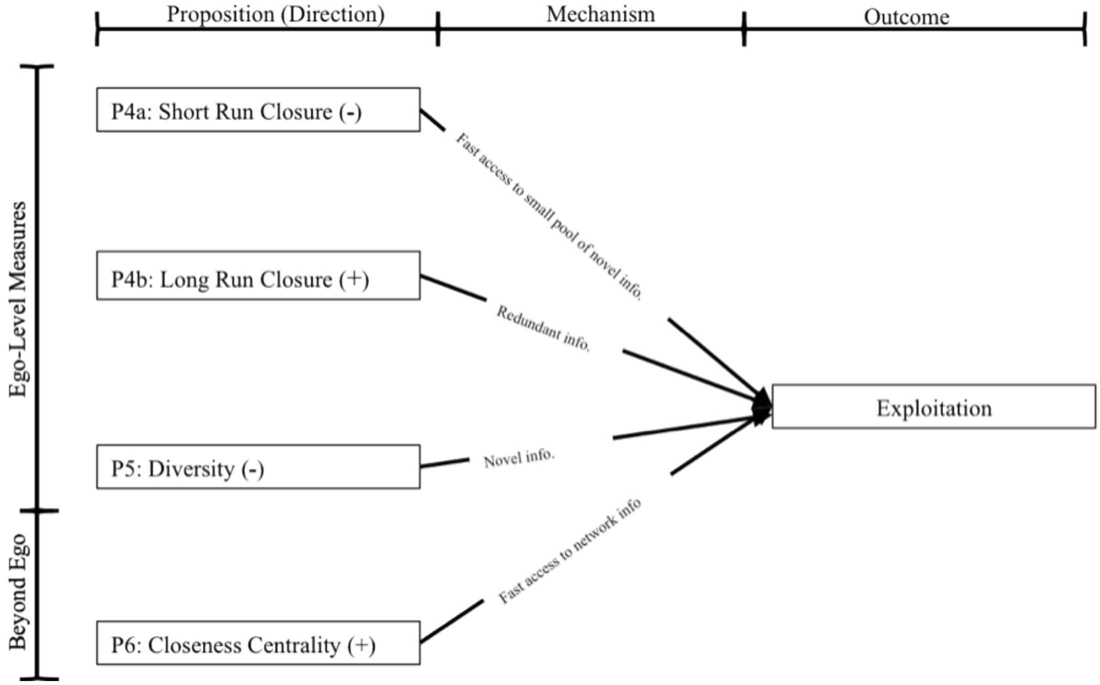


Figure 13. Exploitation model

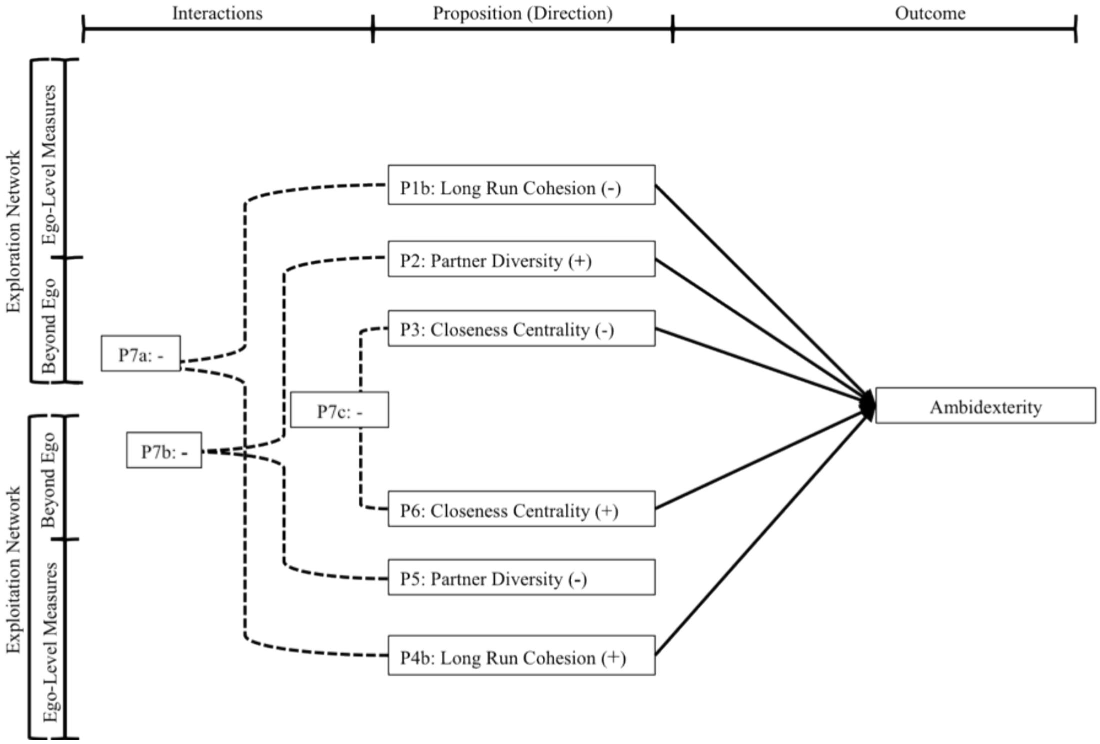


Figure 14. Ambidexterity model

Summary

In this section, I developed eleven propositions relating network characteristics to organizational ambidexterity. The underlying mechanism I chose to focus on is how network characteristics shape the information that reaches a focal firm in a network. I chose this because past search shows that ambidexterity's constituent parts, exploration and exploitation, benefits from different types of information. Specifically, network characteristics that provide novel information to a focal firm should aid in exploration and network characteristic that provide redundant information to a focal firm should aid in exploitation. The next chapter describes the research methodology, data, and empirical setting I use in this dissertation. The next chapter also includes specific hypotheses based on the propositions developed in this section, but drawing on the specifics of the empirical setting I use in this dissertation.

CHAPTER IV

SETTING, DATA, AND RESEARCH METHODOLOGY

In this chapter, I describe how I bring the propositions developed in the previous chapter to an empirical test. First, I describe the field of green chemistry, which serves as the empirical setting for this dissertation. Second, I describe the various types of data available on technology commercialization in green chemistry and how I collected data on firms' green chemistry activities. Next, I convert the more abstract propositions from the previous chapter into specific hypotheses testable with the data available in the field of green chemistry. Finally, I describe the statistical approach I use for testing these hypotheses.

Empirical Setting

The empirical setting for this dissertation is a specific area of scientific research known as *green chemistry*. Green chemistry is an attempt "to make humanity's approach to chemicals—especially synthetic organic chemicals—environmentally sustainable" (Linthorst, 2009). Firms participating in green chemistry focus on "the prevention of problems before they occur by (re)designing chemicals and chemical production processes at a molecular level." (Woodhouse & Breyman, 2005, pg 200). Perhaps the most well known example of green chemistry is the Boots Corporation's redesign of the chemical process for producing Ibuprofen, resulting in a 40% efficient process (60% waste) becoming a 99% efficient (1% waste) process (Woodhouse & Breyman, 2005). More generally, the US EPA's Office of Pollution Prevention and Toxics (1997) reports the following example from the pharmaceutical industry:

> *“[Green Chemistry] revolutionized bulk pharmaceutical manufacturing. The process provides an elegant solution to a prevalent problem encountered in bulk pharmaceutical synthesis (i.e., how to avoid the large quantities of solvents and wastes associated with the traditional stoichiometric use of auxiliary chemicals for chemical conversions). Large volumes of aqueous wastes (salts) normally associated with such manufacturing are virtually eliminated…. The nearly complete atom utilization of this streamlined process truly makes it a waste-minimizing, environmentally friendly technology.”*

Although pharmaceutical firms are the most common participants in green chemistry due to their high e-factor (ratio of waste to final product by weight) (Poliakoff, Fitzpatrick, Farren & Anastas, 2002), firms in numerous other industries also develop green chemistry-based technologies. Examples include Dow’s development of a new carbon dioxide-based blowing agent for manufacturing polystyrene packaging materials and the Rohm and Haas Company’s invention of a marine bottom paint with superior performance characteristics that also results in less bioaccumulation in marine organisms (Woodhouse & Breymen, 2005).

Table 4. The 12 principles of green chemistry

1. **Prevention**
   It is better to prevent waste than to treat or clean up waste after it has been created.
2. **Atom Economy**
   Synthetic methods should be designed to maximize the incorporation of all materials used in the process into the final product.
3. **Less Hazardous Chemical Syntheses**
   Wherever practicable, synthetic methods should be designed to use and generate substances that possess little or no toxicity to human health and the environment.
4. **Designing Safer Chemicals**
   Chemical products should be designed to effect their desired function while minimizing their toxicity.
5. **Safer Solvents and Auxiliaries**
   The use of auxiliary substances (e.g., solvents, separation agents, etc.) should be made unnecessary wherever possible and innocuous when used.
6. **Design for Energy Efficiency**
   Energy requirements of chemical processes should be recognized for their environmental and economic impacts and should be minimized. If possible, synthetic methods should be conducted at ambient temperature and pressure.
7. **Use of Renewable Feedstocks**
   A raw material or feedstock should be renewable rather than depleting whenever technically and economically practicable.
8. **Reduce Derivatives**
   Unnecessary derivatization (use of blocking groups, protection/ deprotection, temporary modification of physical/chemical processes) should be minimized or avoided if possible, because such steps require additional reagents and can generate waste.
9. **Catalysis**
   Catalytic reagents (as selective as possible) are superior to stoichiometric reagents.
10. **Design for Degradation**
    Chemical products should be designed so that at the end of their function they break down into innocuous degradation products and do not persist in the environment.
11. **Real-time analysis for Pollution Prevention**
    Analytical methodologies need to be further developed to allow for real-time, in-process monitoring and control prior to the formation of hazardous substances.
12. **Inherently Safer Chemistry for Accident Prevention**
    Substances and the form of a substance used in a chemical process should be chosen to minimize the potential for chemical accidents, including releases, explosions, and fires.

Green Chemistry as a Scientific Field

According to Linthorst (2009) green chemistry was one of several environmentally oriented terms including, clean chemistry, benign chemistry, sustainable chemistry, and environmental chemistry, which entered the field of chemistry in the 1980s and 1990s. Although Metzger & Eissen (2002) point out the exact definition of these terms was initially unclear, since, 1998 the term “green chemistry” has come to dominate this area of chemistry as measured by keyword searches in ISI Web of Knowledge. Linthorst (2009) credits the publication of Green Chemistry: An Overview in Green Chemistry: Designing Chemistry for the Environment by Anastas & Williamson (1996) with presenting the first “green chemistry philosophy” (pg 56) that became highly cited in future research. From 1998 onward, green chemistry experienced dramatic growth in the number or articles published. Ultimately green chemistry coalesced around 12 guiding principles first articulated by Anastas & Warner their book Green Chemistry: Theory and Practice (1998) (Linthorst, 2009). Table 4 lists these 12 principles.

Linthorst (2009) starts his history of green chemistry with Rachel Carson’s Silent Spring (1962). This led, in part, to the creation of the US Environmental Protection Agency (US EPA) in 1970. The EPA initially took a “command and control” approach to pollution prevention focusing on regulating “end of pipe” emissions. By the mid 1980s the EPA started shifting from “end of pipe” emission controls to pollution prevention (Stephan & Atcheson, 1989), where the EPA cooperated with the chemical industry to pursue inherently safer chemicals. One program intended to foster such collaboration was the EPA’s Office of Pollution and Toxics “Alternative Synthetic Design for Pollution Prevention”, the direct ancestor of green chemistry.

In the late 1990s, green chemistry began to exhibit the trappings of a distinct “scientific specialty” (Mullins 1972). According to Mullins (1972), recruitment procedures, tests of membership, journals, meetings, and supporting locations are signs of a scientific specialty. The Green Chemistry Institute (GCI) was founded in 1997 and the peer-reviewed journal *Green Chemistry* was first published in 1999. Chemistry’s major professional organizations recognized green chemistry as a distinct subfield within chemistry by merging the Green Chemistry Network (GCN) with Britain's Royal Chemical Society (RCS) in 1998 and merging the Green Chemistry Institute with the American Chemical Society (ACS) in 2001. The ACS Green Chemistry Institute now has 26 chapters worldwide. The current state of green chemistry also meets Hambrick and Chen's (2008) definition of an academic field. Specifically, green chemists both "evaluate their own members" by way of a dedicated peer-reviewed journal *Green Chemistry* and have "some permanence in the academic establishment" as seen with the GCN's merger with the RCS, GCI's merger with the ACS, and ongoing conferences such the annual ACS-sponsored Green Chemistry and Engineering Conference.

Sampling Frame

As with other empirical settings common in technology commercialization research, such as biotechnology, the field of green chemistry features a diverse ecosystem of organizations including firms, universities, government agencies, and research foundations. Although the focus of this dissertation is on the firms involved in commercializing green chemistry-based technologies, selecting a broad enough sample frames to capture these other types of organizations is necessary for testing my network closure, diversity, and closeness centrality hypotheses. As a result I cast a fairly wide net by starting with the field of green chemistry as whole, rather than following past technology commercialization research by focusing on a narrower slice of technologies such as those invented by a single or small group of universities (e.g. Nerkar & Shane, 2007; Mowery, Sampat & Ziedonis, 2002; Katila & Shane, 2005).

Consistent with past research on ambidexterity (e.g. Hess & Rothaermel, 2011; Rothaermel & Deeds, 2004) I use two interrelated sampling frames to identify firms involved in green chemistry. First, to test exploration-oriented hypotheses derived from Propositions 1 through 4 I use research articles published in academic journals to identify firms active in producing the basic science undergirding green chemistry. Such publications are the premiere channel for reporting scientific discoveries and their contents fit well with March & Levinthal's (1993) notion of "things that might come to be known." Historically, university-based researchers have almost exclusively authored articles found in peer-reviewed journals, however such articles are increasing published by either firm-based researchers or combinations of university and firm-based researchers (Zucker, Darby & Armstrong, 2002). Publications in the field of green chemistry reflect similar diversity, featuring articles published by researchers at universities, various governmental agencies, and firms.

To test exploitation-oriented hypotheses derived from propositions 5 through 8, I use green chemistry patenting as the sampling frame. Similar to green chemistry publications, green chemistry patents feature a diverse ecosystem of organizations. Use of patents vary by industry, but patenting is common amongst the types of firms active in green chemistry, specifically firms in the pharmaceutical and bulk chemical industries (Cohen, Nelson & Walsh 2000; Ahuja, 2000). In contrast to publications, patents had historically been a practice common to industry, but rare in academics. However, much like with publications becoming common amongst firm-based researchers, patenting has become common amongst university-based researchers (Mowery et al., 2002).

As a whole, these sampling frames allow two distinct paths for firms to enter data sets used in this dissertation. First, a firm can enter when one of its researchers discovers a new means-ends relationship and publishes this discovery in a peer-reviewed journal.

Second, a firm can enter when it applies for or is assigned a green chemistry-based patent. By merging these frames, I can distinguish firms involved in both publication and patenting from firms only engaging in one of these activities. As a practical constraint, I limited both of these sampling frames to firms for which I could find secondary information such as annual revenue. I also excluded firms that had not published or patented at least twice over the period of the study. I did not exclude private or non-US firms, since databases like PrivCo cover many of these firms. However, this limitation likely means this sample tilts towards larger and longer-lived firms.

To ensure a group of counterfactual firms in my analysis, I also included firms that had neither published nor patented but had been nominated for a Presidential Green Chemistry Award. Including these firms helps guard against making false assumptions regarding the importance of publishing and patenting networks in general. Capturing firms that do not publish or patent is especially important for this study since network research is unique in theorizing both the presence *and* absence of relationships (Kilduff & Brass, 2010). If this had been the only sampling frame, it would raise concerns of "sampling on the dependent variable", however there were only 24 firms that had received a PGCCA nomination but not published or patented at least twice. Furthermore, these firms received only 36 of 1166 total PGGCA nominations, meaning the vast majority of nominated firmed entered the sample by either publishing or patenting.

Using this tripartite sample frame, I identified 168 firms to analyze in this study. To answer my research questions on exploration I track the publishing and patenting activities of these firms from 1997 to 2008, for 2,016 firm-years. For my exploitation research questions, I track the patenting activity and PGCCA nominations of these same firms from 1997 to 2011, for 2,520 firm-years. Although these firms are all involved in some aspect of chemistry, many are not solely or even primarily chemical firms. Consistent with past research showing the inter-industry nature of the green chemistry field, the 168 firms in this study come from industries including, pharmaceutical, bulk chemicals, consumer goods, electronics, energy, and basic materials. Table 5 shows the top 20 firms for publishing, patenting, and PGCCA nomination respectively.

Table 5. Top firms in green chemistry by measure

Publications		**Patents**		**PGCCA Nominations**	
Merck & Co	13	BASF AG	252	DuPont	25
Pfizer Inc	13	IBM Corp	221	Nalco Co	24
GlaxoSmithKline	12	General Electric	167	Dow Chemical Co	16
DuPont	11	Procter & Gamble Co	165	Cytec Industries Inc	16
DSM	8	Merck & Co	156	Pfizer Inc	11
Dr Reddy's Laboratories	8	Pfizer, Inc	119	Codexis Inc	10
Evonik AG	7	Bayer AG	114	Cognis	9
Novartis Pharmaceutical Corp	6	3M	108	Merck & Co	7
AstraZeneca	6	UOP LLC	82	Bayer AG	7
Johnson & Johnson	6	Eastman Kodak Co	60	Akzo Nobel	7
BASF AG	5	Xerox Corp	59	Eli Lilly and Co	7
Roche	5	Mitsubishi Chemical Corp	55	PPG Industries Inc	7
Cognis	5	Mitsui Chemical Inc	51	3M	6
Asahi Kasei Corp	5	Ecolab Inc	50	Ecolab Inc	6
Wockhardt Ltd	5	Henkel Corp	49	Ashland Inc	6
Eli Lilly and Co	4	Monsanto Co	49	Stepan Co	6
Indian Oil Corp Ltd	4	Roche	43	IBM Corp	5
LG Life Science Ltd	4	Arkema Inc	42	Eastman Kodak Co	5
Mitsubishi Chemical Corp	3	Evonik AG	42	Henkel Corp	5
Rhodia Inc	3	ExxonMobil	41	Monsanto Co	5
Air Products and Chemicals, Inc	3			Eastman Chemical Co	5
Kao Corp	3			Ciba Specialty Chemicals	5
Akzo Nobel	3			Cargill Inc	5
Toyota Motor Corp	3			Solutia Inc	5
Dow Chemical Co	3				
Isis Pharmaceut Inc	3				
Richter Gedeon Rt	3				

Data Sources and Collection

Publications

The first data source I draw on for this dissertation is a database of published scholarly research in green chemistry. This database captures all English-language scientific research articles published in green chemistry in the SciFinder Scholar database before, 2009. Identifying the boundaries of a scientific field can be difficult, especially early in its development (Kaplan & Radin, 2011; Nelson, Earle, Howard-Grenville, Haack & Young, 2012), as labels maybe contested or practices may be adopted in a concealed manner (Granqvist, Grodal & Woolley, 2012; Terlaak & Gong, 2008). Similarly, if a field becomes popular, practices may be adopted, but only symbolically so (Westphal & Zajac, 1994; Fiss, 2008).

To avoid both of these problems a cross-disciplinary team of researchers in management and chemistry created and executed a two-part strategy for gathering green chemistry publications. First, we generated a broad list of keyword search terms and used these to locate articles in the SciFinder database. Next, a chemist inspected each of 10,231 abstracts for these articles to assess its fit with one or more of green chemistry's principles (Table 4). Although one chemist did most of the sorting, he utilized colleagues to help classify ambiguous articles. Additionally, it is important to note that the green chemistry principles have relatively little technical ambiguity and past research shows that someone with proper technical training can easily identify such "manifest content" (Lee, 2009). The final database included 4,763 articles and is summarized in Table 8.

Scholarly publications have a number of features useful for management researchers. For example, researchers have used citations included in these articles to investigate questions of intellectual lineages and search strategies (e.g. Fleming & Sorenson, 2004; Murray & Stern, 2007). In this dissertation, I focus on different features of these documents. Specifically, in addition to listing the author(s) of a given article, each document also lists a given author's affiliated organization. Some of these articles have a single author, whereas others have multiple authors. Of these multiple authored articles, some have authors within a single organization, whereas other articles have authors spread across multiple organizations. It is this latter group of articles that I use in this dissertation as a measure of inter-organizational exploration.

Although firm-based researchers are increasingly active in publishing in academic journals, it is important to highlight how inter-organizational collaboration differs for these researchers when compared to their university-based peers. The independence of university-based researchers means that inter-organizational collaboration is likely to be only coincidentally inter-organizational. Instead, it likely reflects personal connections between researchers, even if these connections are a number of degrees apart (e.g. two postdoctoral researchers at different universities appear as coauthors of a publication despite not knowing one another because their respective primary investigators do know one another and decided to conduct a joint study).

In conversations in preparation for this dissertation, I learned the inter-organizational collaboration for firm-based researchers is different. Specifically, firm-based researchers interested in conducting a study with researchers at another organization must gain permission from their supervisor(s) and clearance from their firms' legal and marketing departments before performing the study. This indicates that inter-organizational co-authorship involving firm-based researchers is actually an organization-level process, rather than an individual-level process as seen with university-based researchers. Based on this observation, I use co-authorship across organizations by firm-based researchers as a measure of linkages between these researchers' affiliated organizations.

Patents

The second data source I use in this dissertation is a database of green chemistry patents and patent applications. Since green chemistry does not map to a particular patent class, I used a slightly modified version of the green chemistry patent filter developed by Nameroff, Garant & Albert (2004) to assemble this database. My slight modification of this patent filter is because I lack access to the CHI Research database Nameroff and colleagues (2004) use in their study. Instead, I used their same search terms and general search strategy, but translated into a syntax used by the freely accessible FPO patent database. The FPO database draws data from the USPTO and similar sources, but features a more user-friendly interface and superior organization and exportation tools as compared to the USPTO's in house access portal. I elected to restrict my patent search to USPTO records to aid in comparisons across documents. Although this may seem overly restrictive, firms from outside of the US commonly pursue patent protection with the USPTO. This patent filter applied to the FPO database returned a total of 26,230 patents and patent applications. Since the focus of this dissertation is on organizations rather than individual inventors, I cut patents not assigned to an organization, resulting in final database of 16,888 green chemistry patents and patent applications.

I collected patent applications in addition to patents for a number of reasons. First, since this dissertation uses quite recent data (through 2011), the delay between patent filling and publication right-censors any of the patent related variables, leading to a greatly reduce sample. Adding patent applications to the database helps to alleviate this issue by capturing inventions under consideration for patent protection even if such protection has not yet been granted or made public by the USPTO. Second, my primary concern in this dissertation is capturing inter-organizational collaboration rather than specific inventions that clear the legal hurdle for patent protection. Therefore, if a green chemistry patent application were to eventually be denied, but still show evidence of inter-organizational collaboration, it would still be a valid data point for this particular study. Lastly, the relative rarity of co-assigned patents and patent applications means I do not have adequate data to address issues of “tie weight” or repeated collaboration in this dissertation. As a result I treat bilateral organizational collaboration as a binary variable in a given firm-year, eliminating the possibility of double counting the same invention described in both an application and a subsequent patent.

Since I use this green chemistry patent database in a number of ways in this dissertation, it is important to address what exactly patents are and how researchers have used them in past research. At their cores, patents grant rights to exclude others from making, using, or selling a particular invention (Ziedonis, Forthcoming). Although patent systems vary by country, justifications for such systems are largely consistent. By granting a right of exclusion, patents allow an inventor to capture value created by their invention thereby providing incentives for continued inventive activity. In exchange for this exclusionary grant, inventors must disclose details of her or his inventions in patent documents that eventually become public. These public patent documents can then inform subsequent inventions further promoting future innovative activity. Although other forms of intellectual property protection exist, such as trademarks, copyrights, and trade secretes, patents have attracted the lion's share of attention from management scholars (Ziedonis, Forthcoming).

In her forthcoming review of research on intellectual property, Ziedonis indentifies two primary ways management scholars have used patents in past research. First, scholars often use patents as outcome variables to capture firm "innovativeness". Researchers model such innovativeness as function of any number of mechanism including R&D spending (Hausman, Hall, & Griliches, 1984), scale and scope economies in R&D (Cockburn & Henderson, 1996), acquisitions (Ahuja & Katila, 2001), cross-organization type collaboration (Cockburn & Henderson, 1998), and inter-organizational networks (Ahuja, 2001). More recently, research using patents as a measure of innovativeness has moved beyond dependent variables based on simple patent counts. For example, Jaffe & Trajtenberg (2002) developed a method for weighting the value patents according to citations they subsequently receive, thereby differentiating between lower and higher value patents.

As useful as patent data have been as a measure of innovativeness, they have a number of drawbacks. At the most basic level some inventions are simply not eligible for patent protection. For example, software firms historically protected their intellectual property with copyrights rather than patents until a series of court rulings on the subject in the 1990s (Ziedonis, Forthcoming; Graham & Mowery 2003). The propensity to patent also varies considerably by industry (Cohen at al., 2000, Hall & Ziedonis, 2001). Finally, the legal landscape underlying the patent system can shift making distinguishing changes in inventive behavior from changes driven by conforming to a new set of institutional requirements difficult (Ziedonis, Forthcoming).

A second way researchers use patents is by taking advantage of the information contained in the patent documents themselves. Similar to using patents to measure innovativeness, using patents as "paper trails" has also spawned considerable research. For example, researchers have used citations included in patent documents to trace knowledge flows across geographic (Jaffe, Trajtenberg, & Henderson, 1993) and technological space (Rosenkopf & Nerkar, 2001). This, and similar approaches using citations in academic publications (e.g. Fleming & Sorenson, 2004), is one of the few ways researchers have to trace knowledge flows across a reasonably large sample size. As a result, it has attracted considerable attention in the innovation literature.

As with using patents to measure innovativeness, using patents as paper trails has a number of drawbacks. First, patent examiners add approximately 40% of patent citations (Alcacer & Gittleman, 2007), implying these particular citations tell researchers little about the influences on the inventive activity described in the patent document. Even more problematic, these examiner-added citations differ systematically both from the citations added by the inventor (Alcacer & Gittleman, 2007) and by industry (Sampat, 2005). From 2001 onward the US Patent and Trade Office explicitly identifies examiner added citations largely eliminating these as a source of bias because researchers can simply restrict their sample to only inventor added citations if desired. More generally, the information disclosed in patent documents may reflect a host of strategic concerns, such as the litigation environment in a particular industry (e.g. Sampat, 2005), which have little to do with the specific invention described in the patent document.

Highlighting these two ways patents have been used in past research is critical to this dissertation since I actually use patents both as a measure of inventiveness and as a paper trail to capture inventive activity, albeit in different models. Consistent with the former, I use counts of green chemistry-specific patents as the dependent variable in my model of exploration. Consistent with the latter, I use network measures generated from green chemistry patents assigned to more than one organization as the main explanatory variables in my exploitation model. Admittedly using the same data source in different ways in the same study may generate some confusion. However, I believe the benefits of this approach in terms of developing ambidexterity theory outweighs the costs of this possible confusion, especially given that both my uses of patent data are independently consistent with past research.

Green chemistry as an empirical context also lends itself well to patent-based research because most firms active in this field are members of either the chemical or pharmaceutical industries. Firms' propensities to patent inventions vary considerably across industries (Cohen at al., 2000), but chemicals and pharmaceuticals are where patenting tends to be the most essential (Mansfield, 1986), common (Ahuja, 2000) and effective (Teece, 1986). One reason for this high propensity to patent is products in these industries tend to be protected by a small number of specific patents making infringement easy to detect (Teece, 1986; Ziedonis Forthcoming). For example, a new drug developed by a pharmaceutical firm would have a specific chemical structure easily identifiable in an imitation product. As a result, the database of patents I collected for this dissertation seem likely to be a reasonable representation of both inventive outputs and collaboration in this particular context. Figure 15 summarizes annual publication and patenting for both green chemistry as a whole and for the 168 firms I analyze in this dissertation.

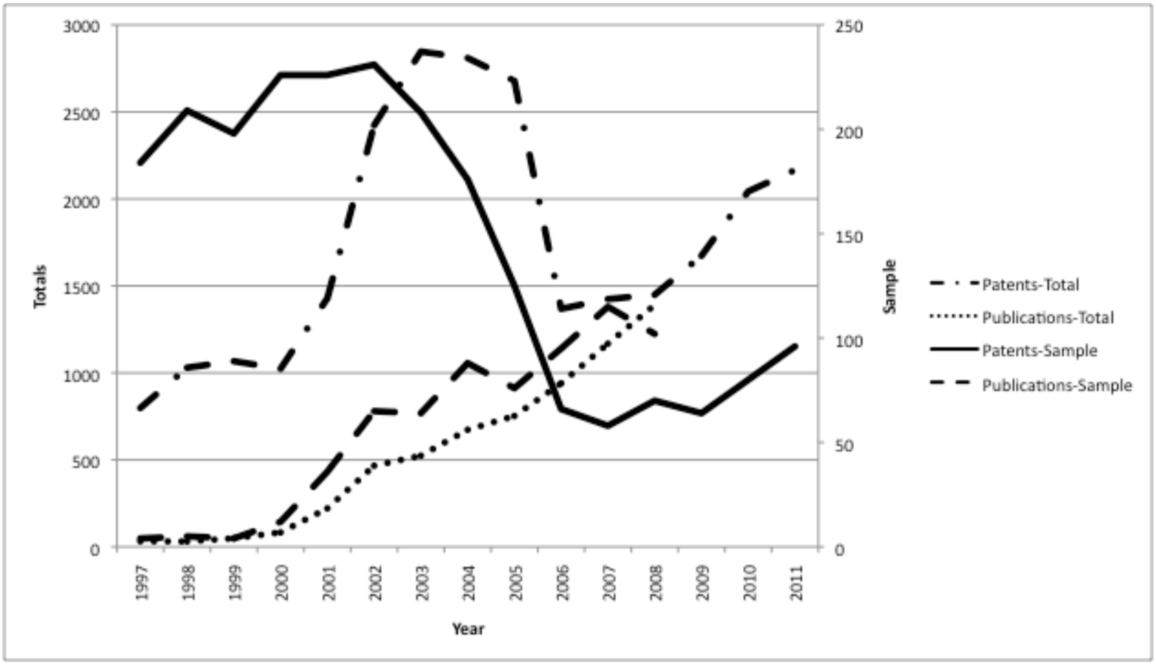


Figure 15. Green chemistry patents and publications

Award Nominations

The third data source I use in this dissertation is official descriptions of the United States Environmental Protect Agency administered *Presidential Green Chemistry Challenge Awards* (PGCCA) nominees. Although academic publications and patents have received relatively more attention, the use of award, contest, and prizes data is not unprecedented in management research (e.g. Rao, 1994). In fact, a system of offering bonuses and other prizes for inventions was seriously considered as an alternative to a patent system during the earlier years of intellectual property protection development in the nineteenth century (Malchup & Penrose 1950) and has been the subject of formal modeling exercises in the economic literature (e.g. Wright, 1983).

The PGCCAs are annual awards given to organizations by the EPA and the American Chemical Society on behalf of the President of the United States in "recogniz[tion of] chemical technologies that incorporate the principles of green chemistry into chemical design, manufacture, and use" (US EPA, 2011). A panel of judges from the America Chemical Society, representing scientific, industrial, governmental, educational, and environmental perspectives, chooses award winners based on three sets of criteria. Table 6 summarizes these criteria.

Table 6. Criteria for Presidential Green Chemistry Challenge Awards (PGCCA)

Criteria	Description	Detail
Science & innovation	The nominated chemistry technology should be innovative and of scientific merit.	• Original (i.e., never employed before). • Scientifically valid, that is, can the nominated technology or strategy stand up to scientific scrutiny through peer review? Does the nomination contain enough chemical detail to reinforce or prove its scientific validity? Has the mechanism of action been clarified via scientific research?
Human health & environmental benefits	The nominated chemistry technology should offer human health and/or environmental benefits at some point in its lifecycle from resource extraction to ultimate disposal.	• Reduce toxicity (acute or chronic) or the potential for illness or injury to humans, animals, or plants. • Reduce flammability or explosion potential. • Reduce the use or generation of hazardous substances, the transport of hazardous substances, or releases to air, water, or land. • Improve the use of natural resources, for example, by substituting a renewable feedstock for a petrochemical feedstock.
Applicability & impact	The nominated chemistry technology should have a significant impact. The technology may be broadly applicable to many chemical processes or industries; alternatively, it may have a great impact on a narrow range of chemistry. Commercial implementation can support the applicability and impact of a technology. Nominations for pre-commercial technologies should discuss economic feasibility	• A practical, cost-effective approach to green chemistry. • A remedy to a real environmental or human health problem. • One or more technical innovations that can be transferred readily to other processes, facilities, or industry sectors.

The EPA gives PGCCA awards in three technological categories, summarized in Table 7, and two additional categories based on entries from certain types of organizations, specifically small businesses[1] and academic institutions. In practice, awards in the three technological categories always have gone to large companies although rules do not necessarily exclude small companies. Award nominees and winners are announced each June at a banquet in Washington DC at which time the EPA makes descriptions of each nominated technology available. These descriptions list technologies' owner(s), its technological category, and a non-technical description (see Appendix 1 for examples). Often these descriptions include information on target market, commercial potential, and financial and/or environmental performance. For the sake of maintaining clarity regarding level of analysis, the EPA gives PGCCAs to *organizations* for developing a certain technology, *not to the technology itself or to the technology's inventor(s)*. An exception to this is the academic awards, which the EPA gives to individual researchers or research teams.

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[1] For the purpose of the PGCCAs, the EPA defines a small business as one with annual sales of less than $40 million, including all domestic and foreign sales by the company, its subsidiaries, and its parent company (US EPA, 2011).

Table 7. PGCCA technological categories

Category	Description	Examples
The use of greener synthetic pathways	This focus area involves implementing a novel, green pathway for a new chemical product. It can also involve using a novel, green pathway to redesign the synthesis of an existing chemical product	• Use greener feedstocks that are innocuous or renewable (e.g., biomass, natural oils). • Use novel reagents or catalysts, including biocatalysts and microorganisms. • Are natural processes, such as fermentation or biomimetic synthesis. • Are atom-economical. • Are convergent syntheses.
The use of greener reaction conditions	This focus area involves improving conditions other than the overall design or redesign of a synthesis. Greener analytical methods often fall within this focus area. .	• Replace hazardous solvents with solvents with a lesser impact on human health and the environment. • Use solventless reaction conditions and solid-state reactions. • Use novel processing methods that prevent pollution at its source. • Eliminate energy- or material-intensive separation and purification steps. • Improve energy efficiency, including reactions running closer to ambient conditions.
The design of greener chemicals	This focus area involves designing and implementing chemical products that are less hazardous than the products or technologies they replace	• Less toxic than current products. • Inherently safer with regard to accident potential. • Recyclable or biodegradable after use. • Safer for the atmosphere (e.g., do not deplete ozone or form smog).

In total, the US EPA reports more than 1,400 PGCCA-nominated technologies. Nominated technologies met all of the criteria listed above, although only 82 of these went on to actually win an award. Combined, the 82 winning technologies alone eliminate 199 million pounds of hazardous waste, save 21 billion gallons of water, and reduce carbon dioxide emissions by 57 million pounds annually. These numbers are certainly impressive, but the EPA recognizes the impact would be many times higher if this calculation considered all nominated technologies (US EPA, 2011).

As a data source the PGCCAs have at least three advantages. First, they capture an outcome much closer to our conceptual definitions of innovation (e.g. a product available for sale or pilot-scale process) rather than simply an invention as captured in patent documents, something rare in studies of innovation (Nerkar & Shane, 2007). Admittedly, a measure such as technology-level return on investment would be a better measure of successful technology commercialization, but these data are simply not publicly available. Furthermore, in interviews with senior researchers and managers at chemical and biotechnology companies done in preparation for this dissertation, respondents indicated such information would be so competitively sensitive (and some doubted whether their respective firms even have such detailed measures) that there is no way their firms would release it, even anonymously.

Second, the PGCCA award descriptions often contain information such as a given technology's target market, economic potential, and environmental performance, that firms are not required to disclose in either legal (e.g. patents), financial reporting (e.g. 10K filings), or other commonly used documents in innovation research (e.g. technology licensing agreements). In other words, PGCCA nominations provide incentives for firms to release information that they might otherwise keep secret.

Third, the multifaceted judging criteria used for the PGCCAs provide for an inclusive definition of commercialization success, including economic, scientific, and environmental benefits of a given technology. What constitutes successful technology commercialization is notoriously hard to define (Nerkar & Shane, 2007), but such an inclusive definition is consistent with both the hybrid logics under which technology-based companies operate (Owen-Smith, 2003) and the stakeholder view of firms (Freeman, 1984; Donaldson & Preston, 1995).

The PGCCA nominations represent a rare empirical outcropping in management research - a reasonably large sample of professionally-vetted and detailed descriptions of successful technology commercialization. However, they also have a number of drawbacks. First, as a dependent variable they are both left-truncated and right-censored in a technological sense, capturing only the best of recently commercialized green chemistry technologies rather than all such technologies (left-truncation) but not capturing the relative performance of these technologies (right-censoring). In recognition of this situation, I frame my theory development and hypotheses in this dissertation in terms of "successful" commercialization (defined as a technology being nominated for a PGCCA) rather than commercialization in general (often defined as product introductions) and treat all PGCCA nominated technologies as equal. Secondly, the process by which a technology becomes nominated for a PGCCA is somewhat opaque. For example, self-nomination of technologies are common (EPA, 2013) meaning firms might choose not to nominate one of their technologies for strategic reasons. However, the high propensity to patent in green chemistry related industries would limit the competitive concerns of such disclosure through self-nomination. Appendix 2 contains the Nomination Package for the current (2013) round of PGCCAs.

In summary, I bring together three novel data sources to investigate organizational ambidexterity and networks in the context of technology commercialization. First, an exhaustive database of academic publications that captures exploration activities of firm-based researchers and their connections to other organizations active in green chemistry.

Second, a patent database that serves to both measure inventive activity and capture collaboration by firms engaged in green chemistry. Third, documents that describe technologies nominated for the Presidential Green Chemistry Challenge Awards Program as measure of successful technology commercialization. Taken together, these provide a uniquely situated data set in which to answer the broad research question I address in this dissertation - How do network characteristics affect an organization's ability to explore and exploit?

Dependent Variables

Consistent with past research on organizational ambidexterity (e.g. Hess & Rothaermel, 2011, Rothaermel & Deeds, 2004), I use two dependent variables, one to capture successful exploration and the other to capture successful exploitation. At the conceptual level, exploration involves discovering new information and exploitation involves utilizing existing information. In the context of technology commercialization, I follow Rothaermel & Deeds (2004) in considering exploration as seeking new technologies with commercial potential and exploration as converting existing technologies into marketable products. This approach is broadly consistent with common definitions of technology commercialization (e.g. Mitchell & Singh, 1996) as a multi-stage process ranging from initial discoveries through refinement to saleable products

Consistent with past research on ambidexterity in technological contexts (e.g. Hess & Rothaermel, 2011), I use the patenting of technologies as a break point between exploration and exploitation. As a result, my operational definition of successful exploration, my first dependent variable, is a firm filing for a patent captured by the patent filter described earlier. It is important to note that successful exploration is necessary, but not sufficient, for organizational ambidexterity. It simply indicates a firm discovered a new technology that it (or another organization) may or may not successfully exploit at some point in the future. This definition of successful exploration even holds in the case of "blocking patents" where a firm tries to prevent a rival from entering a certain technological space (Shepard 1979, Acs & Audretsch, 1989), as a patent requires the applicant to demonstrate the new, useful, and non-obvious nature of a given invention. In the terminology of March & Levinthal (1993), a firm filing for a patent represents a plausible point at which "that which might become known" becomes "that which is known", and therefore creates a plausible end to exploration and beginning of exploitation.

Continuing with patent filings as the break point between exploration and exploitation, my conceptual definition of successful exploitation is firms converting these new technological discoveries into commercialized products and processes that contribute to a firm's financial and environmental performance. Again, this is broadly consistent with past research on technology commercialization and organizational ambidexterity. However, this measure does depart slightly from research set in the context of pharmaceutical development, which tends to consider submissions of drugs for FDA approval as an end point rather than actual commercialization due to the uncertainly and long time lapses in the drug approval process (e.g. Rothaermel & Deeds, 2004, Rothaermel & Hess, 2011). In the context of green chemistry, my operational definition of exploitation is a firm being nominated for a PGCCA.

Independent Variables

The key independent variables in this dissertation are measures of network characteristics formed by two types of inter-organizational relationships; one oriented toward exploration and the other oriented toward exploitation. Although the 168 firms I analyze here are undoubtedly embedded in many networks, for conceptual clarity I focus only on their activities within the field of green chemistry. I operationalize the exploration-oriented network as the co-authorship network of organizations publishing green chemistry research in peer reviewed journals. In this context, if researchers from two or more organizations appear as authors of a journal article, I consider these organizations linked. Although such co-authorship may appear to be an individual-level construct, interviews with firm-based researchers indicated that marketing and legal departments as well as the researcher's supervisor must explicitly approve such collaborations. As a result, a firm-based researcher's name appearing on a scientific publication is actually the result of an organization-level, rather than individual-level, process. I use the Gephi software package to perform all network calculations.

I operationalize the exploitation-oriented network as the co-patenting network of organizations either applying for or having received patents in green chemistry. For this network I take advantage of patents with multiple assignees to link organizations. Like the co-authorship network, the co-patenting network is organization-level since patents are often assigned to organizations rather than individual researchers. For example, discoveries by university-based researchers tend to be assigned to their respective universities and discoveries by firm-based researchers tend to be assigned to their respective firms. Table 8 summarizes the data I use to construct the green chemistry exploration and exploitation networks of the 168 firms in this study.

Table 8. Publication and patent collaboration summary

	Publications	**Patents**
Total Assignees/Authors	8740	21654
Assigned to/Authored by		
- Firm	775	19629
- University	6145	1601
- Government	1069	291
- Other	481	133
Firm Collaboration with		
- One partner	97	709
- Two partners	20	57
- Three or more partners	14	13
Firm Collaboration With		
- Firm	30	471
- University	99	220
- Government	6	53
- Other	12	53

Figure 16. Green chemistry co-publishing and co-patenting

To measure ego network closure I use Gephi's equivalent of Borgatti's (1997) transformation of Burt's original measurement technique, where the degree of closure in a given firm's network is defined as its ego network density exclusive of connections to the focal firm itself. Although I measure ego network closure as a continuous variable with an upper bound of 1, some studies treat ego this measure of ego network density a binary variable. For example, Burt (1992) defines a node in network to occupying a "structural hole" if it scores a zero on this measure (i.e. if a node functions as the only connection between its partners).

Past research used a Herfindal-Hirschman index to measure tie-type diversity (e.g. Blau, 1977; Powell et al., 1996), but since each network considered here has only one tie type (co-publishing or co-patenting, respectively), I use a simpler and more intuitive measure of diversity. Specifically I measure diversity as the count of non-firm organizations in a given firm's ego network. As a first step in calculating this measure, I assigned one of three organization types to each organization in my sample. These three categories, firms, educational institutions (including universities, colleges and technical institutes), and government agencies proved virtually exhaustive of the organizations involved in either publishing or patenting in green chemistry. Since my focus in this dissertation is on firms, I count the number of non-firm organizations a firm collaborates with in a given year as its measure of network diversity

Although there are more complex measures of ego network diversity used in past research, these measures would add little if any information beyond the simple measure I calculate here. Specifically, firms active in green chemistry tend to collaborate with either educational institutions or government agencies on particular publications or patents;

rarely do they collaborate with both. For example of the 898 collaborative patents in green chemistry, only two feature all three types of organizations as assignees. As a result, a measure that can distinguish if a firm's ego network skews toward one type of organizations or another is not needed in this particular study. Similarly, in the vast majority cases a firm collaborates with only one or two other organizations, meaning a measure that can capture an organization type's "market" share of a firm's ego network will also add virtually no additional information to the simple count measure I use in this dissertation. These more complex measures certainly have valid applications, but the particular setting of green chemistry does not appear to be one of them

The two prior measurements focus on the structure and composition of a firm's ego network, but a central theme in network research is the value of looking beyond ego networks to a firm's position within a boarder network. To capture this influence I use Gephi to calculate a "closeness" centrality score for each-firm year. Gephi measures closeness centrality in line with Freeman's (1979) original definition by which higher measures indicate great geodesic distances from other network members. This contrasts to other centrality measure such as eigenvector centrality, where higher scores indicate a node is more central in a given network. Compounding this confusion, high profile studies in management research using network analysis employ an inverted version of Freeman's (1979) original definition (e.g. Powell et al., 1996, pg. 126).

Closeness centrality is one of a family of centrality measures designed to capture the influence of network participants beyond a firm's ego network. Of the various centrality measures develop in the network literature, closeness centrality is particularly well suited to the context of innovation (Borgatti, 2005). This measure also fits well with organizational ambidexterity since closeness centrality affects the speed with which novel information in a network reaches a particular firm.

Control Variables

My central premise in this dissertation is not that network characteristics are the only determinants of ambidexterity in technology commercialization; rather they are one of myriad factors that affect this important organizational activity. So to isolate the effects of these network characteristics on technology commercialization, I propose a number of control variables. Fortunately, most of the firms active in green chemistry are large chemical or pharmaceutical companies for which secondary data are widely available, either because they are publicly traded or because private-company databases cover them.

Past research indicates firm capabilities are a significant predictor of successful technology commercialization (e.g. Teece, 1986; Pennings & Harianto, 1992; Teece, Pisano & Shuen, 1997). To control for firm capabilities I include control variables for overall firm green chemistry publications, patents applications, and revenue. In addition to these explicit control variables, I control for a number of aspects of firm publishing (patenting) including a firm’s annual number of collaborative publications (patents) and number co-publishing (co-patenting) partners.

Table 9. Variables and data summary

Variable	**Type**	**Description (Conceptual)**	**Description (Operational)**	**Type**	**Source(s)**
Exploration	DV	Discovery of a Potentially Valuable Technology	Green chemistry patent assigned to a focal firm	Count	FPO &USPTO Databases
Exploitation	DV	Successful Technology Commercialization	Nomination for Presidential Green Chemistry Challenge Award	Count	USEPA
Ego Network Closure	IV	Access to redundant/novel information	Firm ego network density, excluding tie to focal firm	Continuous, positive, upper limit equal to 1	SciFinder Scholar, ISI Web of Sci., FPO
Ego Network Diversity	IV	Access to redundant/novel information	Count of non-firm organizations in a focal firm's ego network	Count	SciFinder Scholar, ISI Web of Sci., USPTO
Closeness Centrality	IV	Speed of access to redundant/novel information	Sum of geodesic distance	Count	SciFinder Scholar, ISI Web of Sci., USPTO
Firm Inventiveness (in general)	CV	Firm propensity/skill in conducting applied research	Patent Applications	Count	FPO and USPTO
Firm Resources	CV	Internal resources available to explore or exploit	Firm Revenue	Continuous	Mergent & Privco

The particulars of this setting also provide some implicit control. For example the timeframe of this dissertation, 1997-2011, does not contain any major shocks in the chemical industry. In contrast, earlier periods featured radical regulatory changes such as major amendments to the Clean Air Act in 1977 and 1990, and high-profile accidents, such as at Union Carbide's Bhopal fertilizer plant in 1984.

Hypotheses

In this section, I developed specific hypotheses that I bring to an empirical test in the next chapter. These hypotheses map directly to the theoretical propositions offered in the earlier chapter, but here I translate the abstract language of the propositions into hypotheses specific to the context of green chemistry. In the first portion of this section, I introduce my hypotheses linking network characteristics to firm exploration outcomes. In the second portion of this section, I introduce my hypotheses linking network characteristics to firm exploration outcomes. Last, I introduce three configurational hypotheses that I later test in a model integrating exploration and exploitation into a single dependent variable.

Exploration Hypotheses

My first two hypotheses formalize propositions on the effect of network closure on exploration in both the short and long-term. Specifically, I predict that redundant network ties offer quick access to a limited amount of novel information, but that the limited novel information in such a network will lead to reduction in successful exploration in the long-run. As a result, I hypothesize:

> H1: *The higher the level of closure in a firm's green chemistry publication ego-network, the higher that firm's rate of green chemistry patenting*

> H2: *The higher the accumulated level of closure in a firm's green chemistry publication ego–network the lower that firm's rate of green chemistry patenting*

I base my third hypothesis on past research showing that different types of organizations tend to produce different types of information. In the context of technology commercialization, the relevant organizations often include universities, government agencies, and private firms of varying types. All else equal, firms that collaborate with a wide a variety of different types of organizations should have higher rates of successful exploration, leading to my second hypothesis:

> H3: *The higher the number of non-firm organizations in a firm's green chemistry publication ego-network, the higher that firm's rate of green chemistry patenting*

My fourth hypothesis recognizes that network characteristics beyond a firm's ego network may also influence its exploration outcomes. The network perspective offers a unique lens for examining such beyond ego-network influence on a focal actor. One such beyond ego-network measure that I predict will influence exploration is a firm's position within a broader network. Consistent with past research, I use a firm's average geodesic distance from all other nodes in the green chemistry publications network as a proxy for how fast that firm will learn of novel information generated by other network members. Given common features of patent systems discussed earlier, a firm that can learn of discoveries by other network member faster will have higher rates of successful exploration. As a result, I hypothesize:

> H4: *The lower a firm's average geodesic distance to other members of the green chemistry publications network, the higher that firm's rate of green chemistry patenting*

Taken together, these four hypotheses capture various ways a focal firm might access the kind of novel information that lies at the heart of exploration. Although all three of these mechanisms (closure, diversity, and centrality) affect the flow of novel information, they do so in differing ways. For example, a diversity of partners affects the novelty information because of the differences in nodes, while closure affects the novelty of information because of how these nodes are linked. As a result, I predict that these three mechanisms will help explain a firm's exploratory outcomes independently of one another.

Exploitation Hypotheses

Similar to my first two exploration hypotheses, I base my next two hypotheses on the proposition that network closure affects exploitation differently in the short and long-terms. Specifically, I predict that the benefits of closure for exploitation outlined earlier manifest in the long term, but the costs of such relationships must be paid in the short term. This split between the long term and short term effects leads to my first to exploitation hypotheses:

> H5: *The higher the level of closure in a firm's green chemistry patenting ego-network, the lower that firm's rate of Presidential Green Chemistry Challenges Award nominations*

> H6: *The higher the accumulated level of closure in a firm's green chemistry patenting ego–network the higher that firm's rate of Presidential Green Chemistry Challenges Award nominations*

My next hypothesis is the mirror image of Hypothesis 3. As useful as collaborating with a diverse set of partners is for accessing novel information, this same diversity may cause conflict. Specifically, the organizations involved in technology commercialization have differing goals: universities strive to discover new knowledge, private firm seek to make profits, and government agencies have myriad goals ranging from economic development to national defense. These goals are not necessarily incompatible, but they may make it more difficult for a firm to successfully exploit a given technology, leading to the following hypothesis:

> H7: *The higher the number of non-firm organizations in a firm's green chemistry publications ego-network, the lower that firm's rate of Presidential Green Chemistry Challenges Award nominations*

Similar to Hypothesis 4, my next hypothesis draws on a network lens to move beyond analyzing a firm's ego network by predicting the effect of closeness centrality on exploitation. In contrast to Hypothesis 4, a firm in an exploitation-oriented network should benefit from greater geodesic distance from other network members. This occurs because other network members will be slower to learn of what a firm in the far reaches of the network is trying to commercialize and how. Furthermore, this effect should be especially pronounced in industries where lead-time is important to capturing and maintaining competitive advantage, such as with the chemical and pharmaceutical firms accounting for much of the activity in green chemistry.

H8*: The higher a firm's geodesic distance from other members of the green chemistry patenting network, the higher that firm's rate of Presidential Green Chemistry Challenges Award nominations*

As a whole, these four hypotheses predict how a firm's network characteristics should influence the certainty and stability of information needed for successful exploitation. By similar logic to my exploration hypotheses, the mechanisms featured here affect the nature of information received by a focal firm largely through different channels. As a result, I also predict these mechanisms will help explain a firm's explorative outcomes independently of one another.

Combined Hypotheses

I base my next set of hypotheses on propositions 9a through 9c. These predict that certain configurations of network characteristics will prove advantageous to firms seeking to both explore and exploit. For sake of interpretation, I limit these interactions to the same network characteristics measured in exploration and exploitation networks, respectively. Since I predict these configurations will affect both exploration and exploitation, I test these hypotheses by developing a novel "ambidexterity index" described in the "combined model" section of the next chapter.

H9a: The less closed a firm's green chemistry publication ego network and the more closed a firm's green chemistry patenting ego network, the higher its ambidexterity index score

H9b: The more diverse a firm's green chemistry publication ego network and the less diverse a firm's green chemistry patenting ego network, the higher its ambidexterity index score

H9c: The lower a firm's closeness centrality in its green chemistry publication network and high a firm's closeness centrality in its green chemistry patenting network, the higher its ambidexterity index score

Table 10 summarizes the eight hypotheses that form the core of this dissertation. As a whole, they predict a "sign switching" pattern, where the same network characteristics, for the same firms, in the same field, will have the opposite effects on outcomes depending on whether a firm is exploring or exploiting. The next section describes the statistical approach I use to bring these hypotheses to an empirical test.

Table 10. Hypotheses summary

	Exploration Outcomes	Exploitation Outcomes
Ego Network Closure – Short-term	+ (H1)	- (H5)
Ego Network Closure – Long-term	- (H2)	+(H6)
Ego-Network Diversity	+ (H3)	-(H7)
Closeness Centrality	- (H4)	+(H8)
	Ambidexterity Outcomes	
Exploration Closure x Exploitation Closure	- (H9a)	
Exploration Diversity x Exploitation Diversity	- (H9b)	
Exploration Centrality x Exploitation Centrality	- (H9c)	

Statistical Procedures and Model

Since the dependent variables (patent counts and PGCCA nominations) I use in this dissertation are count variables, the standard Ordinary Least-Squares (OLS) model is not an adequate estimation procedure. One key assumption underpinning the OLS model is that the dependent variable can assume any value, positive or negative. Count data are both non-negative and integer, thereby violating this key assumption of OLS and leading to special estimating problems (Kennedy, 2008). As a result, maximum likelihood approaches are almost always used in estimating models featuring count data for dependent variables (Kennedy, 2008).

Maximum likelihood models are a group of statistical procedures which determine if an observed sample of data are more likely to have come from a "real world" characterized by one set of parameter values rather than a "real world" characterized by any alternative set of parameter values (Kennedy, 2008). In other words, a maximum likelihood estimate is the set of parameter values that has the highest probability of obtaining the observed sample. In addition to being appropriate to use with count dependent variables, maximum likelihood estimations exhibit a number of other desirable properties. According to Kennedy (2008), the maximum likelihood estimators are consistent in addition to being asymptotically unbiased, efficient, and normally distributed; with its only theoretical drawback being the assumption of a normally distributed error term. Historically, maximum likelihood models have seen limited use simply because of their high "computational costs", however modern statistical software and more powerful computers have largely overcome these issues (Kennedy, 2008).

Although maximum likelihood models are appropriate for a number of situations where dependent variables are restricted to positive integers, such as dichotomous dependent variables, Kennedy (2008) recommends two specific models for count dependent variables. Specifically, both Poisson and negative binomial models are appropriate for estimation of count data. Kennedy (2008), gives examples including numbers of children in a family, doctor visits, industrial accidents, and patents as appropriate applications of these count variable specific maximum likelihood models. Such models have also become increasing common in management research. For example, Stuart (2000) uses a Poisson estimator to predict firm patenting in the semiconductor industry as a function of a focal firm's alliance partners' characteristics, and Hess & Rothaermel (2011) use a negative binomial estimator to measure the innovation performance of pharmaceutical firms as a function of resource combinations at various points in the value chain.

In this dissertation, both dependent variables are relatively rare, meaning firm-years often have a value of zero for both outcomes. As a result, these particular dependent variables are "over dispersed," meaning their variance is greater than their mean; a characteristic common in count data (Kennedy, 2008). In circumstance of over dispersion, a negative binomial model is preferred to a Poisson model, since the latter assumes the mean of a given variable to equal its variance. Violating this assumption does not affect the consistency of coefficient estimates, rather it introduces bias into the estimation of their variances (Kennedy, 2008). In addition to being the appropriate model to use for over dispersed count dependent variables, negative binomial models are also compatible with fixed and random effects specifications. These specifications help account for unobserved heterogeneity (Cameron and Trivedi, 1986; Greene 2003), which is likely in this dissertation's context of technology commercialization.

As with many empirical settings, organizations involved in technology commercialization undoubtedly possess considerable heterogeneity unobservable to researchers. Such unobserved heterogeneity will produce biased estimators using OLS unless these unobserved variables are completely uncorrelated with the included explanatory variables (Kennedy, 2008). There are two primary ways to account for such unobserved heterogeneity, both of which require panel data such as I use in this dissertation.

The first approach, the fixed effects estimator, effectively assigns a dummy variable to each individual (or organization) in a given sample. This allows each individual to have a unique intercept that accounts for any unobserved heterogeneity. Although the fixed effects estimator effectively solves the unobserved heterogeneity problem, it does have a number of drawbacks. First, implicitly including n-1 dummy variables means loosing n-1 degrees of freedom leading to less efficient estimations. Second, the fixed effects transformation involves subtracting a variable's value in a given time period from its average over the sample period, meaning the coefficient for any variable that does not change over the sample period is by definition zero (Kennedy, 2008). For example, in the context of this dissertation, the influence of variables such as whether a firm is publically traded or its country of origin cannot be estimated using the fixed-effects approach.

The second method to account for unobserved heterogeneity is the random effects model. This approach also assigns differing intercepts to each individual (or organization) in a sample, but does so by assigning intercepts randomly from a pool of possible intercepts (Kennedy, 2008). Although the random effects model overcomes the relative inefficiency and inability to estimate time-invariant variables for the fixed effects model, it also features a number of limitations. The most serious of these is the random effects model can generate biased results if there is correlation between the error term and any of the explanatory variables. Kennedy (2008) offers a concrete example of this limitation by describing a research design that regresses wages on schooling. In this scenario, if ability is unobserved and also correlated with schooling, it will cause the random effects model to generate a biased estimator.

A well-established way to decide between fixed and random effect approaches to dealing unobserved heterogeneity is to apply a version of the Hausman test (Kennedy, 2008). This test tests the null hypotheses that fixed and random effects models are insignificantly different from one another. It does this by including explanatory variables transformed under both approaches into the random effects estimating equation and measuring whether or not the coefficients for the fixed effects transformed explanatory variables differ significantly from zero. In this dissertation, the Hausman test indicates that the fixed effects approach is preferred for all except for one the models. Since the fixed effects approach is more conservative and robust to both selection bias and for when a sample accounts for large portion of given population (Kennedy, 2008), I use this approach for dealing with unobserved heterogeneity in this dissertation. Taken together, using count data as a dependent variable, the over-dispersed nature this type of data, and the need for a robust approach to deal with unobserved heterogeneity, point to a negative binominal with fixed-effects model as the preferred statistical estimation procedure for this dissertation.

The preceding section of this chapter shows why a negative binomial fixed effects model is the appropriate estimating procedure for this dissertation. The next section shifts focus to the explanatory variables I employ in this dissertation. Specifically, it describes the lag structure and normalization procedure I use for transforming the raw independent variables described earlier.

Lag Structures

To help lessen the threat of simultaneity bias and enable causal inference, I follow previous studies in lagging network measures and control variables (Hess & Rothaermel, 2011; Gulati, 1999; Stuart, 2000). This approach, called Grainger-Causality, attributes causality to an independent variable X, if past values of X predict current values of a dependent variable Y (Kennedy, 2008). Although this approach is simple and intuitive, it provides little guidance to as to what the appropriate length of lag is for a particular variable in a particular context. To determine an appropriate lag structure for this dissertation I both rely on past research on technology commercialization and calculate an average lag length for the particular data used in this dissertation.

The key lag for my exploration model is between the green chemistry patenting I use as the dependent variable and the network measures used as explanatory variables drawn from the green chemistry co-publication network. Here, understanding the appropriate lag structure requires a nuanced understanding of how these two types of empirical outcroppings become associated with a particular time period. For the patent data, I chose to use a given patent's filling date rather than its publication date in an effort to pinpoint the time frame of the actual inventive activity described in the patent document as closely as possible. Patent publication dates can be influenced by any number of factors unrelated to the invention itself or its assigned organization, possibly leading to spurious correlations. For example, Griliches (1990) finds government funding of patent offices can significantly affect the lag between the initial filling of a patent and its subsequent publication.

The second part of determining an appropriate lag structure for my exploration model is unpacking the relationships between inventive activity, scientific publications, and patent fillings. Fortunately, past research has helped investigate these relationships in a fair amount of detail. Specifically, firms tend to file for a patent(s) on a given invention before publishing academic papers related to this particular invention. The reason for this is twofold. First, disclosing a new invention in an academic publication or other "public disclosure" before filling a patent limits the legal recourse for the inventing firm if its competitors copy the invention describe in the publication (CalTech, 2013). In the US there is a one-year "grace period" to file a patent application after an initial public disclosure. However, under most other patent systems, including those of many European Union countries, any public disclosure including academic publication, leads to an immediate loss of patent eligibility (CalTech, 2013).

Second, even if a firm submitted a patent application and a scientific article simultaneously, the probability of the patent filling date being earlier than the article publication date is very high because of the lags associated with academic publication. However, we would expect the opposite pattern if comparing publication dates for both documents because the submission-to-publication lags tend to be longer with patents than with publications, at least in the physical sciences (Murray & Stern, 2007). For example if a pharmaceutical firm invents a new molecule during year 0, files a patent application and submits an academic publication in year 1, the patent document will record “year 1” as the filing the date, but the eventual publication will likely show “year 2” (or later) despite being linked to the same underlying inventive activity as the patent. Some journals do report “originally submitted” dates, which would help alleviate this problem, but this practice is far from universal.

The end result is that not lagging the publication network variables actually creates an appropriate lag. This counterintuitive situation occurs because relying on the publications date of a given academic paper to assign it to a particular time period already includes a lag in the form of the delay from initial (but unobserved) submission to eventual (observed) publication. In the context of this dissertation, using a firm’s publication activity in time “t” to predict its patenting activity in the same period is consistent with the Granger-causality criteria, since publications in time “t” actual capture inventive activity in time “t-1” and earlier.

Determining an appropriate lag structure for my exploitation model is perhaps more intuitive than for exploration model, but it is also less studied in past research. Using technologies nominated for PGCCAs as a dependent variable is one of the key differentiating features of this dissertation, however because this is a novel approach to measuring innovation, the existing literature provides little guidance for an appropriate lag structure. Although there is a dearth of guidance in developing specific lag structures, there is general recognition that inventive activity affecting a given outcome variable is not necessarily restricted to the time period immediately preceding the observed outcome (Pakes & Griliches, 1984; Pakes & Schankerman, 1984; Stuart, 2000). For example, in his study of alliances in the semiconductor industry Stuart (2000) argues that including only alliances existing in the previous year "may not allow a sufficient interval of time for the benefits of a cooperative strategy to manifest in the observed performance measures." To address this issue Stuart uses a five-year window lagged by one year (i.e. covering periods t-1 to t-5). Similarly, Pakes & Griliches (1984) estimate an "R&D gestation" lag defined as the length of time from the start of an R&D project until it generates revenue.

These past studies demonstrate the value of both "taking time seriously" and developing appropriate lag structures in technology commercialization research. However, neither the alliance-to-patent nor the R&D-to-initial revenue lags investigated in these past studies provides an exact template for my exploitation model. Conceptually, the lag between a patent filling and prize nomination is similar to the "R&D gestation" lag mentioned earlier, however the patent-nomination lag both starts later (at patent filling rather than R&D project launch) and ends later (demonstrating significant economic and environmental performance rather than first sale) in the commercialization process.

As a result, I develop a context specific lag structure by drawing a random sample of 30 PGCCAs nominations and matching these to specific patents. I was able to do this because some nominations explicitly mention the patent number associated with a particular technology, while other nominations draw nearly verbatim from the description of a technology in its associated patent documents (for an example of this overlap see

Appendix 1). For some of the nominated technologies, I was unable to find an associated patent. This could be because these firms protect their technologies by some other means such a trade secrets (Ziedonis, Forthcoming; Cohen at al., 2000). Alternatively, it could simply be because I do not posses the technical expertise to match a given technology to its associated patents in the absence of a high degree of overlap in the descriptive language used in each document.

Although the first reason is certainly a possibility, it seems unlikely given the high patenting propensity in the industries involved in green chemistry (Teece, 1986; Cohen et al., 2000). Furthermore, the detailed descriptions included in the PGCCA nomination documents directly contradict an intellectual property protection strategy based on trade secrets. As a result, the failure to match some nominations to their associated patents is likely a consequence of my limited technical chemistry background and seems unlikely to correlate in a systematic way with the lag between the patent filling and eventual nomination of a given technology. The lag between patent filing and prize nomination amongst these 30 patent-nomination pairs ranged from 1 to 8 years with an average of 3.8 years and 87% of the sampling falling within a five year window covering years 2 to 6. Based on this sample I use a five-year moving average lagged by 1 year for the control and explanatory variables in my exploitation model.

Past research on technology commercialization shows the importance of developing lag structures that fit both a particular context and set of research questions. Although the common practice of lagging variables by one time period (e.g. Hess & Rothaermel, 2011) provides some evidence of Granger-causality, it should not be applied mechanistically especially in light of contradictory information offered by a specific empirical setting (Stuart, 2000). In following this advice, I developed distinct lag structures for the two models I test in this dissertation. I do not lag the explanatory variables in the exploration model, not because the independent variables instantaneously influence the dependent variable, but rather because the particular paper trails I use in this dissertation for explanatory variable features an *inherent* lag. In contrast, for the exploitation, model I use a 5-year window lagged by one year. This approach is both roughly consistent with past research that reaches further back than the common one period lag (e.g. Stuart, 2000) and appears to fit well with the green chemistry context.

Standardizing Explanatory Variables

The explanatory variables I use in this dissertation tend to be measured on dramatically different scales. For example, the annual revenue for many firms in my sample measure in the billions of dollars, while their measures of ego network closure have an upper bound of 1. To aid in comparison of statistical results I rescaled all explanatory variables using the "standardized variable" routine in STATA (UCLA Statistical Consulting Group). This procedure, also called a "z-score", rescales a variable to have a mean of zero and standard deviation of one. A rescaled variable's coefficient measures its difference from the mean of the original variable in standard deviations. This allows for reasonably straightforward interpretation of regression coefficients as a one standard deviation change in a given variable leads to a unit change in the dependent variable equal to the independent variable's coefficient value.

CHAPTER V

EMPIRICAL RESULTS

In this chapter, I test the influence of network characteristics on exploration and exploitation in green chemistry by the 168 firms in the sample described earlier. I divide this chapter into five sections beginning with statistics describing the data sources introduced in chapter IV. Second, I use regression analysis to test Hypotheses 1-8 developed in chapter III. For reasons laid out in the previous chapter, I use a negative binomial maximum likelihood, rather than the standard OLS, statistical model due to both my dependent variables being "counts". I split the regression analysis into two sections. In the first section, I test the effect of network characteristics on exploration and exploitation, respectively. In the second section, I combine both exploration and exploitation into a model of organizational ambidexterity and test long-run versions of the explanatory variables drawn from the separate models of exploration and exploitation. I conclude this chapter with a summary of my empirical findings.

Investigating Network Influence on Exploration and Exploitation

Descriptive Statistics

Table 11 offers descriptive statistics and correlations for the variables included in my exploration model. None of these correlations reaches levels of 0.8 or 0.9 suggested by Kennedy (2008) as the thresholds for high correlation, with one exception. In this case, the control variables *Collaborative Publications* and *Number of Publication Partners* have a 0.91 correlation. As Kennedy points out with the example of estimating Cobb-Douglas production functions, variables with such high levels of correlation can still produce useful estimates and often simply leaving both variables in the model is the preferred course of action. Another option Kennedy suggests is to simply drop one of the highly correlated variables. I followed this suggestion in results not reported here, and found that omitting either *Collaborative Publications* or *Number of Publication Partners* does not affect the direction or statistical significance of my results. Therefore, I retain both variables.

Table 12 reports descriptive statistics and correlations for the variables in my exploitation model. Unlike my exploration model none of these variables reach Kennedy's (2008) threshold for high correlation. The two that come the closest are *Collaborative Patents* and *Number of Patenting Partners,* and *Patent Network Diversity* and *Number of Patenting Partners,* with correlations 0.75 and 0.77 respectively. As in the case of my exploration model and for similar reasons, I chose to include all three of these variables in my exploitation model. I made this choice both because correlated variables by themselves do not cause biased estimates (Kennedy, 2008) and because the high correlation of these variables is entirely consistent with the constructs they are measuring. In other words, the notion that higher numbers of collaborations is associated with higher numbers of partner organizations and that this larger pool of partners allows for more diversity is largely consistent with technology commercialization as a context.

Table 11. Descriptive statistics and correlations, exploration model

	Mean	S.D.	Min	Max	1	2	3	4	5	6	7	8	9	10
(1) GC Patenting	1.40	3.44	0	40	1.00									
(2) Revenue	16449.13	41183.94	0	477359	0.20	1.00								
(3) Patent Applications	232.66	751.65	0	14562	0.44	0.26	1.00							
(4) GC Publications	0.11	0.43	0	5	0.07	0.07	0.02	1.00						
(5) GC Collaborative Pub.	0.07	0.45	0	6	0.01	0.05	-0.01	0.45	1.00					
(6) # of Pub. Partners	0.09	0.56	0	9	0.00	0.04	-0.01	0.42	0.91	1.00				
(7) Pub. network diversity	0.07	0.37	0	3	0.05	0.05	-0.01	0.38	0.63	0.61	1.00			
(8) Network closure	0.01	0.10	0	1	0.01	0.06	0.00	0.23	0.64	0.68	0.44	1.00		
(9) Cumulative network closure	0.04	0.20	0	2	0.00	0.12	-0.01	0.24	0.46	0.47	0.34	0.58	1.00	
(10) Closeness Centrality	0.21	1.01	0	12.30	0.01	0.12	0.01	0.16	0.16	0.16	0.12	0.11	0.37	1.00

Table 12. Descriptive statistics and correlations, exploitation model

	Mean	S.D.	Min	Max	1	2	3	4	5	6	7	8	9	10
(1) PGCCA nominations	0.15	0.50	0.00	8.00	1.00									
(2) Revenue	15656.04	38014.46	0.00	390670	0.00	1.00								
(3) Patent applications	216.78	667.81	0.00	9278	0.01	0.29	1.00							
(4) GC patents	1.41	3.13	0.00	35.00	0.07	0.24	0.43	1.00						
(5) GC Collaborative patents	0.09	0.32	0.00	4.00	0.06	0.12	0.19	0.26	1.00					
(6) # of Patent Partners	0.06	0.20	0.00	2.00	0.06	0.15	0.15	0.25	0.75	1.00				
(7) Patent network diversity	0.05	0.17	0.00	2.00	0.07	0.11	0.11	0.25	0.67	0.77	1.00			
(8) Network closure	0.00	0.04	0.00	1.00	-0.04	0.04	0.01	0.03	0.37	0.50	0.28	1.00		
(9) Cumulative network closure	0.04	0.21	0.00	2.00	-0.06	0.05	0.01	0.05	0.48	0.53	0.37	0.64	1.00	
(10) Closeness Centrality	0.05	0.16	0.00	1.50	0.07	0.10	0.07	0.19	0.72	0.85	0.82	0.40	0.47	1.00

Analysis of Exploration

The exploration model tests my hypotheses relating network characteristics to exploration outcomes. In this model, I consider three specific network characteristics, ego-network closure, ego-network diversity, and closeness centrality. Table 13 reports the negative binomial regression with fixed-effects results testing the relationship between these characteristics and green chemistry patenting. In model 1, I include only control variables to provide a baseline model against which I compare subsequent models. In models 2 and 3, I add my ego-level and beyond ego-level variables separately. Model 4 includes both sets of variables in a single estimation.

I compare these models using a likelihood ratio (LR) test. This test compares the goodness-of-fit between two models, often a complete model and a "competing" model with fewer parameters. The LR test is assumed to follow a chi-squared distribution. Its degrees of freedom equal the difference in the number of parameters between the competing models (Greene, 2003). Applying this test to the exploration model shows that models 2 and 3 independently offer improved fit over the baseline model, and model 4 improves this fit further still. All of these changes are significant at the 0.01 level.

Table 13. Regression results, exploration model

Dependent variable	Green chemistry patenting Model 1	Green chemistry patenting Model 2	Green chemistry patenting Model 3	Green chemistry patenting Model 4
Constant	0.458*** (0.104)	0.462*** (0.104)	0.527*** (0.113)	0.553*** (0.115)
Revenue	-0.113** (0.020)	-0.115** (0.047)	-0.115** (0.049)	-0.132*** (0.051)
Patent applications	0.125*** (0.028)	0.126*** (0.020)	0.118*** (0.021)	0.119*** (0.021)
Academic publications	-0.045 (0.030)	-0.053* (0.030)	-0.037 (0.031)	-0.035 (0.031)
Collaborative academic publications	0.0446 (0.071)	-0.005 (0.073)	0.081 (0.073)	-0.011 (0.085)
Publication partners	-0.064 (0.067)	-0.065 (0.066)	-0.088 (0.069)	-0.129* (0.070)
Publication network diversity		0.082** (0.033)		0.068** (0.035)
Publication network closure		0.073** (0.032)		0.068** (0.032)
Cumulative publication network closure		-0.109** (0.055)		0.095 (0.086)
Publication network closeness centrality			-0.104*** (0.038)	-0.176** (0.115)
Log likelihood	-1814.97	-1807.72	-1630.34	-1623.99
Wald chi-square	46.43***	58.85***	48.88***	61.27***
Improvement over base (ΔX^2)		14.5***	369.26***	381.96***

The logic underpinning my exploration hypotheses is that a firm's network characteristics will affect its access to the type of novel information at the heart of exploration. In hypothesis 1, I predict that firms with high network closure will have access to novel information in the short-term, leading to higher levels of successful exploration. In the context of green chemistry, this means firms that co-publish with organizations that are themselves connected through co-publishing will have higher rates of patenting. The positive and statistically significant coefficients in models 2 and 4 for *publication network closure*, support Hypothesis 1.

Hypothesis 2 is the long-term counterpart of Hypothesis 11. A highly closed network appears to offer access to a certain amount of novel information in the short-term, however Hypothesis 2 predicts that repeated collaboration with otherwise interconnected partners will eventually lead to a decline in successful exploration. This occurs because organizations that are themselves connected tend to hold similar information, so collaborating with these organizations will eventually provide redundant information to the focal firm. The statistically significant negative coefficient for *Cumulative publication network closure* in model 2 supports Hypothesis 2, showing that firms with more closed networks in the past have lower rates of patenting in the present. However, this coefficient is not significant in model 4, attenuating the support for H2 found in model 2. Taken together these results provide partial support for H2.

In Hypothesis 3, the underlying mechanism is still a focal firm's access to novel information, but here this novelty is generated by the diversity of its collaborating organizations rather the nature of the links between them. Specifically, in Hypothesis 3 I predict a focal firm with a more diverse ego network, as measured by organization type, will have access to more novel information and therefore be more successful at exploring. For this dissertation, Hypothesis 3 predicts firms that tend to collaborate more often with universities and government agencies will have higher rates of patenting in green chemistry. The statistically significant and positive coefficient for *Publication network diversity* in both models 2 and 4 supports Hypothesis 3.

Hypothesis 4 differs from the previous hypotheses by moving beyond ego-network level measures to test the relationship between closeness centrality and exploration. Specifically, Hypothesis 4 predicts that firms with lower closeness centrality (i.e. firms with, on average, fewer links separating them from other network members) will learn of novel information faster than other firms in the network. This faster access to novel information should help a focal firm keep pace with the state-of-the-art and learn of possible fruitful areas of exploration. In the context of green chemistry, Hypothesis 4 predicts firms that tend to co-publish with organizations near the core of the network should have higher rates of patenting. In this case, *less* distance should be associated with *higher* levels of patenting, so the statistically significant negative coefficient for *publication network closeness centrality* supports Hypothesis 4.

As a whole, the results in Table 13 largely support the hypothesized relationships between network characteristics and exploration. Specifically, network characteristics that tend to provide novel information in a timely manner to a focal firm lead to higher rates of successful exploration as measured by patenting. Furthermore, these results show the importance of looking beyond ego-level measures, as adding the single beyond ego-level variable, *publication network closeness centrality,* provides a larger increase in model fit than the other independent variables combined. Next, I perform a similar series of tests on my exploitation model, using co-patenting to generate inter-organizational networks and PGCCA nominations as the measure of successful exploitation.

Analysis of Exploitation

My exploitation model tests hypotheses relating network characteristics to exploitation outcomes. In this model, I consider the same three network characteristics as in my exploration model, ego-network closure, ego-network diversity, and closeness centrality, but I do so in a network formed by co-patenting rather than co-publishing. Table 14 reports the negative binomial regression with fixed effects results testing the relationships between these characteristics and nominations for Presidential Green Chemistry Challenge Awards. Similar to my exploration model, model 1 includes only control variables to provide a baseline against which I compare subsequent models. In models 2 and 3, I add my ego-level and beyond ego-level variables separately. Model 4 includes both sets of variables in a single estimation. Again, I use the likelihood ratio (LR) statistic to assess improvement from one model to the next.

Table 14. Regression results, exploitation model

Dependent variable	PGCCA Nominations Model 1	PGCCA Nominations Model 2	PGCCA Nominations Model 3	PGCCA Nominations Model 4
Constant	0.470 (.344)	0.593 (0.381)	0.399 (0.332)	0.434 (0.353)
Revenue	0.038 (0.232)	-0.067 (0.239)	0.039 (0.231)	-0.059 (0.235)
Patent applications	0.534* (0.298)	0.474 (0.292)	0.495* (0.279)	0.435 (0.271)
Green chemistry patents	-0.096 (0.091)	-0.054 (0.093)	-0.106 (0.090)	-0.056 (0.093)
Collaborative green chemistry patents	0.135* (.080)	0.137 (0.86)	0.120 (0.084)	0.084 (0.094)
Patenting partners	-0.153 (0.102)	0.105 (0.162)	-0.388*** (0.138)	-0.054 (0.168)
Patenting network diversity		-1.875** (0.902)		-0.444*** (0.162)
Patent network closure		--		--
Cumulative patent network closure		0.224** (0.110)		0.237** (0.110)
Patent network closeness centrality			0.338*** (0.125)	0.423*** (0.127)
Log likelihood	-556.17	-552.24	-552.79	-547.21
Wald chi-square	8.19	16.89**	15.18**	27.63***
Improvement over base (ΔX^2)		7.86**	6.67**	11.16***

In contrast to my exploration model, the logic underpinning this model is that network characteristics offering redundant information will lead to higher levels of successful exploitation. In Hypothesis 5, I predict that higher levels of closure in firm's ego network will lead to a lower likelihood of successful exploitation in the short-term. This may occur because networks with redundant ties likely have higher "setup" costs driven by the higher number of linkages relative to more open networks. Unfortunately, this hypothesis proved untestable in this sample because there was not enough annual variance in the closure variable for STATA to include it in the negative binomial estimation. As a result, H5 remains an open question.

Hypothesis 6 examines the same basic question as 5, but in the long-term rather than short-term. In this hypothesis, I predict a firm's ego network closure will lead to higher likelihood of successful exploitation. I propose this occurs because a closed network featuring many redundant ties provides a focal firm with the stability, predictability, limited opportunism, and opportunities for mutual monitoring crucial to successful exploitation. Although such a network requires more ties in the short-term, its pay off should be observable in the long-term. In the context of green chemistry, this means firms that have tended to collaborate with organizations who are themselves interconnected over time, should be more likely to be nominated for a PGCCA in a given year. The positive and statistically significant coefficient for *cumulative patent network closure* in both models 2 and 4 indicates that the more closed a firm's exploitation ego-network tends to be over time, the higher its rate of being nominated for PGCCAs, supporting Hypothesis 6.

As useful as a diverse set of collaborators appears to be for exploration, in Hypothesis 7 I predict such diversity will make successful exploitation more difficult. The reasoning here is organizations commonly involved in technology commercialization tend to have different goals producing non-redundant information. Although this non-redundant information aids exploration, I hypothesize these differing goals hampers exploitation because a group of collaborators cannot simply optimize on a single outcome measure. This does not mean a firm with a diverse set of collaborators will necessarily fail to successfully commercialization technologies; only that failure is more likely here than at an identical firm with more homogeneous collaborators. The negative and statistically significant coefficient for *patenting network diversity* in both models 2 and 4 indicate that organization type diversity in a firm's patenting ego-network leads to a lower rate of PGCCA nominations, supporting Hypothesis 7. This effect also grows considerably in size and statistical significance from the restricted model 2, to the full model 4.

Similar to Hypothesis 4, Hypothesis 8 moves beyond ego-level measures to examine the effect of closeness centrality on exploitation outcomes. In the case of exploration, being closer to other network members appear to help a focal firm rapidly learn about the exploratory activities of other network members, leading to higher rate of successful exploration. However in the case of exploitation, I hypothesize closeness centrality to have the opposite effect because being far away from other networks members will delay network members learning about the exploitative activities of the focal firm. As mentioned earlier, a higher closeness centrality score indicates a farther geodesic distance from a focal firm to other network members. As a result, I predict a higher closeness centrality score in the green chemistry co-patenting network will lead to higher rates of PGCCA nominations. The positive and statistically significant coefficient for *patent network closeness centrality* in both models 2 and 4 supports hypothesis 8.

As with my exploration model, the results in Table 14 largely support my hypothesized relationships between network characteristics and exploitation outcomes. The only exception is Hypothesis 5, which proved untestable given the combination of data sources, statistical model, and econometric software I use in this dissertation. In contrast to my exploration model results, the exploitation model does not exhibit a similar large jump in model fit when I add the closeness centrality variable. However, each model still does show a statistically significant improvement over the baseline model, with the combined model exhibiting the best fit for the observed data. In the next section, I describe a model designed to capture organizational ambidexterity in a single estimation. I use this “combined” model to test long-run version of the explanatory variables tested here and Hypotheses 9a through 9c.

Combined Model

Although past theoretical research on organizational ambidexterity focuses on how organizations can both explore and exploit effectively, empirical research in this area tends to test these constituent parts separately (e.g. Hess & Rothaermel, 2011; Rothaermel & Deeds, 2004). At least part of the difficulty in combining exploration and exploitation models in a single estimation is the appropriate dependent variable for such an effort is not clear for numerous reasons. First simply adding exploration and exploitation outcomes does not capture ambidexterity since such a measure would not distinguish between an ambidextrous firm and a firm that was simply very good at either exploration or exploitation. For example, in the context of green chemistry, such a measure could not distinguish a firm that both routinely patented and was nominated for PGCCAs from a firm that patented slightly more but was never nominated for a PGCCA.

A second issue with selecting a dependent variable capable of capturing both exploration and exploitation is these two activities are not always contemporaneous. Past studies are inconsistent as to whether ambidexterity requires simultaneous exploration and exploitations or if a firm can cycle between these two conflicting activities over time (e.g. Nickerson & Zenger, 2002; Burgelman, 2002; Siggelkow & Levinthal, 2003). If we accept both of these definitions its creates a problem for measuring ambidexterity using the common firm-year approach for constructing data panels. Specifically, using such an approach a firm with "Y" exploration and "Z" exploitation outcomes in time periods 1 and 2 would be ambidextrous. However, a firm with "2Y" exploration and no exploitation outcomes in time period 1, but no exploration and "2Z" exploitation outcomes in time period 2 would not be counted as ambidextrous despite producing the same outcomes over the same time period. Determining which, if either, of these patterns produce better long-term results is a separate empirical question, but this simple example shows that a measure which fails to count the second firm as ambidextrous is problematic.

To address both of these issues, I created an index of ambidexterity to use as a dependent variable in estimating this combined model. First, since PGCCA nominations are far more rare that green chemistry patents, I reweighted each variable according to its relative frequencies in a given year. PGCCA nominations are about ten times as rare as green chemistry patents, so without such reweighting a combined model would be little more than the exploration model with a slightly enlarged error term. To address the problem of non-contemporaneous exploration and exploitation I calculated a five-year moving average for both the reweighted green chemistry patenting and PGCCA nomination variables. Next, to avoid the issues created by adding these measures, I multiple their moving averages in a given year by one another. This index variable, while difficult to interpret, provides a measure of ambidexterity that at least plausibly accounts for its dual nature and temporal dynamics.

To estimate this combined model I use a different statistical approach than with this dissertation's two main models. The construction of this index variable means the dependent variable is no longer a count variable and cannot be estimated with a negative binomial model. Additionally, past exploration and exploitation activities are likely to correlate with such activities in the future, meaning there is likely cross-panel autocorrelation in this sample. To account for both of these issues, I estimate this model with a Generalized Least Squares, rather than the standard OLS, approach. As in previous models, I included firm fixed effects to account for unobserved heterogeneity.

The relationships I hypothesize between network characteristics and ambidexterity are the same as in the exploration and exploitation models independently. The main difference here is my attempt to "take time seriously" by creating an extended window in which to capture ambidexterity. For large firms the notion of doing no exploration or exploitation in a given year seems unlikely, however for smaller firms such cycling maybe the only feasible solution since successful exploitation may be needed to fund future exploration. Additionally exploratory and exploitative activities in large firms may wax and wane relative to one another over time, even if these firms are unlikely to completely neglect one of these activities in a give year.

To create this extended observation window, I measure all of the independent and control variables as 5-year moving averages. The two exceptions are the long-term ego-network closure measures in each network, which I leave the same as in prior models since these measures already incorporate information from previous time periods. Similar to previous models I lag all patent-based measures by two periods. This lag both reflects the lag from patenting to PGCCA nominations and helps alleviate issues arising from using contemporaneous patent-based measures to predict an index which itself consists half of patent outcomes. I also include only my long-term measures of ego-network closure, because my goal in estimating this combined model is to assess ambidexterity over a longer period of time.

As before, I add variables incrementally and assess changes in model fit in successive models as compared to a baseline model. Model 1 contains the combined control variables from my exploration and exploitation models. In model 2, I add the ego-level explanatory variables from both exploration and exploitation models. In model three I included the control and beyond ego-level variables from both models. Finally, in model 4 I combine both sets of variables from both exploration and exploitation models. Table 15 shows the results of these estimations.

Table 15. Regression results, combined model

Dependent variable	Ambidexterity index Model 1	Ambidexterity index Model 2	Ambidexterity index Model 3	Ambidexterity index Model 4
Constant	14.247*** (1.167)	14.946*** (1.177)	15.414*** (1.165)	15.823*** (1.169)
Revenue	-14.935 (10.800)	-16.509 (10.802)	-12.627 (10.767)	-14.556 (10.730)
Patent applications	4.903 (10.537)	2.626 (10.666)	2.289 (10.522)	0.772 (10.611)
Academic publications	-1.464 (2.483)	-3.209 (2.515)	-0.163 (2.528)	-1.472 (2.528)
Collaborative academic publications	30.178*** (3.846)	28.210*** (3.895)	33.021*** (3.901)	30.979*** (3.903)
Publication partners	-32.471*** (3.601)	-32.317*** (3.626)	-27.959*** (3.854)	-26.157*** (3.843)
Collaborative green chemistry patents	18.324*** (4.052)	19.654*** (4.106)	-20.308** (4.099)	20.511*** (4.099)
Patenting partners	9.943** (4.164)	12.134*** (4.515)		15.092*** (5.192)
Publication network diversity		7.524*** (2.430)		11.382*** (2.564)
Cumulative publication network closure		-6.079*** (2.117)		-5.872*** (2.098)
Patenting network diversity		-6.399* (3.546)		-3.999 (3.733)
Cumulative patent network closure		9.896** (4.953)		9.692** (4.913)
Publication network closeness centrality			-10.299*** (3.146)	-15.174*** (3.309)
Patent network closeness centrality			-10.814** (4.845)	-7.62 (5.090)
R-Square	0.123	0.141	0.135	0.1584
F-test	23.40***	17.43***	20.17***	16.83***

Rather than test new hypotheses, my goal in estimating this combined model of ambidexterity is to see if my previous hypotheses are both stable over an extended period of time and can fruitfully explain exploration and exploitation in concert as well as in isolation. Model 2 shows the relationships between the long-term versions of the ego-level explanatory variables and the ambidexterity index described earlier. The model as a whole is statistically significant and the pattern of results from the separate exploration and exploitation models hold. First, the statistically significant positive and negative coefficients for *publication network diversity* and *patenting network diversity*, respectively, show ego network diversity has opposite effects in firms co-publishing and co-patenting networks over time. This finding supports the notion that partner diversity aids in exploration but can inhibit exploitation. Second, the results for ego network closure exhibit similar consistency with the separate exploration and expiration models. Specifically, *cumulative publication network closure* and *cumulative patenting network closure* have opposite and statistically significant coefficients; supporting the notion that such closure may lead to success in exploitation but hamper exploration over time.

Model 3 tests the effect of firms' closeness centrality in both co-publishing and co-patenting networks on ambidexterity. Here, unlike the ego-level measures, the long-term results diverge somewhat from those presented earlier. In the green chemistry publication network, the coefficient for closeness centrality remains negative and statistically significant indicating that closer average geodesic distance to other network members increases ambidexterity. However, the coefficient for patenting network closeness centrality changes sign from the previous models while remaining statistically significant. This indicates that firms with lower average geodesic distance to other network members in the co-patenting network are more, rather than less, likely to be ambidextrous, although this result fails to hold in the fully specified model four.

Model 4 combines ego and beyond-ego level variables. These combined results are both statistically significant overall and offer an improvement over both the previous models. Again, the results of the separate exportation and exploitation models largely hold, with both closure measures, *publication diversity, and publication network closeness centrality* all exhibiting statistical significant coefficients of the predicted sign. The exception to this consistency are *patenting network diversity* and *patenting network closeness centrality*, which generate non-significant results in the model 4.

Configurational Hypotheses

In addition to testing the long-term versions of the explanatory variables from my exploration and exploitation models, this combined model also allows me to test the interaction effects predicted in hypotheses 9a-c. Each of these hypotheses predicts particular "configurations" of network characteristics should help a firm be ambidextrous overtime. To help with interpretation, I focus on two-way interactions between the same characteristics measured in different networks. For example H9a, predicts a negative interaction between ego network diversity in firms' co-publishing and co-patenting networks. The logic of this interaction is high levels of diversity have the inverse affect in each respective network, so a configuration with low diversity in a firm's patenting network and high diversity in a firm's publishing network should produce a negative interaction effect when used to predict ambidexterity. The logic underpinning the two other interactions is the same, since these network characteristics should also inversely relate to ambidexterity. Table 16 summarizes the results of the combined model testing these interaction terms.

Table 16. Regression results, configurational model

Dependent variable	Configurational Model 1	Configurational Model 2	Configurational Model 3	Configurational Model 4
Constant	15.886*** (1.169)	15.657*** (1.168)	15.816*** (1.169)	15.578*** (1.165)
Revenue	-14.533 (10.711)	-16.056 (10.779)	-14.878 (2.532)	-14.597 (10.712)
Patent applications	0.685 (10.592)	1.138 (10.645)	0.797 (10.625)	1.190 (10.562
Academic publications	-1.487 (2.529)	-1.306 (2.526)	-1.438 (2.532)	-1.451 (2.521)
Collaborative academic publications	30.914*** (3.904)	31.288*** (3.899)	31.046*** (3.901)	30.930*** (3.893)
Publication partners	-26.116*** (3.844)	-26.428*** (3.838)	-26.164*** (3.845)	-26.628*** (3.832)
Collaborative green chemistry patents	20.547 *** (4.101)	19.901*** (4.095)	20.421*** (4.105)	20.144*** (4.090)
Patenting partners	15.021 *** (5.195)	15.531*** (5.182)	15.156*** (5.196)	15.306 (5.177)***
Publication network diversity	11.601 *** (2.586)	11.176*** (2.562)	11.347*** (2.568)	11.470*** (2.577)
Cumulative publication network closure	-5.898 *** (2.099)	-5.970*** (2.095)	-5.899*** (2.010)	-5.843*** (2.092)
Patenting network diversity	-3.992 (3.734)	-4.429 (3.729)	-4.041 (3.736)	-4.525 (3.725)
Cumulative patent network closure	9.816 ** (4.917)	9.847** (4.909)	9.647** (4.918)	10.552** (4.907)
Publication network closeness centrality	-15.282*** (3.313)	-14.980*** (3.305)	-15.192*** (3.311)	-14.678*** (3.307)
Patent network closeness centrality	-7.616 (5.093)	-7.884 (5.079)	-7.592 (5.092)	-8.470* (5.080)
Publication Closure x Patent Closure	-1.914 (2.805)			-1.808 (2.815)
Publication diversity x Patent diversity		6.788** (2.850)		14.665*** (4.477)
Publication Centrality x Patent Centrality			1.084 (2.985)	-10.538** (4.700)
R-Square	0.159	0.1625	0.1585	0.167
F-test	15.65***	16.10***	15.63***	14.49***

Similar to the other ambidexterity models, I use a GLS regression with fixed effects to test these hypotheses. I start with model 1 and add the lagged interaction variables one at a time. These tests generate mixed results. The positive and statistically significant coefficient for the *network diversity* interaction term contradicts hypothesis 9b. Hypothesis 9a is also not supported because although the coefficient for the closure interaction term is the predicted sign, the coefficient is not significantly different from zero. In contrast, hypothesis 9c predicting a negative interaction between closeness centrality in these differing networks is supported.

In this section, I developed a novel ambidexterity index to allow for exploration and exploration to be meaningfully investigate in the same estimations. This index measure overcomes a number of theoretical and empirical issues facing researchers interested in organizational ambidexterity by capturing exploration and exploitation over time and combining them in such a way as to account for their relative frequencies and ensure that firms are in fact engaging in both activities. I used this index as the dependent variable to retest long-run versions of the explanatory variables from my exploration and exploitation models, and my "configurational" hypotheses, H9a-c. These long-term results proved reasonably consistent with my exploration and exploitation models when estimated in isolation, with four of six variables featuring the expected sign and achieving statistical significance and the full model producing no contrary results. Support for the "configurational" hypotheses proved less consistent.

Summary and Discussion of Empirical Findings

My central research question in this dissertation is *how do network characteristics affect an organization's ability to explore and exploit?* This question guided me to develop an extension of organizational ambidexterity theory by drawing on network research. This extension represents a logical step for organizational ambidexterity research since it has gradually considered more macro levels of analysis, with recent empirical work examining organizational dyads (Lavie & Rosenkopf, 2006; Simsek, 2009; Lavie et al., 2010) and simulation work considering networks (Siggelkow & Levinthal 2003; Lazer & Friedman, 2007; Lin et al., 2007). Since a full exploration of the confluence of network and ambidexterity is outside of the scope of a single study, I chose to focus on the theme of information flow that is common to both theories. Specifically, I build theory predicting how three types of network characteristics, closure, diversity, and centrality, affect ambidexterity by influencing both the speed and novelty of information reaching a focal firm.

The essence of this model is network characteristics that aid exploration hamper exploitation and vice versa. Firms can resolve this apparent paradox because their inter-organizational relationships can be disaggregated into exploratory or exploitative in orientation (Parmigiani & River-Santos, 2011). This disaggregation should allow firms to collaborate in differing ways in networks built from these differing types of relationships. Past network research offers considerable guidance on what types of network characteristics influence the relative novelty of information available to network members and how this information moves throughout a given network. As a result, the intersection of these two areas of research produces conceptually clear predictions, which I bring to an empirical test in this dissertation. Table 17 summarizes the hypotheses and results for the separate exploration and exploitation models.

Table 17. Results summary for separate models

	Dependent Variable: Green Chemistry Patents		Dependent Variable: PGCCA Nominations	
	Hypothesized	Result	Hypothesized	Result
Ego Network Closure – Short-term (H1 & H4)	+	+	-	-
Ego Network Closure – Long-term (H2 & H5)	-	-	+	∅
Ego-Network Diversity (H3 & H6)	+	(+)	-	-
Closeness Centrality (H4 & H7)	-	-	+	+
Key: + or - = Strong support (+) or (-) = Partial support ns = Not significant ∅ = Untestable				

The core theoretical prediction of this dissertation is higher levels of each network characteristic will have opposite effects on exploration and exploitation. The results in Table 17 are largely consistent with this overall prediction. These results include no contradictory results, although the relationships between long-term closure and exploration received only partial support, and the relationship between short-run closure and exploitation proved untestable due to insufficient data. This overall pattern of results demonstrates the utility of separating exploration and exploitation-oriented relationships as suggested by Parmigiani & River Santos (2011). These findings also provide evidence for the time and task dependency of the relationships between network characteristics and desired outcomes (Levin & Cross, 2004; Obstfeld, 2005; Reagans & McEvily, 2003). In other words, this dissertation examines the same firms working in the same technological domain, but the relationship between their network characteristics and outcomes inverts almost perfectly as the task changes from exploration to exploitation. Furthermore, my results show distinct changes in the effects of network closure on these tasks in the short and long-terms, respectively.

The result from hypothesis 1 suggests that, in the short-term, collaborating with a tightly interconnected set of organizations increases a focal firm's exploration outcomes. At first, this seems to run contrary to the "strength of weak ties" arguments common in network studies (Granovetter, 1973, 1983). However, the central claims of these studies are that weak ties produce information that is more novel in general, not that this information is immediately accessible to a focal network member. A firm with redundant ties may also benefit in the short-term by receiving consistent information from its collaborators and such consistency may facilitate faster decisions regarding exploration. Both of these ideas point to a short-term – long-term split in the relationship between ego network closure and exploration.

Hypothesis 2 provides some support for this split by showing firms that tend to collaborate with otherwise interconnected organizations tend to have poorer exploration performance over time. Although this result only holds in the ego-level model, it provides some evidence of how the effect of closure on outcomes changes over time, with the short-term benefits of speed or consistency giving way to the longer-term benefits of more novel information. These results highlight the importance of taking time seriously since the observed relationship could switch between positive, negative and not significantly different from zero simply by considering the short, long, or medium term, respectively.

The hypotheses regarding partner diversity are consistent and strongly supported in both exploration and exploitation models. These findings echo research on the commercialization of university technologies that highlights tensions when private firms collaborate with universities (Markman et al., 2008). In these studies, universities are common and increasingly important sources of new technologies for private firms (Powell et al., 1996; Ahuja, 2000; Hagadoorn, 2002). However, differences in goals, rewards systems, and cultures between these types of organizations have been found to inhibit the successful commercialization of these technologies (Siegel, Waldman & Link 2003; Markman et al., 2008). Although this negative effect of network diversity has been largely studied in the context of firm-university relationships, it seems likely to hold for firm-government relationships too. Recent failures of government-firm partnerships in the areas of alternative energy (e.g. Solyndra) and automobile manufacturing (e.g. Fisker) are possible examples of such partnerships successfully exploring for, but failing to effectively exploit, new ideas.

Like the results for network partner diversity, the results for closeness centrality are strong and consistent across models. These results suggest that being closer to other network members helps exploration, but being far away from these members help exploitation. This seems to contradict the notion of invention “coming from the fringe”, but makes sense given this dissertation’s particular empirical context. Returning to the example of the pharmaceutical industry where a firm starts with approximately 10,000 chemical compounds to develop one marketable drug (Giovanetti & Morrison, 2000;

Rothaermel & Deeds, 2004). A firm may benefit from being closer to other network members when trying to locate these 10,000 novel compounds or in early stage testing when no firm knows which of the 10,000 compounds is commercially viable. However, the same firm might benefit from distancing itself from other network members once it identifies a promising compound in later stage trials. Put more generally, in exploration networks the "benefits" of inbound information from other network members might outweigh the "costs" of outbound information about the focal firm's activities, whereas in the case of exploitation these costs and benefits are reversed. Unfortunately, the data I use in this dissertation does not indicate directionality of information flows for either co-publishing or co-patenting in green chemistry; so investigating the effects of inbound and outbound information on ambidexterity will need to be addressed in future research.

Although not quite as consistent as the separate exploration and exploitation models, the combined model results are perhaps the most interesting in this dissertation. First, the ambidexterity index I develop for use as a dependent variable reflects both the dual nature of ambidexterity and captures some of its temporal dynamics implied by past research. Although there is nothing inherently optimal about using a five-year window to measure technology commercialization, such a longer window does seem to better match the reality of this process than a standard one-year window (Stuart, 2000). Second, the majority of the network characteristics that seem to affect exportation and exploitation in the short-term, also seem to affect ambidexterity in a similar way in the long-term. In combination, these dependent variables could have simply canceled one another out, but they appear not to. The results summarized in Table 18 are especially strong for the exploration variables, where hypotheses regarding network closure, diversity, and centrality are all strongly and consistently support across models.

Table 18. Results summary for combined model

	Dependent Variable: Ambidexterity Index			
	Exploration Measure		Exploitation Measures	
	Hypothesized	Result	Hypothesized	Result
Ego Network Closure – Long-term	-	-	+	+
Ego-Network Diversity	+	+	-	(-)
Closeness Centrality	-	-	+	(-)
	Hypothesized		Result	
Closure Interaction (H9a)	-		ns	
Diversity Interaction (H9b)	-		+	
Centrality Interaction (H9c)	-		-	
Key: + or - = Strong support (+) or (-) = Partial support ns = Not significant ∅ = Untestable				

The combined model generates a number of unexpected results. In the full model, both *patenting network diversity* and *patent network closeness centrality* are not statistically significant, and the latter has a significant coefficient with a sign opposite of expected in hypothesis 8. These inconsistencies could be due in part to using co-patenting to capture firms' exploitative activities. Patenting is an admittedly early than would be ideal part of the exploitation process to observe. Since it is early in the process for many firms, co-patenting may be capturing both exploration and exploitation to a certain extent. By the same logic closeness centrality based on co-patenting data might be picking up a similar dual-role for patents.

This problem might be avoided by looking at inter-organizational relationships further down the commercialization path. For example, production and marketing alliances might better capture pure exploitation. Alliances have been used in research on network and innovation (e.g. Ahuja, 2000), but in this case such alliance would need to be green chemistry-specific to makes sense as predictors for PGCCA nominations.

The configurational hypotheses offer the least consistent results of the three main sets of estimations in this dissertation. The positive results for 9b, indicates network partner diversity actually appears to help both exploration and exploitation over time. This result is not surprising if patents tend to serve both exploration and exploitative purposes. Put another way, a patent may be a logical starting point for exploitation, but the research leading up to a patent is likely to involve at least some degree of exploration. Determining exactly where exploration stops and exploitation starts, or alternatively if there is a gradual transition between the two, is an ongoing debate in the organizational ambidexterity literature (Lavie et al., 2010).

The non-significant result for 9a may be as much a result of the interaction process itself as any underlying phenomena. Since collaborating with network members who are themselves otherwise interconnected in the network is a fairly rare event and produces a value of zero for most firm-years in both exploration and exploitation networks. A standard interaction between these two measures would be zero for any firm-year with a value of zero in either network, making the chance capturing the effect even less likely. Using a 5-year moving average avoids creating interaction values of zero for firms with closure measures of zero in alternating years, however this measure still produces sparse data for testing this interaction. Of course, this non-significant result could simply be reflecting the underlying phenomenon, but the thinness of the data for his particular measure makes it difficult to distinguish between the two.

The results for hypothesis 9c show a negative and significant interaction between closeness centrality in exploration and exploitation networks. This finding is especially interesting in light of the support for hypotheses 4 and 8 in both the separate and combined models. All of this evidence suggests that a firm will be more ambidextrous if it can occupy a central position in exploration networks and a peripheral position in exploitation networks.

In this section, I discussed this dissertation's empirical findings (summarized in Tables 17 and 18). These findings feature three types of variables, short-term, long-term, and interactions, tested in three models, exploration and exploitation in isolation and a novel combined model. In my first two sets of analyses, I follow past ambidexterity research in testing relationships between short-term explanatory variables in separate models of exportation and exploration. My third set of analyses departs from these past approaches by using a dependent variable capable of capturing both exploration and exploitation in the same model and using this to test long-run versions of this dissertation's explanatory variables. Finally, my fourth set of analyses tests the notion that certain network configurations will influence firm ambidexterity above and beyond the direct effects of the explanatory variables examined in earlier models.

Taken together, these results provide evidence that organizational ambidexterity applies at the network level. Network characteristics that should theoretically influence exploration and exploitation by firms for the most part do so in the hypothesized directions. Furthermore, these network characteristics exert significant influence on ambidexterity in the predicted directions even after controlling for firm heterogeneity. These results also largely hold over both the short and long-term, and in separate and combined models. The core theoretical prediction of this dissertation is the direction of influence of network closure, diversity, and centrality will "flip" from exploration to exploitation networks. Although this pattern is not perfectly represented in this dissertation's analysis of technology commercialization in green chemistry, the preponderance of the results do support this pattern.

Limitations

Although this dissertation represent a useful extension of organizational ambidexterity research, its also has a number of limitations. As with all empirical studies, I needed to make a number decisions regarding research design that likely limit the generalizability of my findings. One limitation is this dissertation focuses only on the field of green chemistry. As described earlier, the observable "artifacts" produced by this field in the form of publications, patents, and award nominations is one of the main reasons why this dissertation was feasible. However, this also means the extent to which these finding generalize to fields outside of green chemistry is an open question. A related limitation is green chemistry being a scientific field. In such fields, exploration and exploitation tend to be fairly well defined and somewhat linear (Rothaermel & Deeds, 2004). Other settings, such as ambidexterity in service firms, may be quite different from ambidexterity in the pharmaceutical and bulk chemical firms that are prevalent in green chemistry.

My measures of both network ties and outcomes also have a number of limitations. By using co-publishing and co-patenting, I only capture formal inter-organizational relationships. The notion that such formal ties are embedded in informal ties, is well established in network research (Polanyi, 1968; Granovetter, 1985; Uzzi, 1997). However, directly measuring such informal ties on any scale is an ongoing challenge for researchers. If the formal ties I observe in this dissertation provide reliable proxies for informal inter-organizational ties, the results would actually be strengthened if I were somehow able to incorporate these informal ties in to my analyses. However, if these informal ties differed systematically from the observed formal ties, it could call into question the results presented earlier. Although not being able to observe these informal ties between organizations is a reason to interpret my findings with some degree of caution, the same issues affect all research relying on formal network ties.

In terms of outcome measures, both patents and PGCCA nominations also have a number of limitations. Although the types of firms active in green chemistry also tend to have a high propensity to patent their inventions (Mansfield, 1986; Cohen et al., 2001), some firms may be using other methods to protect their intellectual property. In this dissertation, firms using these other methods would appear to have low levels of exploration, when in fact this may not be the case. Similarly if firms did not co-publish or co-patent with other organizations, but collaborated by different means, such as through sponsored research or technology licensing these collaborations would not be captured in this dissertation. Seeing if such alternative types of exploration and exploitation oriented relationships produced similar results to publication and patents is a logical area for future research.

The PGCCA nominations are a critical empirical outcropping for both testing my models of exploitation and ambidexterity, but they have a number of limitations. First, they do not represent all successfully commercialized technologies in the field of green chemistry. Instead, they represent a relatively small group of technologies judged to have superior economic and environmental performance. Unlike empirical settings such as pharmaceuticals, there are no records of all green chemistry product introductions or an established hurdle for success (e.g. passing FDA trials). As a result, the findings here may be more accurately interpreted as predicting the "far right" tail, rather than the entire distribution, of technology commercialization in green chemistry. The PGCCA nomination documents are also inconsistent as to whether they report actual financial and environmental performance metrics for their focal technology, so I am limited to using them as count variables. Third, the PGCCA nomination process is somewhat opaque. All nominated technologies must credibility demonstrate financial and environment performance, but the actual vetting of these technologies takes place behind closed doors. Despite these limitations, the PGCCA nominations represent a rare data source that allow researchers to move beyond patents in a reasonably rigorous and large scale way.

These limitations invite caution in interpreting and generalizing my findings in this dissertation. However, the limitations discussed in this section are quite common in empirical research generally. As a result, my findings in this dissertation should be interpreted with the same caution as most any empirical findings in the literature. In the next chapter, I conclude this dissertation by summarizing my theoretical and empirical contributions, highlighting a number of implications of my findings and outlining areas for future research.

CHAPTER VI

CONCLUSION

Overview and Summary

My main goal in this dissertation was to answer the research question *how do an organization's network characteristics affect its ability to explore and exploit?* To do this I developed theory on how network closure, diversity, and centrality influence firms' exploration and exploitation activities. This theory development informed eleven hypotheses that I brought to an empirical test using three novel data sources drawn from the field of green chemistry

Prior Research

The observation at the core of organizational ambidexterity theory is organizations must often perform seemingly conflicting activities to survive and thrive (Tushman & O'Reilly, 1997). One of the most common sets of these conflicting activities is the exploration for new ideas and the exploitation of existing ones (March, 1991; Levinthal & March, 1993). Prior research has examined various prescriptions for organizations trying to balance and integrate these two types of activities. These include adopting specialized types of organizational structures (Christenson, 1998; Benner & Tushman 2003; Gilbert, 2005), following specific management practices (Gibson & Birkinshaw, 2004; Lubatkin, 2006) and cycling between these activities over time (Brown & Eisenhardt, 1998; Benner & Tushman 2003; Siggelkow & Levinthal 2003; Rothaermel & Deeds, 2004). Past research has also considered these prescriptions at other levels of analysis including individuals (e.g. Ambile, 1996; Mom et al., 2007), teams (e.g. Lubatkin et al., 2006; Jansen et al., 2008), and organizational dyads (e.g. Homqvist, 2004; Lavie & Rosenkopf, 2006) . However, organizations are increasing exploring and exploiting through inter-organizational networks (Powell et al., 1996; Ahuja, 2000; Hagadoorn, 2002; Adner, 2006), and this level of analysis has only been considered in conceptual and simulation research in the organizational ambidexterity literature (e.g. Lazer & Friedman, 2007; Lin et al., 2007).

Extending Ambidexterity by Considering Networks

My extension of organizational ambidexterity research to the network level has two motivating factors. First is to provide theoretical and empirical evidence that organizational ambidexterity can be usefully extended to the network level. The simulation studies done in past research (e.g. Lazer & Friedman, 2007; Lin et al., 2007) hint at this possibility, but to the best of my knowledge, no other study has done this empirically. The second motivating factor goes beyond simply extending the organizational ambidexterity literature to recognizing the importance of considering network of inter-organizational relationships for any number of outcomes studied in the management literature. For example, in this dissertation's setting of technology commercialization, exploring and exploiting through inter-organizational relationships is perhaps the dominant model. As result, extending ambidexterity research by considering networks will likely make both theoretical and practical contributions.

Theoretical Propositions

The theoretical propositions I developed in this dissertation focus on the nature of information underpinning exploitation and exploitation activities and how this information is shaped by three specific network characteristics, closure, diversity, and centrality. These propositions predict that network characteristics that supply a focal firm with novel information will promote exploration whereas those that supply redundant information will promote exploitation. A focal firm can avoid what appears to be a one-to-one tradeoff by differentiating how it structures its networks based on whether a particular set of inter-organizational relationships is exploratory or exploitative in orientation.

The consequence of this differentiation is firms should be able to become more ambidextrous by structuring their inter-organizational relationships specific to each type of network. In terms of the three network characteristics considered in this dissertation, a firm's exploration network should be more effective if it features high low closure, high diversity, and low closeness centrality. In contrast, a firm's exploitation network should be more effective if it features the opposite; high closure, low diversity and high closeness centrality. Bringing this "sign switching" pattern to an empirical test through eleven specific hypotheses, has been the central empirical concern of this dissertation.

Setting, Analysis, and Findings

Testing this "sign switching" pattern required an empirical setting with a number of unusual attributes. First, this setting must have separate plausible outcome measures for exploration and exploitation (Rothaermel & Deeds, 2004). Second, it must have firms with distinct exploration and exploitation-oriented inter-organizational relationships (Parmigiani & Rivera-Santos, 2011). One setting that meets both of these criteria, and has received considerable attention in its own right, is technology commercialization (Mitchell & Singh, 1996; Zahra & Nielsen, 2002). Technology commercialization research documents numerous relationships that fit the definition of exploratory and exploitative in orientation used in this dissertation. However, while this stream of research has numerous measures for exploration outcomes, it has relatively few for exploitation outcomes such as those that might capture successfully commercialized technologies. Green chemistry, the empirical setting for this dissertation, is an exception because each year firms in this particular field are nominated for a prestigious award based the economic and environmental performance of technologies they developed. These nominations, in combinations with green chemistry patents and academic publications allow me to empirically test the "sign switching" pattern proposed in the theoretical portion of this dissertation.

I use these green chemistry data to test eleven hypotheses relating network characteristics to firm outcomes in the forms of patents and award nominations. I started by following past ambidexterity research by estimating annual exploration and exploitation outcomes in separate models. The results of these estimations largely supported the predicted "sign switching" pattern. The third model merges exploration and exploitation outcomes into a single variable and tests the long-run version of the explanatory variables from the separate models. Although the results from this combined model are somewhat less consistent than the separate models, the balance of these results support the predicted “sign switching” pattern. The explanatory variables from the exploration model proved especially powerful in the combined model. This could be because academic publications are a more “pure” measure of exploration than patents are of exploitation, or because exploitation necessitates successful exploration.

Contributions and Implications

The theoretical and empirical results from this dissertation make several contributions to existing areas of research. These findings also carry implications for both future organizational research and for practicing managers. In this section, I discuss how this dissertation may inform future research on organizational ambidexterity, technology commercialization, and innovation more generally. Next, I explain some managerial implications of these finding. I close with some possible future research directions.

Ambidexterity Research

The primary contribution of this dissertation is an empirically validated extension of organizational ambidexterity theory. My motivation for this extension is both to contribute to this area of research, but also to have it better reflect the reality facing firms involved in inherently ambidextrous activities such as technology commercialization (Rothaermel & Deeds, 2004; Adner, 2006; Hess & Rothaermel, 2011). Simulation based ambidexterity research (Lazer & Friedman, 2007; Lin et al., 2007) hints at this utility of this extension, but it has remained under theorized and not empirically tested.

My results show, at least in the case of technology commercialization in green chemistry, that network characteristics do affect firms’ ability to explore and exploit effectively. Furthermore, network closure, diversity, and closeness centrality influence exploration and exploitation in ways consistent with how these network characteristics shape a focal firm's access to novel and redundant information. These patterns of influence also largely hold up over time, providing evidence for the ambidexterity premise (Raisch & Birkinshaw, 2008) and showing the benefits of considering extended time periods when researching such inherently temporal research questions (Stuart, 2000; Mitchell & James, 2001; Sasson & Minola, 2010) rather than relying only on cross-sectional data (e.g. Lubatkin et al., 2006; Tiwana, 2008).

Although raising the level of analysis from the organization to the network has intuitive appeal and a sound theoretical basis, its poses a problem for solutions suggested in past research. Specifically, suggestions for promoting ambidexterity offered in past research, such as temporal cycling, changing organizational structures, adopting certain HR practices, are problematic at the network level. As a result, past research is unclear about whether the ambidexterity concept usefully elevates to the network level, and offers little guidance on how a focal firm can shape its network to supplement internal ambidexterity efforts.

Results from this dissertation provide empirical evidence supporting the utility of ramping up ambidexterity research to the network level suggested in simulation studies (Lazer & Friedman, 2007; Lin et al., 2007). However, they also imply that future ambidexterity research needs to account for network level forces affecting ambidexterity if it wants to truly isolate the effect of internal ambidexterity efforts on outcomes. Consistent with Holmqvist's (2004) case study, this also implies that unpacking the relationship between network-level and organization-level ambidexterity might be a useful exercise. Although such cross-level theorizing is never easy, in this case investigating the difference and similarities between internal and external ambidexterity efforts would further refine the initial extension I propose in this dissertation.

Innovation and Technology Commercialization Research

Although my primary focus in this dissertation is on extending the organizational ambidexterity literature, it also holds a number of implications for research on technology commercialization and innovation. The first implication is demonstrating the value of moving beyond patents as outcome measures. As useful as patent data are for answering many research questions, there remains a fundamental problem with using patents to measure firm innovation – they do not actually measure innovation. Patents measure invention and largely correlate with product introduction and similar measures. However, relying on such indirect and noisy measures to capture what is a central construct in so much research is problematic. For example, had I done this dissertation using patents as the only outcome variable, I would have arrived at the misguided conclusion that networks with low closure, high diversity, and low closeness centrality are better for "innovation." In contrast, the findings in this dissertation suggest that such network characteristics would likely leave a firm awash in partially developed ideas. Furthermore, if firm were is in such a situation, it would likely be better off doing the opposite of the advice from this hypothetical patent-only study. Specifically, this firm should benefit from participating in a network with high closure, low diversity, and high closeness centrality.

The second implication for innovation and technology commercialization research is to do more to explicitly bring in networks both for theorizing and for empirical testing.

With innovation increasing being carried out by a diverse group of organizations rather than by large vertically integrated firms, network measures should be a regular part of research in this area. Of course, not all studies focus on network-level research questions as I do here, but researchers should at least consider network measures as an important set of controls in efforts to isolate the effects of organizational-level processes. I am not the first to recognize how taking networks seriously could contribute to innovation research. However dramatic improvements in software programs for analyzing networks along with increased recognition of the importance networks more generally, may finally make following such advice this feasible.

Managers

This dissertation's findings also carry a number of implications for practicing managers. In general, they provide evidence of a path forward for firms stuck either in the productivity dilemma of over-exploitation or languishing in a sea of half-developed ideas due to over-exploration. These implications go beyond admonishments to balance these activities, by showing specific actions a firm can take in shaping and leveraging the networks in which it is embedded to increase both exploration and exploitation outcomes. How firms can best integrate these network approaches to ambidexterity with internal efforts remains an open question. However, based on past research it seems unlikely that these external processes could ever totally replace internal processes. Therefore, the following implications are "all else equal."

A large part of considering implications for firms is understanding which aspects of their respective networks they can actually influence. For example, a firm likely cannot prevent its collaborators from collaborating with one another, thereby increasing focal firm's level of network closure. In terms of the network characteristics examined in this dissertation, partner diversity is perhaps where firms have the most control over their respective networks. The results of this dissertation suggest firms that are stuck in the productivity dilemma may benefit from collaborating with a more diverse set of organizations. Similarly, if a firm is struggling with an abundance of underdeveloped ideas it may benefit from limiting such diversity when trying to refine these ideas into marketable products and services. In terms of network closure, although firms cannot realistically prevent their collaborators from collaborating, purposely fostering such interactions in exploitation networks appears to positively affect outcomes.

The starkly different effects of ego network closure in the short and long-terms also have implications for practicing managers. Specifically, exploring with a set of interconnected partners appears to produce a similar pattern to the “productivity dilemma” in that firms appear to enjoy an initial increase in performance followed by long-term decline. With this in mind, firms ought to benefit from limiting closure in the long-term in their exploration-oriented relationships. As mentioned, limiting collaboration between firm’s existing network partners may be difficult, but this is not the only way a firm can limit the closure of its exploration networks. For example, firms could accomplish this goal by continually collaborating with new organizations that are not connected to the focal firm's existing collaborators. The results showing that long-term closure in exploration networks tends to lower performance also implies that network “pruning” might be a useful activity after such relationships no longer grant access to novel information.

Future Research and Conclusion

This dissertation is a first attempt to extended organizational ambidexterity research to the network level. Although it contributes theoretically and empirically to this effort, it also suggests a number of directions for future research. First, I consider only three types of network characteristics, but any such characteristics that influence the novelty of information available to a focal firm should prove useful in explaining ambidexterity through inter-organizational networks. A second potentially fruitful direction is to examine relationships between internal and external ambidexterity efforts. Current research is unclear as to whether these processes are substitutes, complements, or have some potentially more complex relationship. Finally, ambidexterity research might benefit from raising the level of analysis yet again by investigating the effect of network characteristics on network level outputs (e.g. formalized research consortia like SEMATECH) in addition to the firm level outputs I use in this dissertation.

Organizations often must perform seeming incompatible tasks, of which "exploring for new possibilities and exploiting old certainties" is perhaps the most common. The results of this dissertation suggest success in these activities is not simply a matter of the internal efforts of a given firm. Rather the characteristics of various networks in which a firm is embedded also influences these outcomes. Such network influence is not an entirely exogenous factor with which firms must simply contend. By recognizing the differing purposes of these networks, a firm can work to consciously structure its positions within its varying types of network to both explore and exploit more effectively.

APPENDIX A

EXAMPLES OF PATENTS MATCHED TO PGCCA NOMINATIONS

Example 1:

PGCCA Description:

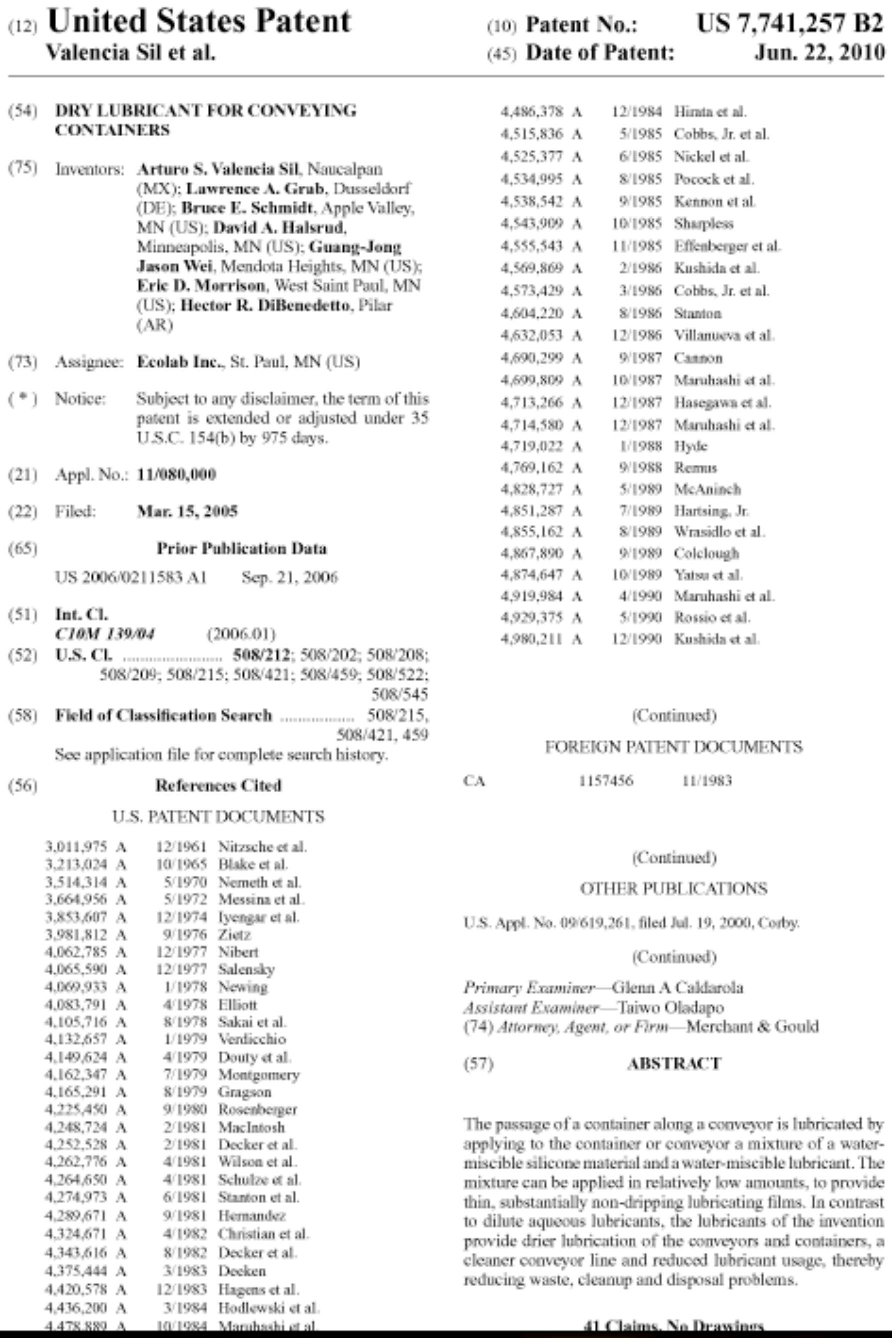
DryExx Conveyor Lubricant Program

In commercial food and beverage container filling operations, conveying systems typically move at very high speeds. Copious amounts of dilute, aqueous lubricant solutions are applied to the conveyors or containers with spraying or pumping equipment. Traditionally, these solutions lubricate the conveyor chain, run off the conveyor, and eventually enter the facility's effluent stream. Concentrated lubricant solutions often consist of fatty acid or fatty amine surfactants.

Traditional lubricant solutions and their associated technology have several disadvantages. First, dilute aqueous lubricants typically require large amounts of water on the conveyor line. The area near the conveyor line becomes very wet and the excess water must then be disposed of or recycled. Second, some aqueous lubricants can promote microbial growth. Third, diluting the concentrated lubricant before use can produce variable concentrations of dilute solution and thus, variable performance. Finally, variations in water quality can alter the performance of the dilute lubrication solution. For example, alkaline water can lead to environmental stress cracks in poly(ethylene terephthalate) (PET) bottles.

The DryExx Conveyor Lubricant Program lubricates conveyor chains without added water. The DryExx Program consists of the DryExx chemical formulation and a dispensing concept. The DryExx formulation contains a mixture of water-miscible silicone material and a water-miscible lubricant. It contains no hazardous ingredients in quantities requiring reporting. The product is targeted for food and beverage bottlers who package products in PET containers using conveyors with plastic or polyacetyl chains. Currently, Ecolab estimates this program is saving U.S. bottling facilities 240 million gallons of water annually and is preventing an additional 1 million gallons of conventional lubricant concentrate from entering the effluent stream.

Matching Patent:



(12) **United States Patent**
Valencia Sil et al.

(10) **Patent No.: US 7,741,257 B2**
(45) **Date of Patent: Jun. 22, 2010**

(54) **DRY LUBRICANT FOR CONVEYING CONTAINERS**

(75) Inventors: **Arturo S. Valencia Sil**, Naucalpan (MX); **Lawrence A. Grab**, Dusseldorf (DE); **Bruce E. Schmidt**, Apple Valley, MN (US); **David A. Halsrud**, Minneapolis, MN (US); **Guang-Jong Jason Wei**, Mendota Heights, MN (US); **Eric D. Morrison**, West Saint Paul, MN (US); **Hector R. DiBenedetto**, Pilar (AR)

(73) Assignee: **Ecolab Inc.**, St. Paul, MN (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 975 days.

(21) Appl. No.: **11/080,000**

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(51) **Int. Cl.**
C10M 139/04 (2006.01)
(52) **U.S. Cl.** **508/212**; 508/202; 508/208; 508/209; 508/215; 508/421; 508/459; 508/522; 508/545
(58) **Field of Classification Search** 508/215, 508/421, 459
See application file for complete search history.

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Primary Examiner—Glenn A Caldarola
Assistant Examiner—Taiwo Oladapo
(74) *Attorney, Agent, or Firm*—Merchant & Gould

(57) **ABSTRACT**

The passage of a container along a conveyor is lubricated by applying to the container or conveyor a mixture of a water-miscible silicone material and a water-miscible lubricant. The mixture can be applied in relatively low amounts, to provide thin, substantially non-dripping lubricating films. In contrast to dilute aqueous lubricants, the lubricants of the invention provide drier lubrication of the conveyors and containers, a cleaner conveyor line and reduced lubricant usage, thereby reducing waste, cleanup and disposal problems.

41 Claims, No Drawings

Example 2:

GCCA Description:

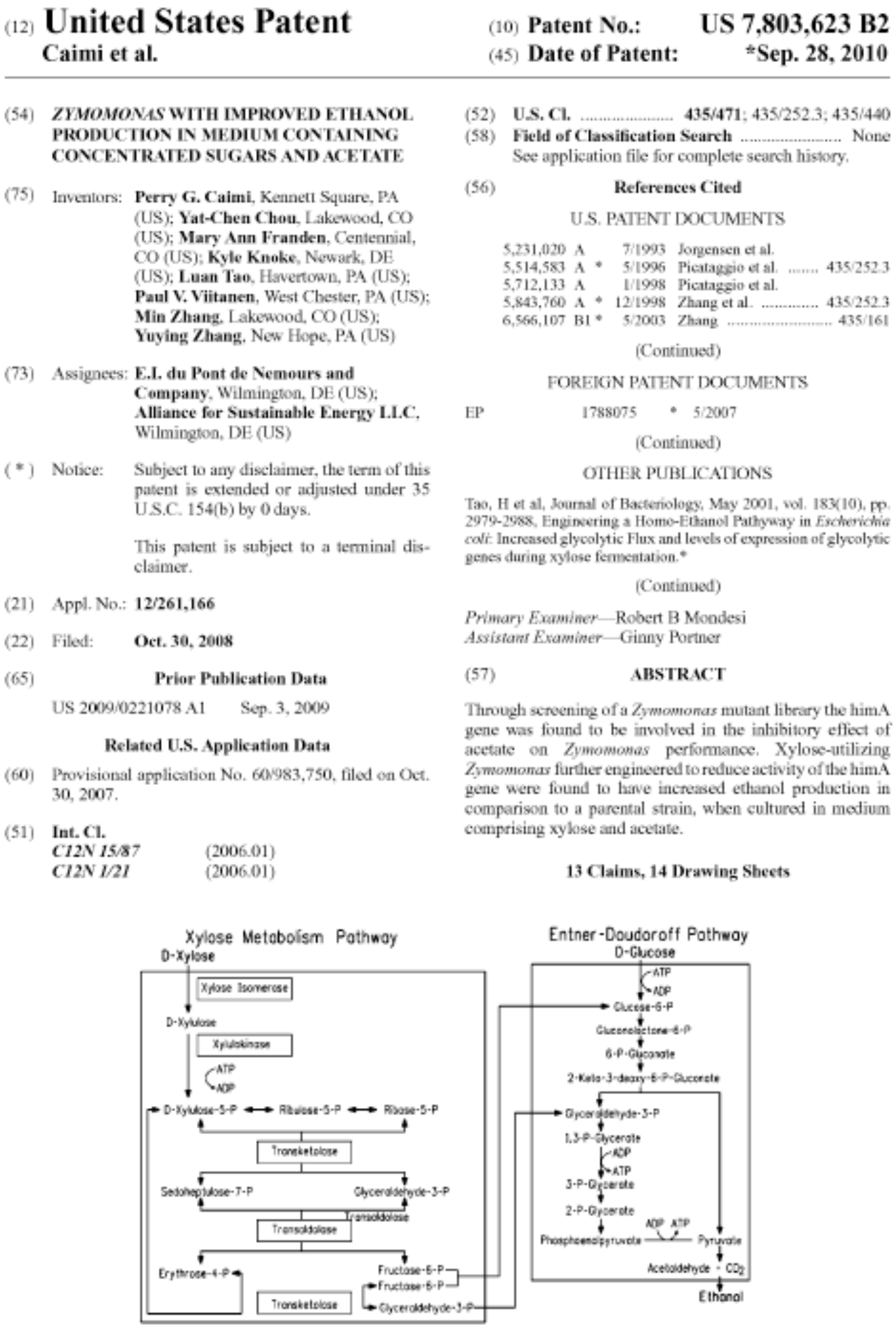
Development of a Commercially Viable, Integrated Cellulosic Ethanol Technology

DuPont and Genencor have developed and scaled up an improved biochemical technology for producing ethanol from lignocellulosic biomass. This process integrates three components. First, dilute ammonia pretreatment prepares the biomass for hydrolysis with minimal formation of compounds that inhibit subsequent fermentation. This pretreatment runs at up to 70 percent biomass with less than 10 percent ammonia by weight. Second, genetically engineered cellulase and hemicellulase enzymes from Hypocrea jecorina (a filamentous fungus) produce high yields of fermentable sugars at high titers. Third, optimized metabolic pathways of a recombinant ethanologen (Zymomonas mobilis) produce ethanol efficiently by metabolizing both 6-carbon and 5-carbon sugars from the sugars produced by pretreatment and enzymatic hydrolysis. Integrating and optimizing these three components enables a very efficient process and a green footprint with lower cost and less capital investment than other known cellulosic ethanol processes. At the 200 liter semiworks scale, this technology achieves consistent ethanol yields of over 80 gallons per U.S. ton of biomass and ethanol titers of over 80 grams per liter.

Removing the yield, titer, and cost barriers to commercializing cellulosic ethanol is a significant step toward large-scale production of cleaner, more sustainable liquid transportation fuels. Comprehensive well-to-wheel lifecycle assessments (WTW LCA) show that this combined process could potentially reduce greenhouse gas (GHG) emissions by over 100 percent compared to gasoline. The combined process could potentially have significantly lower GHG emissions than current grain-based ethanol processes. If suitable feedstocks cost $50 per ton, the ethanol from this process could cost $2 per gallon.

In, 2010, a flexible-feedstock, 250,000 gallon-per-year facility began operating in Vonore, Tennessee, to scale up this technology and develop basic data for commercial-scale facilities. The first commercial plant, a facility to convert corn stover feedstock to over 25 million gallons per year of ethanol, is expected to start up in 2013 in the U.S. Midwest.

Matching Patent:



(12) **United States Patent**
Caimi et al.

(10) **Patent No.: US 7,803,623 B2**
(45) **Date of Patent: *Sep. 28, 2010**

(54) ***ZYMOMONAS* WITH IMPROVED ETHANOL PRODUCTION IN MEDIUM CONTAINING CONCENTRATED SUGARS AND ACETATE**

(75) Inventors: **Perry G. Caimi**, Kennett Square, PA (US); **Yat-Chen Chou**, Lakewood, CO (US); **Mary Ann Franden**, Centennial, CO (US); **Kyle Knoke**, Newark, DE (US); **Luan Tao**, Havertown, PA (US); **Paul V. Viitanen**, West Chester, PA (US); **Min Zhang**, Lakewood, CO (US); **Yuying Zhang**, New Hope, PA (US)

(73) Assignees: **E.I. du Pont de Nemours and Company**, Wilmington, DE (US); **Alliance for Sustainable Energy LLC**, Wilmington, DE (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **12/261,166**

(22) Filed: **Oct. 30, 2008**

(65) **Prior Publication Data**

US 2009/0221078 A1 Sep. 3, 2009

Related U.S. Application Data

(60) Provisional application No. 60/983,750, filed on Oct. 30, 2007.

(51) **Int. Cl.**
C12N 15/87 (2006.01)
C12N 1/21 (2006.01)

(52) **U.S. Cl.** **435/471**; 435/252.3; 435/440
(58) **Field of Classification Search** .... None
See application file for complete search history.

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(Continued)

Primary Examiner—Robert B Mondesi
Assistant Examiner—Ginny Portner

(57) **ABSTRACT**

Through screening of a *Zymomonas* mutant library the himA gene was found to be involved in the inhibitory effect of acetate on *Zymomonas* performance. Xylose-utilizing *Zymomonas* further engineered to reduce activity of the himA gene were found to have increased ethanol production in comparison to a parental strain, when cultured in medium comprising xylose and acetate.

13 Claims, 14 Drawing Sheets

APPENDIX B

2013 PGCCA NOMINATION PACKET

EPA
United States
Environmental
Protection
Agency

Presidential Green Chemistry Challenge Awards Program:

Nomination Package for 2013 Awards

GREEN CHEMISTRY CHALLENGE

A U.S. EPA Program

Closing Date: April 30, 2013

An electronic version of this document is available at http://www.epa.gov/greenchemistry

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Presidential Green Chemistry Challenge Awards Program:
Nomination Package for 2013 Awards

Contents

Presidential Green Chemistry Challenge Awards Program:

Nomination Package for 2013 Awards

Introduction

THE PRESIDENTIAL GREEN CHEMISTRY CHALLENGE AWARDS promote the environmental and economic benefits of novel green chemistry. These prestigious annual awards recognize chemical technologies that incorporate green chemistry into chemical design, manufacture, and use.

EPA's Office of Chemical Safety and Pollution Prevention sponsors the Presidential Green Chemistry Challenge Awards in partnership with the American Chemical Society Green Chemistry Institute® and other members of the chemical community.

This nomination package contains explicit instructions on how to enter the competition. **Entries must be sent no later than April 30, 2013**. EPA will present the awards in the fall in Washington, D.C.

For 2013, EPA is particularly interested in receiving nominations on innovative approaches or technologies that reduce or eliminate the need for brominated flame retardant chemicals.

Definitions

A. Green Chemistry

Green chemistry is the design of chemical products and processes that reduce or eliminate the use or generation of hazardous substances. Green chemistry applies across the lifecycle of a chemical product, including its design, manufacture, use, and ultimate disposal. Green chemistry is also known as sustainable chemistry.

Green chemistry reduces pollution at its source by minimizing or eliminating the hazards of chemical feedstocks, reagents, solvents, and products. This is unlike treating pollution after it is formed (also called remediation), which involves end-of-the-pipe treatment or cleaning up of environmental spills and other releases. Remediation may include separating hazardous chemicals from other materials, then treating them so they are no longer hazardous or concentrating them for safe disposal. Most remediation activities do not involve green chemistry. Remediation removes hazardous materials from the environment; on the other hand, green chemistry keeps the hazardous materials out of the environment in the first place.

However, if a technology reduces or eliminates the hazardous chemicals used to clean up environmental contaminants, this technology would qualify as a green chemistry technology. One example is replacing a hazardous sorbent [chemical] used to capture mercury from the air for safe disposal with an effective, but nonhazardous sorbent. Using the nonhazardous sorbent means that the hazardous sorbent is never manufactured so the remediation technology meets the definition of green chemistry.

B. Source Reduction

For the purposes of the program, EPA defines green chemistry as the use of chemistry for source reduction.

The term “source reduction” includes any practice which:

> (i) reduces the amount of any hazardous substance, pollutant, or contaminant entering any waste stream or otherwise released into the environment (including fugitive emissions) prior to recycling, treatment, or disposal; and
>
> (ii) reduces the hazards to public health and the environment associated with the release of such substances, pollutants, or contaminants.

Source reduction:

- Includes: equipment or technology modifications, process or procedure modifications, reformulation or redesign of products, substitution of raw materials, and improvements in housekeeping, maintenance, training, or inventory control.
- Does not include: any practice which alters the physical, chemical, or biological characteristics or the volume of a hazardous substance, pollutant, or contaminant through a process or activity which itself is not integral to and necessary for the production of a product or providing a service.
- Prevents the formation of any hazardous substance in any chemical product or process. Source reduction is the highest tier of the risk management hierarchy as described in the Pollution Prevention Act of 1990 (PPA).
- Is preferable to recycling, treatment, or disposal. Chemical technologies that include recycling, treatment, and disposal may be eligible for an award if they offer source reduction over traditional technologies for recycling, treatment, and disposal.

Award Categories

EPA usually presents one Presidential Green Chemistry Challenge Award in each of these five categories.

- Focus Area 1: Greener Synthetic Pathways
- Focus Area 2: Greener Reaction Conditions
- Focus Area 3: The Design of Greener Chemicals
- Small Business* (for a technology in any of the three focus areas developed by a small business)
- Academic (for a technology in any of the three focus areas developed by an academic researcher)

*A small business for purposes of this award must have annual sales of less than $40 million, including all domestic and foreign sales by the company, its subsidiaries, and its parent company.

More detail about the three Focus Areas is included below.

Scope of the Program

To be eligible for an award, a nominated technology must meet the scope of the Presidential Green Chemistry Challenge program by meeting each of these six criteria:

1. It must be a **green chemistry technology** with a significant chemistry component
2. It must include **source reduction**
3. It must be submitted by an **eligible organization or its representative(s)**
4. It must have a **significant milestone** in its development within the past five years
5. It must have a **significant U.S. component**
6. It must fit within at least one of the **three focus areas** of the program

1. Green Chemistry Technologies

Green chemistry technologies are extremely diverse. As a group, they…

- Improve upon any chemical product or process by reducing negative impacts on human health and the environment relative to competing technologies
- Include all chemical processes: synthesis, catalysis, reaction conditions, separations, analysis, and monitoring
- Make improvements at any stage of a chemical's lifecycle, for example, substituting a greener feedstock, reagent, catalyst, or solvent in an existing synthetic pathway
- May substitute a single improved product or an entire synthetic pathway
- Benefit human health and the environment at any point of the technology's lifecycle: extraction, synthesis, use, and ultimate fate
- Incorporate green chemistry at the earliest design stages of a new product or process
- Employ a significant change in chemistry, although they may also incorporate green engineering practices

2. Source Reduction

For this program, EPA defines green chemistry as the use of chemistry for **source reduction**. Chemical technologies that include recycling, treatment, or disposal may meet the scope of the program if they offer source reduction over competing technologies.

3. Eligible Organizations

Companies (including academic institutions and other nonprofit organizations) and their representatives are eligible for Presidential Green Chemistry Challenge Awards for outstanding or innovative source reduction technologies.

Public academic institutions, such as state and tribal universities and their representatives, are eligible for Presidential Green Chemistry Challenge Awards for technologies that prevent, reduce, or eliminate air or water pollution or the adverse health effects of solid waste entering into the waste stream.

4. Significant Milestone

A green chemistry technology must have reached a significant milestone within the past five years. Some examples are: critical discovery made, results published, patent application submitted or approved, pilot plant constructed, relevant regulatory review (e.g., by EPA under TSCA[1] or FIFRA[2]; by the U.S. Food and Drug Administration under FFDCA[3]) initiated or completed, and technology implemented or launched commercially.

5. Significant U.S. Component

A significant amount of the research, development, or other aspects of the technology must have occurred within the United States. If the only aspect of the technology within the Unites States is product sales, the technology may not meet the scope of the program.

6. Focus Areas of the Presidential Green Chemistry Challenge

Green chemistry technologies fit into at least one of the three focus areas below. Technologies that do not fit within at least one focus area may not fall within the scope of the program.

Focus Area 1: Greener Synthetic Pathways

This focus area involves designing and implementing a novel, green pathway to produce either a new or existing chemical substance.

Examples include synthetic pathways that:

- Use greener feedstocks that are innocuous or renewable (e.g., biomass, triglycerides)
- Use novel reagents or catalysts, including biocatalysts and microorganisms
- Use natural processes, such as fermentation or biomimetic syntheses
- Are atom-economical
- Are convergent syntheses

Focus Area 2: Greener Reaction Conditions

This focus area involves improving conditions other than the overall design or redesign of a synthesis. Greener analytical methods often fall within this focus area.

Examples include reaction conditions that:

- Replace hazardous solvents with solvents that have less impact on human health and the environment
- Use solventless reaction conditions and solid-state reactions
- Use novel processing methods that prevent pollution at its source
- Eliminate energy- or material-intensive separation and purification steps
- Improve energy efficiency, including reactions running closer to ambient conditions

Focus Area 3: The Design of Greener Chemicals

This focus area involves designing and implementing chemical products that replace more hazardous products.

Examples include chemical products that are:

- Less toxic than current products
- Inherently safer because they reduce the likelihood or severity of accidents
- Recyclable or biodegradable after use
- Safer for the atmosphere (e.g., do not deplete ozone or form smog)

Selection Criteria

Nominated chemistry technologies that meet the **scope of the program** will be judged on how well they meet the following three selection criteria:

A. Science and Innovation

The nominated chemistry technology should be innovative and of scientific merit.

The technology should be, for example:

- Original (i.e., never employed before) and
- Scientifically valid, that is, can the nominated technology or strategy stand up to scientific scrutiny through peer review? Does the nomination contain enough chemical detail to reinforce or prove its scientific validity? Has the mechanism of action been clarified via scientific research?

B. Human Health and Environmental Benefits

The nominated chemistry technology should offer human health and/or environmental benefits at some point in its lifecycle from resource extraction to ultimate disposal. Quantitative statements of benefits are more useful to the judges than are qualitative ones.

The technology might, for example:

- Reduce toxicity (acute or chronic) or the potential for illness or injury to humans, animals, or plants
- Reduce flammability or explosion potential
- Reduce the use or generation of hazardous substances, the transport of hazardous substances, or their releases to air, water, or land
- Improve the use of natural resources, for example, by substituting a renewable feedstock for a petrochemical feedstock
- Save water or energy
- Reduce the generation of waste, even if the waste is not hazardous

C. Applicability and Impact

The nominated chemistry technology should have a significant impact. The technology may be broadly applicable to many chemical processes or industries; alternatively, it may have a large impact on a narrow area of chemistry. Commercial implementation can help demonstrate the applicability and impact of a technology. Nominations for pre-commercial technologies should discuss the economic feasibility of the technology.

The nominated technology should offer three advantages:

- A practical, cost-effective approach to green chemistry
- A remedy to a real environmental or human health problem
- One or more technical innovations that are readily transferrable to other processes, facilities, or industry sectors

Awards Process

A. How to Enter

1. Basic Information

- **Award nominations are due to the EPA by April 30, 2013.** Awards will be presented in the fall in Washington, D.C.
- Self-nominations are typical.
- There is no entry fee.
- There is no standard entry form, but nominations must meet certain requirements or EPA may reject them.
- You may nominate more than one technology, but you must submit a separate, stand-alone nomination for each one. Multiple applications of the same general technology are most likely to win an award if you combine them in a single nomination.

2. Overall Format

Nominations must have:

- No more than eight pages, including the cover page
- Single-spaced, 12-point type, but references, captions, and footnotes may be as small as 10-point type
- Margins of at least 1 inch when printed on 8½-by-11-inch paper

Nominations may include:

- Chemical reactions, tables, graphs, charts, photographs, diagrams, and other illustrations within their eight pages
- Text or illustrations in color, but the judges may read the nominations printed in black and white; therefore, nominations should not require color for interpretation.
- Hot links to published articles, patents, etc. Nominations should not rely on information in links to present their technology because judges may not follow any links.

3. Structure of Nominations

The first page must be a cover page with the:

- **Technology title** and **date** of the nomination
- **Primary sponsor(s)**: the individual or organizational owner(s) of the technology. For academic nominations, the primary sponsor is usually the principal investigator. For nominations with more than one sponsor, each co-sponsor should have had a significant role in the research, development, or implementation of the technology

- **Contact person** with full mailing address, email address, and telephone number: the one individual with whom EPA will communicate regarding the nomination. For academic nominations, the contact person is usually the principal investigator. For other nominations, the contact should be a project manager or other technical representative. We add the person listed as the contact to the list of subscribers for our electronic newsletter. Periodically, we email reminders and updates about the program to those on our list. You may opt out at any time.
- **Contributors** (optional): those individuals or organizations that provided financial or technical support to develop or implement the technology

The second page should contain the following information:

- **Technology title**
- A sentence indicating whether the nominated technology is eligible for the **small business** award, the **academic** award, both, or neither.
- The name (or number) of the EPA award **focus area** (or areas) that fits your technology. The focus areas are (1) greener synthetic pathways; (2) greener reaction conditions; and (3) the design of greener chemicals. No explanation is needed.
- One- or two-line description of the **most recent milestone** for the nominated technology and **the year it occurred**. Only one milestone and year are required; the milestone must be within the last five years.
- One or two sentences describing the **U.S. component** of the technology: the research, development, implementation, or other activities of the technology that occurred within the United States.
- An **abstract** (not to exceed 300 words) that describes the nominated technology, the problem it addresses, and its benefits. Include the degree of implementation (or commercialization) of the technology and any quantitative benefits such as the amount (or potential amount) of hazardous substances eliminated, energy saved, carbon dioxide emissions eliminated, water saved, etc. EPA plans to publish these abstracts in its annual Summary of Award Entries and Recipients. If you are nominating a technology you submitted in a previous year, you may use the abstract previously published by EPA in whole or in part. Links to previous annual summaries of award entries and recipients are available on the award winner page of our website: http://www.epa.gov/greenchemistry/.

The information in this section should fit on page 2, but you may continue on page 3 if necessary.

The **remaining pages** should show how your technology meets both the:

- **Scope of the program** and
- Three **selection criteria**

The judges will look for detailed explanations of:

- The **problem** (environmental or human health risk) that your technology addresses, its importance, and how your technology solves it.

- The **chemistry** of your new technology, emphasizing its novelty and scientific merit. To be eligible for an award, your technology must include a significant chemistry component. Include as much nonproprietary detail as possible, such as the specifics of your chemistry and detailed reaction pathways. Consider using chemical structure diagrams to describe your chemistry. You may include patent numbers or references to peer-reviewed publications, but add only the most important, recent ones because references take space away from other details of your technology.
- **Realized or potential benefits and drawbacks.** These may occur across all stages of your technology's lifecycle: from feedstocks to manufacture, use, and the ultimate disposal of the product. Include the human health, environmental, and economic benefits of your technology such as toxicity data and quantities of hazardous substances reduced or eliminated. If you have not done a full lifecycle analysis, discuss the impacts of your technology across the lifecycle to the extent you know them.
- **How your technology compares** with any other technologies that address the same problem. Comparing the cost, performance, and environmental profile of your technology with any competing technologies may demonstrate the broad applicability of your technology.
- **Current and planned commercialization**. For example, is your technology currently on the market? Are you building a pilot or manufacturing plant? If your technology is or is about to be commercially available, also discuss the regulatory status of any novel chemical substance or organism under any applicable laws such as TSCA[1], FIFRA[2], or FFDCA[3]. EPA must assure that winning technologies comply with these laws.

4. Submitting Your Nomination to EPA

Submit an electronic copy of your nomination in a format so that EPA can select and copy text. Include the primary sponsor's name in the file name. You may want to submit your nomination as a .pdf file to minimize possible reading errors, but EPA accepts and can read all common file types. Send the electronic copy by email to greenchemistry@epa.gov. If you encounter problems submitting your nomination electronically, please contact us at greenchemistry@epa.gov or (202) 564-8740.

B. Receipt of Nominations

- EPA will consider all entries as public information.
- EPA will not return any material.
- EPA is not responsible for lost or damaged entries.
- EPA acknowledges receipt of nominations by email to the Contact Person identified in the nomination. If EPA does not acknowledge your nomination within two weeks after you submit it, please contact us at greenchemistry@epa.gov or (202) 564-8740.

C. Judging entries

A panel of technical experts convened by the American Chemical Society Green Chemistry Institute® will judge nominations. These anonymous experts might include members of the scientific, industrial, governmental, educational, and environmental communities. EPA may ask the designated contact person to verify any chemistry described or claims made in nominations on behalf of the judges. The judges will select as award recipients those green chemistry technologies that best meet the selection criteria. The judges may use their discretion, however, to make more than one award (or no award) in any one category.

D. Notification of winners

EPA will notify winners prior to the official public announcement, which will be made in the fall in Washington, D.C. EPA will present a commemorative crystal sculpture to the primary sponsor(s) of the winning green chemistry technology in each of the five award categories and certificates to individuals identified by the primary sponsor(s) who contributed to the research, development, or implementation of the technology.

Contact Us

If you have questions about the scope of the program, nomination procedures, or the Presidential Green Chemistry Challenge Program, please email EPA's Industrial Chemistry Branch at greenchemistry@epa.gov or call (202) 564-8740.

Sample Cover Page

Please use the format below for the cover page of your nomination.

Nominations with an Academic Sponsor

Title of Nomination
Date of Nomination

Primary Sponsor(s):
Full Name (Primary Investigator)
Name of Institution

Contact Person:
Full name
Title
Address
Phone
Email

Contributor(s): (optional) Individuals and/or organizations

Nominations with a Business Sponsor

Title of Nomination
Date of Nomination

Primary Sponsor(s):
Company Name

Contact Person:
Full name
Title
Address
Phone
Email

Contributor(s): (optional) Individuals and/or organizations

Award Nomination Checklist

Include the following components (see “How to Enter,” page 6, for details):

☐ Cover page
☐ One sentence indicating whether the nomination is eligible for the academic category, the small business category, both, or neither
☐ Name or number of the EPA award focus area(s) for the nominated technology
☐ One- or two-line description of the most recent milestone and the year it occurred
☐ One or two sentences describing the activities that took place within the United States
☐ Abstract (300 words or fewer)
☐ Detailed description of how the nominated technology meets the scope of the program and the selection criteria

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[1] TSCA is the Toxic Substances Control Act.
[2] FIFRA is the Federal Insecticide, Fungicide, and Rodenticide Act.
[3] FFDCA is the Federal Food, Drug, and Cosmetic Act.

Office of Pollution
Prevention and
Toxics (7406M)

744K13001
January 2013
www.epa.gov

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