THE RESEARCH PROBLEM OF RESEARCH OBSTACLES

by

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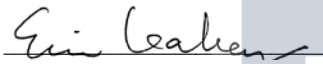
As members of the Dissertation Committee, we certify that we have read the dissertation prepared by ***David J. McBee***, titled ***The Research Problem of Research Obstacles*** and recommend that it be accepted as fulfilling the dissertation requirement for the Degree of Doctor of Philosophy.



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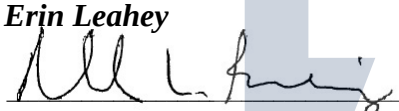

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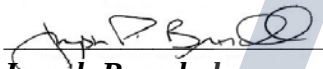

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Final approval and acceptance of this dissertation is contingent upon the candidate's submission of the final copies of the dissertation to the Graduate College.

I hereby certify that I have read this dissertation prepared under my direction and recommend that it be accepted as fulfilling the dissertation requirement.

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STATEMENT BY AUTHOR

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ABSTRACT

Problem solving is regarded as an essential to scientific work, yet remains a curiously understudied topic. This is due, in part, to the different meanings attributed to the word 'problem' by different lines of research and different disciplines. While scientists do choose research topics, battle for control of their jurisdictions, and have opportunities to apply their abstract knowledge, they also face research obstacles – problems that must be overcome in order to fulfill the aims of research. A lot can – and does – go wrong during the course of innovative scientific work. In fact, many of the most innovative scientific fields have high failure rates. This is very apparent in the biopharmaceutical field, the field that I chose to study. Biopharmaceutical scientists must often deal with research-related obstacles that crop up during the course of their work if their projects are to move forward. Fortunately, these biopharmaceutical scientists do not face such obstacles alone but have the support and backing of their organizations, project teams, and social networks. Thus, problem solving in the realm of biopharmaceutical science involves social processes. My dissertation seeks to provide an understanding of these social processes through three studies. The first study investigates how biopharmaceutical scientists deal with research obstacles by interviewing 36 core scientists working on biopharmaceutical research and development. These conversations reveal that personal jurisdictions, functional area teams, and multifunctional project teams provide a template of action for biopharmaceutical scientists that draws upon specialist knowledge and interdisciplinary teamwork. Additionally, scientists' accounts of legal boundaries associated with utilizing interorganizational network ties suggests the biopharmaceutical field relies on formal authority structures to organize scientists' problem solving efforts. The second study asks what kind of social network contacts facilitate problem solving. Recent work on social networks and creative innovation claims that social network

contacts with different types of characteristics will prove useful for different innovation phases. Because problem solving moves through similar phases, I argue by analogy that different types of social network contacts will prove useful for different problem solving phases. Further, I test whether path dependence exists between problem solving phases. To address these questions, I utilize a multi-level path model to model survey data from members of the American Association of Pharmaceutical Scientists. Results indicate that biopharmaceutical scientists associate the characteristics of strong social network ties, leadership relationships, and competence-based trust with problem solving. Additionally, social network contacts that provide useful assistance at an earlier problem solving phase are more likely to provide useful assistance at a later problem solving phase. Thus, path dependence exists between phases of problem solving. The third study asks why some biopharmaceutical scientists are more effective at problem solving than others. To ask this question, I draw upon research on the strength of ties, the knowledge components of networks, individual job performance, team science, and problem solving. To address this question, I utilize the same survey of biopharmaceutical scientists affiliated with the American Association of Pharmaceutical Scientists. Results of a structural equation model show two pathways. The first emphasizes social networks. The influence of the strength of ties on scientists' problem solving effectiveness is mediated by the knowledge components of networks. The second path emphasizes performance. The influence of team performance runs through the job performance of individual scientists. These studies build a holistic understanding of the social processes associated with problem solving in the field of biopharmaceutical science.

INTRODUCTION

SCIENTIFIC PROBLEM SOLVING

Social scientists have long been interested in scientific problem solving. However, much of the research involving problems and problem solving falls treats problems as opportunities. Less attention has been given to how scientists deal with obstacles that crop up during the course of research, the type of problems that occur after research puzzles have been selected and pursued. In the sociology of knowledge and science, researchers have been fascinated with the question of why scientists choose to pursue certain problems within a discipline or a line of research (Gieryn 1978, Gieryn and Merton 1978, Rushforth, Franssen and de Rijcke 2018). These types of puzzles present scientists with opportunities to fill gaps in existing knowledge (Booth, Colomb and Williams 1995, Kuhn 1962, Yang 2012). Research in the realm of professional and disciplinary jurisdiction studies the "turf" or the problems, clients, and tasks for which a group of professionals is qualified to treat or address, often because of abstract knowledge they possess (Abbott 1988, Abbott 2001, Cohen, March and Olsen 1972, Feyereisen, Broschak and Goodrick 2017, Lamont 2009, Leahey and Hunter 2012).

Problem formation can be thought of as the process of simplifying a complex set of issues through interpretation and sense-making (Reiter-Palmon and Illies 2004). As noted by Rittel and Webber (1973), many problems are "wicked" in the sense that they have many stake holders, are understood in terms of their solutions, may be continuous or ongoing, involve moral or cultural values, are one-shot operations, are unique, carry liability issues, and relate to other problems. For instance, income equality is an intensely moral issue that involves tradeoffs; decreasing income inequality decreases job growth, which undermines the desired outcome of reducing income inequality (Kenworthy 2007). Coupled with uncertain environments (Reiter-Palmon and Illies 2004), the only outcome one can hope for is a realignment of priorities (Rittel

and Webber 1973). Framed another way, choosing what problems to pursue *is* the problem (Baer, Dirks and Nickerson 2013). Actors engaged in problem formation identify symptoms and sets of causes which explain those symptoms. Because concrete solutions are not possible, problem formulation relies on sense-making more than problem solving, a situation where actors steer the set of solutions under consideration into or away from their zone of influence (Baer, Dirks and Nickerson 2013, Nickerson and Zenger 2004, Rittel and Webber 1973), much like professional groups contest the control of tasks by appealing to their realm of abstract knowledge in order to further their interests (Abbott 1988, Fligstein and McAdam 2012). By focusing on aspects of selection and control, problems are characterized as opportunities.

In contrast to the idea that problems are seem like opportunities at times, some lines of research treat problems as obstacles or disruptions. Within cognitive psychology, a problem occurs when an actor has a goal, but does not know how that goal is to be reached from the current situation (Duncker 1945, Novick and Bassok 2005, Rittel and Webber 1973). Additional problem solving phases show actors establishing an understanding of the problem, evaluating its impact, generating a solution or plan to address the problem, executing the solution or plan, and communicating about with others (Collins and Evans 2007, National Research Council 2013, Novick and Bassok 2005, Obstfeld 2017, Perry-Smith and Mannucci 2017, Reiter-Palmon and Illies 2004). Those engaging in problem solving have a much greater awareness of the characteristics of their situation and the desired situation than those engaging in problem formation. This very linear sense of problem solving may not apply to complex ill-structured problems like social issues or organizational strategy well (Baer, Dirks and Nickerson 2013, Nickerson and Zenger 2004, Rittel and Webber 1973) and it may not apply well to scientific problem-choice (Gieryn 1978, Gieryn and Merton 1978), but it certainly applies to planned

activities that experience disruptions (Obstfeld 2017, Perry and Pescosolido 2010, Perry and Pescosolido 2012).

Scientific projects do experience disruptions, especially innovative projects. Perhaps this is no more apparent than within the biopharmaceutical field. The biopharmaceutical field – the merger of the biotechnology and pharmaceutical fields (Nerkar and Paruchuri 2005) – has long been characterized as innovative by social scientists (Powell 1990, Powell, Koput and Smith-Doerr 1996) and faces high failure rates. As Firestein (2016: 206) writes:

> I love Big Pharma. They are the biggest and best failures in science. They fail a lot and they fail reliably. The numbers are staggering. Of those drugs that make it as far as clinical trials, 19 in 20 ultimately fail to gain approval. The success rate drops to 1 in 100 (99/100 failures) if you go back to the early preclinical development stages of a potential drug. […] The costs accompanying these failure rates are equally immense, ranging from $200 million to $1 billion.

While Firestein's figures about the success rates of clinical trials may be overblown (DiMasi, Grabowski and Hansen 2016), failure rates are high – and staggeringly high at the early phases of drug discovery. Taking industrial R&D as emblematic of all biopharmaceutical science, the failure rate of projects in the "play" phase (in which scientists run experiments and gather data in order to motivate a full project) is over 99% (Firestein 2016). Once these projects receive administrative approval, funding, and small teams in the discovery phase, the failure rate is still around 98% (Bartfai and Lees 2006). Each year, several drugs fail in late R&D phases (Philippidis 2016). By the time the project enters an expensive clinical trial, the failure rate drops to 20% (Firestein 2016). But even after a clinical trial, when a biopharmaceutical company files a New Drug Application prior to starting sales, the failure rate is about 10% (DiMasi, Hansen and Grabowski 2003). A lot can – and does – go wrong between the time a scientist has an idea and the final implementation of that idea. These numbers suggest that industrial biopharmaceutical R&D projects face diffilculties , yet many biopharmaceutical projects

succeed. It would seem then, that biopharmaceutical scientists must engage in problem solving in order to move their project forward.

[Figure 1]

To focus attention on problem solving, I introduce the idea of a research obstacle. As I define it, a research obstacle is a challenge that must be overcome in order to fulfill specific research aims pursued by individuals, teams, or other social units. This concept focuses attention on situations in which researchers are aware of the state of their project, the desired research aims, and the course of action they pursue, even if their awareness remains tacit. Thus, problem solving is the process by which research obstacles are handled and, perhaps, overcome.

The overarching research question is *How do biopharmaceutical scientist deal with research obstacles?* Like other problem solvers, they do not operate alone. Problems are relative to the actor or actors experiencing them; a problem for one person is not necessarily a problem for another person who understands how to deal with that type of problem (Collins and Evans 2007, Novick and Bassok 2005, Rittel and Webber 1973). Actors with different backgrounds and experiences are likely to interpret the current situation, desired situation, and activities that transform one into the other in different ways (Novick and Bassok 2005, Rittel and Webber 1973, Thornton, Ocasio and Lounsbury 2012). Thus, one's contacts – members of one's social networks – are expected to play a fundamental role, as they do in almost any knowledge-intensive or innovative context (Burt 2005, Phelps, Heidl and Wadhwa 2012, Powell, Koput and Smith-Doerr 1996, Uzzi and Spiro 2005). This over-arching research question, coupled with the expectation that the answer lies in how scientists' utilize social networks, informs the following three studies.

Study 1

The first empirical study (Appendix B) examines the organizational form – the formal structure, patterns of activity, and norms (Hannan and Freeman 1977) – of biopharmaceutical companies by asking *How do biopharmaceutical scientists deal with research obstacles?* It examines how the organizational structure of industrial biopharmaceutical organizations enables and constrains the ability of biopharmaceutical scientists to engage their network contacts while problem solving. It pits two different accounts of the form of biopharmaceutical organizations (organizational form) against each other. On the one hand, advocates of the network organizational form (Powell 1990, Smith-Doerr 2004, Smith-Doerr 2005) set expectations that biopharmaceutical scientists in the present will retain informal control over interorganizational networks for the purpose of problem solving. On the other hand, recent research suggests that the biopharmaceutical field has drifted away from the network organizational form because of growing concerns with boundary management (Nerkar and Paruchuri 2005). Whereas the network organizational form describes a network governance system that relies on the discretion of scientists (the informal organizational structure), the boundary management perspective sets an expectation that network governance resides within the formal organizational structure. Because research obstacles are associated with R&D, a core activity in the biopharmaceutical field, they operate as a stress-test that reveals the structure of biopharmaceutical organizations.

To gain a better understanding of the organizational form and social networks within the biopharmaceutical field, I interviewed 36 core biopharmaceutical scientists working on industrial research and development projects. These conversations describe the structure of their organizations, how social networks are typically utilized, and how scientists dealt with research obstacles encountered during associated with an ongoing R&D projects. Once analyzed, these

conversations support the idea that many biopharmaceutical organizations retain the vestiges of the network organizational form in that they are less hierarchical than many other types of organizations and function to promote organizational learning, but the formal structure plays a stronger role during problem solving than expected. To maintain a handhold on its intellectual property, biopharmaceutical organizations contain problem solving efforts within organizational boundaries for as long as possible. This is not to say that problem solving efforts are not supported. A complex matrix structure of functional areas and cross-functional teams provide biopharmaceutical scientists with the depth and breadth of expertise necessary to address most research obstacles. Should this structure fail, a biopharmaceutical scientist's organization initiates interorganizational ties but only with formal oversight.

Study 2

The second study (see Appendix C) addresses the question of *What types of social network contacts facilitate scientific problem solving?* There are many ways to characterize social network contacts and several phases within the problem solving process. To simplify the argument, analysis, and presentation, this study focuses on the identification and understanding phases of problem solving and characterizes network contacts based on research on the strength of ties, knowledge networks, and formal authority. While the theory behind each of these three types of network contacts sets expectations about how each will support both phases of problem solving, there is an additional expectation regarding path dependence between these two problem solving phases. A recent perspective on social networks and creativity, the needs perspective put forth by Perry-Smith and Mannucci (2017), suggests that each problem solving phase will be facilitated by opposing types of social network contacts. This contradicts several different lines of social network research (Burt 2005, Feld 1984, Molm, Whitham and Melamed 2012, Perry

and Pescosolido 2012, Pescosolido 1992, Uzzi 1997) that set expectations for path dependence between problem solving phases. Once a network contact proves useful for the purpose of helping a scientist identify the presence of a research obstacle, that contact is more likely to prove useful for the purpose of helping the scientist understand the underlying nature of that research obstacle.

To address this research question, I surveyed members of the American Association of Pharmaceutical Scientists (AAPS) about a research obstacle encountered during one of their biopharmaceutical R&D projects and the network contacts they utilized to address this problem. Results from a multi-level path analytic model tests hypotheses about which types of social network contact facilitate which problem solving phases and whether path dependence exists between problem solving phases. As expected, strong ties – network ties associated with emotional closeness and frequent communication – are more useful than weak ties during the identification phase. Contrary to expectations, there is no evidence that weak ties are more useful than strong ties during the following phase that involves trying to understand the obstacle. This is due to path dependence; the identification phase "pulls in" strong ties, who remain present to provide useful advice during the understanding phase. These findings strongly contradict the bold expectations from the needs perspective (Perry-Smith and Mannucci 2017), but are consistent with several other lines of social network research which expect the presence of path dependence (Burt 2005, Feld and Grofman 2009, Molm, Whitham and Melamed 2012, Perry and Pescosolido 2012, Uzzi 1997).

Study 3

The third study (see Appendix D) asks *Why some biopharmaceutical scientists are more effective at problem solving than others?* Motivation for explanatory factors draws upon research

on strength of ties (Granovetter 1973), the knowledge components of networks (Phelps, Heidl and Wadhwa 2012, Yuan et al. 2010), individual job performance (Campbell et al. 1993), team science (Fiore 2008, Wuchty, Jones and Uzzi 2007), and problem solving (National Research Council 2013, Novick and Bassok 2005). In addition to direct effects, some of these factors are expected to affect problem solving indirectly.

To address this question, I utilize the same survey of AAPS members. Because these factors are conceptualized as multifaceted latent variables and are expected to influence each other, I utilize a structural equation modeling approach (Acock 2013, Bollen 1989, Kline 2015) with clustered robust standard errors (Cameron and Miller 2015) to account for the fact that each biopharmaceutical scientist utilized several social network contacts for the purpose of problem solving.

Results of these models show interesting patterns. First, there are two main pathways that support biopharmaceutical scientists' problem solving effectiveness. One path emphasizes social networks. This originates with tie strength (duration of relationship, communication frequency, and emotional closeness) and runs through knowledge networks (respondents' awareness of, overlap with, and trust in the expertise and experiences of their network contacts) to promote problem solving effectiveness. It is largely consistent with expectations set by Contractor and Monge (2002) and Yuan et al. (2010). The other path originates at team performance (the capability to produce excellence, competency, and efficiency while focusing on goals and being competent as a team) and runs through individual level performance (the capability of an individual scientist to produce excellence, competence, and efficiency while working well with team members and team leaders) to promote problem solving effectiveness. This path is largely

consistent with the ideas and research of Katzenbach and Smith (2003), Wuchty, Jones and Uzzi (2007), and National Research Council (2015).

DISCUSSION

A major take away for researchers interested in innovation, science, teams, and social networks is that the informal structure of the biotechnology field, the network organizational form of Powell (1990), has undergone formalization as the biotechnology and pharmaceutical fields merged into the biopharmaceutical field (Nerkar and Paruchuri 2005). Contrary to expectations set by (Smith-Doerr 2005) scientists rely on the formal organizational structure to utilize interorganizational ties for the purpose of problem solving. But, in many cases, they do not have to. The matrix organizational structure that many biopharmaceutical organizations have adopted (Nakagawa and Lehman 2015) makes the informal utilization of personal contacts less necessary; core scientists' affiliations with functional areas provides them with depth of expertise and their cross-functional teams provide core scientists with breadth of expertise. As a result, because of the effectiveness of these two types of teams, core scientists "own" proportionally less of their social capital (Sorenson and Rogan 2014) when it comes to utilizing interorganizational ties. It is no wonder, then, that biopharmaceutical scientists utilize their team members and turn to their team leaders when research obstacles are present.

Interestingly, biopharmaceutical scientists tended to laud this organizational structure and its associated boundaries. While not discussed in Appendix B, many of the biopharmaceutical scientists whom I interviewed expressed the idea that these tight legal boundaries came with many benefits. One such benefit was a sense of freedom to discuss the intimate details of their science projects with competent, interested colleagues. Thus, while they have limited ability to utilize external contacts unless non-disclosure agreements or contracts are signed, they have an

increased ability to develop their organizational social capital, compared with their experiences in academic institutions that had loose legal boundaries but tight social boundaries.

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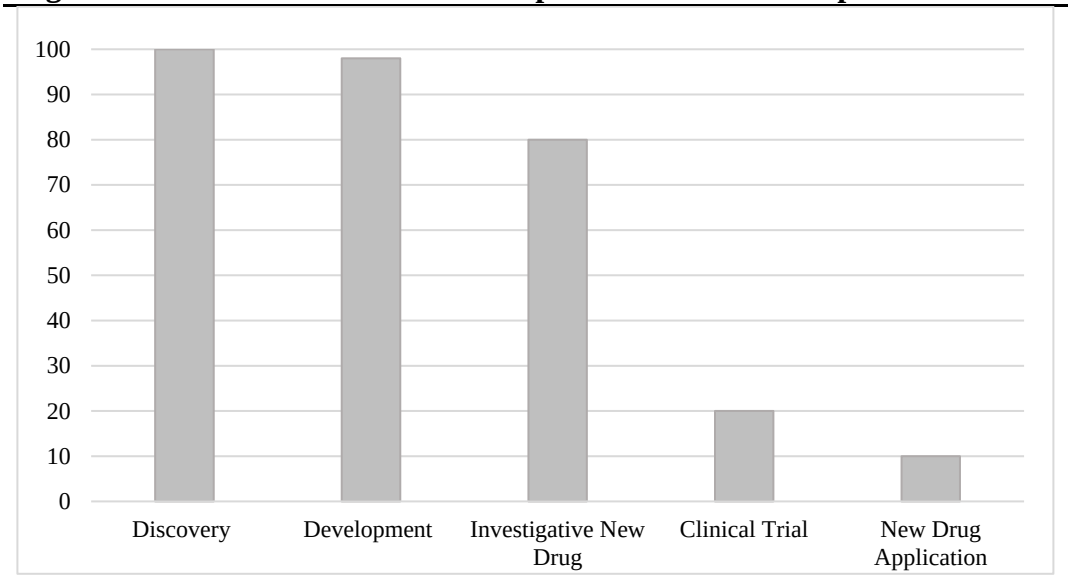
TABLES AND FIGURES

Figure 1. Failure rates in different biopharmaceutical R&D phases



Sources: (Bartfai and Lees 2006, DiMasi, Grabowski and Hansen 2014, DiMasi, Hansen and Grabowski 2003, Firestein 2016)

APPENDIX A

Human Subjects

THE UNIVERSITY OF ARIZONA

Human Subjects
Protection Program

1618 E. Helen St.
P.O.Box 245137
Tucson, AZ 85724-5137
Tel: (520) 626-6721
http://orcr.arizona.edu/hspp

Date:	October 06, 2014
Principal Investigator:	David J Mcbee
Protocol Number:	1409477935
Protocol Title:	The Research Problem of Research Obstacles
Level of Review:	Exempt
Determination:	Approved
Documents Reviewed Concurrently:	**Data Collection Tools:** *Dissertation Interview Schedule 2.0.docx* **Data Collection Tools:** *Research Obstacle Survey 2.0.docx* **HSPP Forms/Correspondence:** *McBee F107 2.1.doc* **HSPP Forms/Correspondence:** *McBee F200 2.1 (1).docx* **Informed Consent/PHI Forms:** *Interview Invitation 2.0 (1).pdf* **Informed Consent/PHI Forms:** *Survey Invitation 2.0 (1).pdf* **Participant Material:** *Interview Script 2.0.docx* **Recruitment Material:** *Follow Up 2.0.docx*

This submission meets the criteria for exemption under 45 CFR 46.101(b).

- The University of Arizona maintains a Federalwide Assurance with the Office for Human Research Protections (FWA #00004218).
- All research procedures should be conducted in full accordance with all applicable sections of the Investigator Manual.
- Exempt projects do not have a continuing review requirement.
- Amendments to exempt projects that change the nature of the project should be submitted to the Human Subjects Protection Program (HSPP) for a new determination. See the Investigator Manual, 'Appendix C Exemptions,' for more information on changes that affect the determination of exemption. Please contact the HSPP to consult on whether the proposed changes need further review.
- All documents referenced in this submission have been reviewed and approved. Documents are filed with the HSPP Office. If subjects will be consented the approved consent(s) are attached to the approval notification from the HSPP Office.

Your proposal is in compliance with Federalwide Assurance 00004218. This project should be conducted in full accordance with all applicable sections of the IRB Investigators Manual and you should notify the IRB immediately of any proposed changes that affect the protocol. You should report any unanticipated problems involving risks to the participants or others to the IRB.

This project has been reviewed and approved by an IRB Chair or designee.

Research
Office for Research & Discovery

Human Subjects
Protection Program

1618 E. Helen St.
P.O.Box 245137
Tucson, AZ 85724-5137
Tel: (520) 626-6721
http://rgw.arizona.edu/compliance/home

Date:	May 05, 2016
Principal Investigator:	David J Mcbee
Protocol Number:	1409477935A001
Protocol Title:	The Research Problem of Research Obstacles
Level of Review:	Exempt
Determination:	Approved
Change Description:	I have secured research funding (NSF 1565607) and would like to offer subject compensation.

Documents Reviewed Concurrently:

HSPP Forms/Correspondence: *McBee (1409477935) f213 (2016.4.29) SIGNED.pdf*
Informed Consent/PHI Forms: *Interview Invitation 3.3.pdf*
Informed Consent/PHI Forms: *Survey Invitation 3.3.pdf*

This submission meets the criteria for approval under 45 CFR 46.101(b).

- The University of Arizona maintains a Federalwide Assurance with the Office for Human Research Protections (FWA #00004218).
- All research procedures should be conducted according to the approved protocol and the policies and guidance of the IRB.
- Exempt projects do not have a continuing review requirement
- Amendments to exempt projects that change the nature of the project should be submitted to the Human Subjects Protection Program (HSPP) for a new determination. See the Investigator Manual, 'Appendix C Exemptions,' for more information on changes that affect the determination of exemption. Please contact the HSPP to consult on whether the proposed changes need further review.
- All documents referenced in this submission have been reviewed and approved. Documents are filed with the HSPP Office. If subjects will be consented the approved consent(s) are attached to the approval notification from the HSPP Office.

APPENDIX B

Organizational Form and Scientific Problem Solving:
Research Obstacles in the Field of Biopharmaceutical Science

ABSTRACT

In this study, I examine how the structure of biopharmaceutical organizations shapes the social networks of biopharmaceutical scientists as they attempt to solve research-related problems. The biopharmaceutical field is characterized as innovative because of its cutting-edge science but also because of its unique organizational form that promotes scientific learning though networks – the network organizational form. In particular, scientists are encouraged to freely collaborate across organizational boundaries, which promotes learning, awareness, and problem-solving. However, recent research suggests that the biopharmaceutical field has drifted away from the network organizational form towards active boundary-management. To better understand the current organizational form of biopharmaceutical organizations and how it shapes scientists' social networks, I interview 36 core scientists working on research and development projects in the biopharmaceutical field about the structure of their organizations and how they dealt with scientific obstacles encountered during research and development, a key activity within the biopharmaceutical field that requires access to novel information that is often located in other organizations. But whereas proponents of the network organizational form expect the governance of interorganizational networks to fall to the scientists, proponents of the active boundary-management perspective expect network governance to reside in the formal organizational structure. Scientists' accounts of how research obstacles are dealt with offers unique insight into the organizational form of biopharmaceutical organizations.

INTRODUCTION

Social scientists have often pointed to biotechnology as a key exemplar of an innovative field because of its scientific approach, but also because of its organizational form. By utilizing a unique scientific approach that drew on molecular biology and genetics, biotechnology firms gained a competitive advantage against pharmaceutical organizations that relied largely upon organic chemistry (Powell, Koput and Smith-Doerr 1996). Yet the real interest for many social scientists concerns the distinct organizational form biotechnology companies adopted. To support their science, biotechnology companies adopted a network form of organization during the early stages of the field that was less hierarchical than the pharmaceutical template (Powell 1990, Whittington and Smith-Doerr 2005, Whittington and Smith-Doerr 2008). Compared to pharmaceutical scientists, biotechnology scientists have collaborated more freely with scientists in other organizations, worked in a more-horizontal authority structure, and enjoyed flexible project participation (Croissant and Smith-Doerr 2008, Powell 1990, Smith-Doerr 2004, Smith-Doerr 2005, Whittington and Smith-Doerr 2005). To make biotechnology science a success, biotech companies encouraged their scientists to span boundaries and learn (Powell 1990).

While this network form characterized the emergence and early development of the biotechnology field, there are good reasons to believe that the organizational form has changed. Many researchers argue that the biotechnology and pharmaceutical fields have merged together into the biopharmaceutical field though a long series of mergers, acquisitions, and jurisdictional poaching touched off by the Great Recession and flagging innovation (May 2010). Pharmaceuticals bought small biotech companies for their intellectual property and the most successful biotech companies purchased pharmaceutical companies for their production and distribution capabilities (Paruchuri 2010). Biopharmaceutical companies are likely to have

adopted an organizational form that is more guarded, centralized, and structured than the network form characterized by Powell (1990) and Smith-Doerr (2005). In particular, biopharmaceutical scientists face more organizational oversight with regard to their advice-seeking across organizational boundaries.

In this study, I examine how scientists working in the biopharmaceutical field deal with obstacles that occur during research and development (R&D) because it reveals aspects of the organizational form – the formal structure, informal norms, and relations with other organizations (Hannan and Freeman 1977) – when they seek advice from other scientists. In particular, research obstacles and the associated advice-seeking involves a tension. On the one hand, R&D is a core activity in the biopharmaceutical field (Powell, Koput and Smith-Doerr 1996) and therefore expected to be strongly protected (Hannan and Freeman 1977, Williamson 1981). On the other hand, solving complex problems requires expertise and novel information that is often located in other organizations (Burt 2005, Cross and Cummings 2004, Powell, Koput and Smith-Doerr 1996). Accessing such information requires fine-grained exchanges between individuals of both organizations, which risks proprietary knowledge getting loose (Bouncken and Kraus 2013, Bouncken et al. 2017).

Two different theoretical perspectives generate expectations regarding how these interorganizational ties will be governed. The first perspective, championed by Powell (1990) and later by Smith-Doerr (2005) and Whittington and Smith-Doerr (2008) describes scientists working in biotech organizations as collaborating more freely, operating in a horizontal authority structure, and taking personal ownership of research projects. From this, it is expected that core scientists of biopharmaceutical project teams face comparatively few restrictions when seeking advice from their personal network contacts in other organizations. This is possible due to high

levels of institutional trust and norms of fairness (Powell 1990, Ring and Van de Ven 1994) associated with the needs of an emerging field characterized by rapid innovation.

In contrast to the network organizational form, the boundary-management perspective argues that, because the biopharmaceutical field is more settled than its earlier characterizations as an emerging field (Paruchuri 2010, Powell, Koput and Smith-Doerr 1996), biopharmaceutical companies are expected to keep tight boundaries around R&D projects when problems arise (Felin and Zenger 2014, Nickerson and Zenger 2004, Santos and Eisenhardt 2005). As a result, biopharmaceutical scientists rely on formal authority structures, even when seeking advice from their network contacts. Relative to scientists working for biotechnology companies during the emergence of the biotechnology field, advice-seeking in the present biopharmaceutical field has an increased presence of organizational oversight that functions to safeguard the intellectual property of biopharmaceutical organizations.

Examining the process through which biopharmaceutical scientists deal with research obstacles ought to reveal the organizational structure and patterns of activity associated with scientific problem solving and activating interorganizational ties. To that end, I interview 36 biopharmaceutical scientists engaging in research and development work. We spoke about the formal structure of their organizations, communication norms, and the problem-solving process they followed to deal with a recent research obstacle that they considered serious or important to an ongoing research and development project. These conversations reveal that problem-solving is more guarded and involves more hierarchical structure than expected from research about the organizational form of early biotechnology organizations.

LITERATURE REVIEW

Organizational Forms

The idea of an organizational form captures the interplay between the formal structure and informal structure of an organization as well as how an organization relates to its environment. As conceptualized by Hannan and Freeman (1977: 935), an organizational form is:

> a blueprint for organizational action, for transforming inputs into outputs […] [that is] inferred, albeit in somewhat different ways, by examining any of the following: (1) the formal structure of the organization in the narrow sense – tables of organization, written rules of operation, etc.; (2) the patterns of activity within the organization – what actually gets done by whom; or (3) the normative order – the ways of organizing that are defined as right and proper by both members and relevant sectors of the environment.

This concept accounts for much more than an organization's physical layout and organizational chart; it aims to capture the goals, resource-flows, and governance of an organization (Aldrich 1999). An organizational form presents a picture of how organizations function, take advantage of opportunities, adapt to changing circumstances, shape their environments, and survive changing circumstances (Child and McGrath 2001, Hannan and Freeman 1977, Heydebrand 1989, Murmann 2003). It enables and constrains social networks within and between organizations (Castilla, Lan and Rissing 2013). In the case of the biotechnology field, companies promoted flexible activity patterns and norms of mutual support across organizational boundaries that maximized organizational learning and awareness of the field through interorganizational ties activated and by scientists that laid the groundwork for formal collaborations (Powell, Koput and Smith-Doerr 1996).

Knowledge, Social Networks, and Innovation

Networks are essential to knowledge-intensive fields like biopharmaceutical science. Individuals, teams, and organizations face a steady stream of complex projects, rapidly-changing technologies, and non-routine tasks (Cross and Cummings 2004, Jacobs 2017, Powell, Koput and

Smith-Doerr 1996). To succeed in this context, knowledge must be combined from multiple sources (Burt 2005, Gardner 2017, National Academy of Sciences 2005, Powell, Koput and Smith-Doerr 1996). Whether they bridge social circles (Granovetter 1973), corporate divisions (Burt 1992, Burt 2005), professions (Gardner 2017), academic disciplines (Leahey, Beckman and Stanko 2017, McBee and Leahey 2016), sub-disciplines (Leahey and Moody 2014), organizational types (Powell, Koput and Smith-Doerr 1996), fields (Fligstein and McAdam 2012), institutions (Thornton, Ocasio and Lounsbury 2012), or virtually any other social unit; social networks have the potential to connect actors to diverse knowledge, which is vitally important (Burt 2005, Erickson 2003, Huang and Cummings 2011, Reagans and McEvily 2003). Social networks support knowledge-flows, which in turn support key organizational activities.

Maximizing the effectiveness of social networks leads to two dilemmas. The first dilemma concerns diversity (March 1991). On the one hand, opening the doors of communication across boundaries supports a diverse knowledge-base which is adaptable to the problem at hand (Cross and Cummings 2004, Nickerson and Zenger 2004). On the other hand, closing these doors reinforces boundaries, increases internal communication, develops a shared knowledge-base, and focuses attention (Burt 2005, Hernes 2003, March 1991, Oldenhof, Stoopendaal and Putters 2016). The second dilemma involves awareness. Complex problems require exchanges of fine-grained or tacit knowledge that require a common mental map of the situation (Salazar et al. 2012). Thus, both parties are intimately aware of each other's knowledge and the characteristics of the problem (Cross and Cummings 2004). To receive useful knowledge, communication must run both ways, which risks losing proprietary information (Bouncken and Kraus 2013, Bouncken et al. 2017), a major concern in the biopharmaceutical

field (Bartfai and Lees 2006, Child and McGrath 2001). How are these dilemmas of diversity and awareness resolved?

The Network Organizational Form

The idea of an organizational network form provides one answer. Proponents of this perspective argue that organizations should take a collaborative approach that facilitates innovation through knowledge sharing, learning, diversity, and boundary spanning over time (Powell 1990, Powell, Koput and Smith-Doerr 1996). This is accomplished through flatter organizational structures, flexible activity patterns, and normative orders that support more open interorganizational networks and fairness (Croissant and Smith-Doerr 2008, Smith-Doerr et al. 1999, Smith-Doerr 2004, Smith-Doerr 2005, Whittington and Smith-Doerr 2005). Individual scientists are encouraged to pursue research projects that they find interesting, share recognition, and exchange information with contacts outside of their organization (Smith-Doerr 2004). In addition to scientific knowledge, personal knowledge flows freely through these networks, which provides reputational sanctions against scientific malfeasance (Powell 1990, Smith-Doerr 2004). Here, formal structure gives way to the informal structure; boundaries around core activities are permeable enough to allow scientists' networks to operate as freely as possible. While discussing complex problems may give away proprietary information (Smith-Doerr 2005), this lays the groundwork for additional collaborations (Powell 1990). Because networks are governed through the informal organizational structure and norms in the scientific community, the boundaries associated with core activities are permeable. This form is exemplified by the biotechnology during its emergence as biotechnology organizations struggled to understand the fundamental insights of their novel science (Powell 1990, Powell, Koput and Smith-Doerr 1996).

Boundary-Management and Problem-Solving

In sharp contrast to the network organizational form, extant theories of organizations that examine boundary-management set an expectation that tighter boundaries are drawn around core activities, indicating that interorganizational networks fall under the formal oversight of organizations. Transaction cost economics (TCE) argues that organizations exist to govern transactions and align interests by forming boundaries around key activities. The more specific the materials, geography, and knowledge-embodiment; the more that exchanges are expected to be located internally and managed within an organization's hierarchy because it is more efficient (Williamson 1981). All these conditions are present in the biopharmaceutical field where companies depend on specific materials (Murray 2010, Powell 1990), are clustered in geographic regions (Saxenian 1994, Sonmez 2017, Whittington, Owen-Smith and Powell 2009), and rely on the embodied expertise and experiences of doctoral level scientists (Bartfai and Lees 2006, Luo, Koput and Powell 2009).

More recent theoretical developments argue that hierarchical and centralized structures give organizations better leverage with their existing knowledge (Santos and Eisenhardt 2005), especially when working to understand complex problems (Felin and Zenger 2014). This is not to say that isolation is desirable. Rather, the boundary-management perspective argues for the active role the formal structure must take to aid understanding of problems and to support problem-solving activities by actively shaping boundaries around key activities, loosening or tightening boundaries as necessary (Baer, Dirks and Nickerson 2013, Felin and Zenger 2014, Heydebrand 1989, Nickerson and Zenger 2004). Because networks and boundaries are governed by the formal organizational structure, boundaries associated with core activities are expected to

be more tightly-drawn and networks more hierarchical than the network organizational form prescribes.

Problems and Problem-Solving

Research and development is a core activity within the biopharmaceutical field (Daghlian 2013, Friedhoff 2009, Powell, Koput and Smith-Doerr 1996). Each year, biopharmaceutical companies release blockbuster drugs worth hundreds of billions of dollars that influence patient health and shareholder wealth (Bartfai and Lees 2006, Nakagawa and Lehman 2015, Ng 2004, World Health Organization 2013). To deliver these blockbusters, biopharmaceutical companies constantly expand into new scientific territory (Powell, Koput and Smith-Doerr 1996). Interestingly, biopharmaceutical research and development is characterized by failure (Firestein 2016). As a project moves through the various phases, it becomes more likely to succeed, as indicated in Table 1, below. Based on figures presented by several researchers, the failure rate starts at about 99.98% in the earliest "play" phase and diminishes to 10% after a New Drug Application is approved (Bartfai and Lees 2006, DiMasi, Grabowski and Hansen 2014, DiMasi, Hansen and Grabowski 2003, Firestein 2016). Even though projects are more likely to succeed in later phases, failure and delays become more costly (Philippidis 2016).

[Figure 1 Here]

These data support the claim that biopharmaceutical R&D projects are under constant threat of failure; in order to avoid project failure, scientists must engage in problem-solving. Problems occur when an actor has a goal, but does not know how that goal is to be reached from the current situation (Duncker 1945, Novick and Bassok 2005, Rittel and Webber 1973). Potential problem-solvers must be aware – to a greater or lesser extent – of the characteristics of the situation they face (the source situation) and the desired situation (the target situation). A

problem is relative to the actor or actors experiencing it; a problem for one actor is not necessarily a problem for another actor who understands how to deal with it (Collins and Evans 2007, Novick and Bassok 2005, Rittel and Webber 1973). Actors with different backgrounds and different experiences are likely to represent the current situation, desired situation, or transitional steps differently (Novick and Bassok 2005, Rittel and Webber 1973, Thornton, Ocasio and Lounsbury 2012). Here, a scientist with an obstacle approaches someone else for a solution.

To focus attention on problems related to biopharmaceutical research and not other types of problems like problems related to organizational strategy (Reiter-Palmon and Illies 2004) or social problems (Rittel and Webber 1973) that call for different types of processes, I introduce the idea of a research obstacle. A research obstacle is a challenge that must be overcome in order to fulfill specific research aims pursued by individuals, teams, or other social units[1]. By focusing on research that is underway, the concept of a research obstacle selects situations where actors are most aware of the state of their R&D project, the desired research aims, and course of action; even if such awareness remains tacit. Moreover, research obstacles have the potential to seriously threaten R&D projects, a core component of the biopharmaceutical field.

Examining how biopharmaceutical scientists are supported and constrained by organizational structures and norms as they engage with problem-solving to deal with research obstacles acts as a stress-test to better understand the organizational form of biopharmaceutical organizations. Because of this sense of threat, it is expected that boundaries associated with core R&D projects will be tight and governed more by biopharmaceutical organizations' formal structure more than their informal structure.

[1] A research aim is what research seeks to accomplish National Institute of Neurological Disorders and Stroke. 2014, "How to Write a Research Project Grant Application": National Institute of Neurological Disorders and Stroke. Retrieved February 15, 2014, 2014 (http://www.ninds.nih.gov/funding/write_grant_doc.htm).

DATA AND METHODS

The Biopharmaceutical Field

The research context is the biopharmaceutical field. It is a massive, knowledge-intensive industry that is constantly expanding into new frontiers of knowledge (Powell, Koput and Smith-Doerr 1996). This field is somewhat unique, due to its large research and development spending and interorganizational collaborations (Daghlian 2013, Friedhoff 2009, Powell, Koput and Smith-Doerr 1996). To deal with the complexity of biopharmaceutical research and development, biopharmaceutical companies employ large numbers of scientists with doctorates and other advanced degrees (Luo, Koput and Powell 2009) who fulfill their scientific pursuits in well-funded labs (Bartfai and Lees 2006, Smith-Doerr 2005). Core scientists are affiliated with teams in their functional areas to develop scientific approaches and broad lines of research (Nakagawa and Lehman 2015). This depth of expertise is complemented by working in teams. A formal matrix structure that matches functional areas to ongoing projects brings scientists with different expertise to work together on each R&D project (Aldrich and Ruef 2006, Nakagawa and Lehman 2015). Moreover, there is structured turnover. As projects move through R&D phases, they drop and add scientists from different functional areas (Friedhoff 2009, Nakagawa and Lehman 2015).

The biopharmaceutical R&D process is broken into distinct phases, although it is important to note that each phase may be elaborated further or blur into adjacent phases at times (Nakagawa and Lehman 2015). Although not generally acknowledged in the literature or public mind, the majority of biopharmaceutical projects start from a "play" phase where ideas that may eventually become names projects are pursued enough to spark interest (Firestein 2016). In the next phase, called discovery, scientists work to learn more about how a specific target functions and the chemicals that could intervene in its functioning. After discovery, the project moves into

the development phase where scientists work to establish effectiveness and model the process by which the drug enters a human body, travels to the target, interacts with the target, interacts with the human body, and leaves a human body (Ng 2004). Chemical manufacturing and control starts to adapt the in-house manufacturing process to large-scale production for clinical trials and market demand; it often requires using commercially-available chemical libraries and contract research organizations (Bartfai and Lees 2006). In order to move into clinical trials in the United States, biopharmaceutical companies must file an Investigational New Drug application with the Food and Drug Administration that allows the drug to be shipped across state lines (Bartfai and Lees 2006, Ng 2004). While an Investigative New Drug application allows a clinical trial to begin, it is also a public event that triggers the start of a twenty-year patent clock (Finkel 2012). Unless there are hurdles that cannot be overcome, the drug then enters into a clinical trial phase that establishes the safety, dosing efficacy, side effects, and effectiveness of the drug in three phases (DiMasi, Hansen and Grabowski 2003). Success in the clinical trial allows the company to file a New Drug Application with the FDA (Nakagawa and Lehman 2015, Ng 2004). After approval, the company is allowed to market and sell its drug, within restrictions. The clinical trial continues to be monitored by the FDA, which can last over a decade, depending on the nature of the drug and how it is marketed (DiMasi, Hansen and Grabowski 2003).

Sample

To investigate how biopharmaceutical scientists deal with research obstacles, I interviewed 36 scientists working in the biopharmaceutical industry. In an effort to partially control for the social norms of different geographic regions, recruitment initially focused on the Greater Boston area because it is a major biopharmaceutical cluster with a high concentration of biopharmaceutical companies, research institutes, universities, and a growing norm of industry-

university collaboration (Saxenian 1994, Smith-Doerr 2004, Smith-Doerr 2005, Werth 2014). Recruitment efforts began in the spring of 2015 and focused on the core scientists of two companies, a biotechnology company and a biopharmaceutical company, working in the earlier phases of research (discovery and development). In addition to interviews with 27 scientists in the Greater Boston area, recruitment expanded through the summer of 2016 to include biopharmaceutical scientists in the Tri-State area through LinkedIn. After surveying members of the American Association of Pharmaceutical Scientists (AAPS) for the other studies in this dissertation, I also interviewed a small subset of them, which included a couple of scientists working in the Bay Area of California and other locations. In total, I interviewed 36 biopharmaceutical scientists.

While interviewees are clustered in the Greater Boston area, they represent deep knowledge of their organization and the biopharmaceutical field over the past decade. To maximize comparisons with extant research that focuses on biotech companies (Powell, Koput and Smith-Doerr 1996, Smith-Doerr 2004, Smith-Doerr 2005), half (50%) of respondents worked for biotech companies; 28% work for biopharmaceutical companies, and 11% work for pharmaceutical companies, as shown in figure 2C[2]. As indicated in figure 2B, the majority (75%) of respondents work in the Greater Boston area; another 11% work in the adjacent Tristate area, 6% worked in the Bay Areas, and the remainder worked in other locations. Based on respondents' LinkedIn profiles and interview transcripts, they had worked in the biopharmaceutical field for an average of 14.6 years (sd = 4.6). The vast majority (83%) had worked in the same organization for two years or more. Organizational tenure ranged from one year to 16.7 years, but averaged 5.5 years (sd = 4.6). Most respondents (70%) had worked in at

[2] Company websites were reviewed to determine the organizational type.

least one other biopharmaceutical company before their current employment, discounting post-doctorate positions. Half of respondents (50%) earned one or more doctorate and just over one-third (36%) held a Master's degree. (See figure 2A.) These respondents represent good coverage of the major research phases. The positions of seven respondents (19%) allowed them to substantially engage with more than one research phase. These overlaps are included in Figure 2D. When compared with percentages provided by the American Association of Pharmaceutical Scientists (2016), the discovery phase is over-represented by about 20%; the development phase and clinical trial phase are under-represented by 13% and 9%, respectively.

[Figure 2 Here]

The Interviews

The interview guide was developed in consultation with a lawyer who had practiced intellectual property law, a former project manager for a multinational pharmaceutical company, and several project leaders in the biopharmaceutical field who provided background information. These efforts aided rapport as it allowed me to become familiar with concepts, terms, and organizational boundaries of the biopharmaceutical field. My rapport with interviewees was generally excellent and aided by our common experiences in graduate school. Taking my set of questions as a guide (Weiss 1994), I offered no objections if they steered the conversations into personal matters, but we mostly discussed the formal structure of their organization, norms associated with network activation, and the process they followed when dealing with a recent research obstacle that they considered serious or important to an ongoing R&D project. Because interview questions focused on ongoing research projects, respondents were encouraged to discuss the social aspects of their work and avoid technical aspects.

Interviews were conducted by phone at a time chosen by respondents, conducted through *Skype*, recorded using *MP3 Skype Recorder*. Conversations with interviewees ranged in duration from 20 minutes to almost three hours, although most lasted between forty-five minutes and an hour. Most recordings were transcribed by a professional transcription service that utilized technology, to maintain anonymity on their end; I transcribed the small remainder. Then, I extensively de-identified these transcriptions to ensure confidentiality by obfuscating respondents' speech idiosyncrasies and any mention of an individual, organization, project, location, or scientific term, unless it was exceptionally general or rhetorical. Thus, I made extensive use of pseudonyms and modified direct quotes. De-identified transcripts were loaded into ATLAS.ti8, a popular computer-assisted qualitative data analysis software that was used to for various coding steps (Friese 2012). I coded the entirety of transcripts following a generic coding method described in Saldana (2013) and Strauss and Corbin (1998) that aimed to capture *a priori* codes, generate inductive codes, and flesh out subcodes during open/initial coding. Following Friese (2017), organizational type (Biotech, Biopharmaceutical, Pharmaceutical, and Other) and organizational size (Small < 100 employees, Medium < 1,000 employees, Large = 1,000+ employees) were entered as "variables" or characteristics that are prefixed by a hashtag. Organizational type (#type) was recorded from self-descriptions of respondents' organizations' public websites, e.g., Celegene would be considered a biopharmaceutical organization because its official website describes it as "… a major global biopharmaceutical corporation…" (Celgene 2017). Organizational size (#size) was determined by referencing data from a survey of scientists affiliated with the American Association of Pharmaceutical Scientists. About 50% of survey respondents worked in organizations with fewer than 125 scientists; 30% worked in organizations with fewer than 1,000 scientists, and the remaining 20% worked in organizations

with more than one thousand scientists. It appeared reasonable to categorize small organizations as those with 125 or fewer scientists, medium-sized organizations as those with up to 1,000 scientists, and large organizations as those with 1,000 or more scientists. These thresholds correspond relatively well to the accounts of interviewees. Scientists in small companies (fewer than 125 scientists) often referred to their company as "small" or "tiny." Many times, when interviewees referenced the size of companies, they referred to very large organizations with more than 1,000 employees. For instance, Raham, who works at a biotech company, said, "I've [interacted with] a couple of big companies. I can name them – Merck, Johnson and Johnson, Amgen …" While not precise, these thresholds appear to match the account of interviewees as well as descriptive data from a survey of scientists working in the biopharmaceutical field.

To better capture the context of these conversations, I coded simultaneously at the level of paragraphs or conversational response (Saldana 2013). Having selected organizational form and problem-solving as central codes, axial coding was performed on these two codes to relate structure and process (Strauss and Corbin 1998). Selective/theoretical coding was then used to integrate other codes and generate a narrative for the data (Saldana 2013, Strauss and Corbin 1998). To use anlaysis features of ATLAS.ti8 to explore possible differences between organizational type and organizational size, I applied the qualitative variables (Friese 2017) to entire responses. Key codes, qualitative variables, and their conceptualizations appear in Table 1, below.

[Table 1. Here]

RESULTS

The Organizational Form

As expected, biopharmaceutical companies are organized along the lines of functional

areas, teams, and project leaders. These structures contribute to the organizational form – the formal structure, patterns of activities, and norms (Hannan and Freeman 1977) – of biopharmaceutical organizations. Functional areas focus the attention of core scientists on developing capabilities in certain methodologies or areas of unmet need. Often, functional areas form around research phases, areas of expertise, or targets, e.g., a company may have functional areas for development, biostatistics, cancer, and pain. Each functional area works to ensure their scientists are up to speed with new developments in their respective fields. Frederick, the vice president of research of a medium biopharmaceutical company whose work focuses on the discovery phase, described the complicated, shifting affiliations with his company's platform technology group, which is an interdisciplinary functional area. When I asked if most of the people in this group had a similar disciplinary background, Frederick said:

> Our team is very, very interdisciplinary. We have chemistry, we have people from different areas of chemistry. There's RNA synthesis, medicinal chemistry. There's biology, and even biology, right, has a couple of different flavors. We have the screeners, the cell culture *in vitro* type of people, but then we have also people who run *in vivo* biology and animal models. Then we have people who know more about the biochemistry and do some biochemical assays. […] some activities get de-prioritized. So people can move around. […] That flexibility, if it's done well so people really understand why they are moving and what the underlying rationale is, then it works very well. Nobody really wants to be on a team when they have nothing to do. Because that makes you feel sort of obsolete. That's not a good feeling to have.

In addition to being affiliated with one or more functional areas, core biopharmaceutical scientists contribute to one or more project teams. Aaron, who is a senior scientist at a small biotech company, discussed how teams are set up to ensure that someone from each relevant functional area is represented on each team at each R&D phase.

> The way [a team is] is set up – a project leader is assigned. That project leader puts together a group of people to represent each work-flow, each functional group, along our work-flow chart. You essentially have a point-person that's going to be responsible for every single functional task that needs to be performed in order for you to push the project along. […] [But] they evolve. Say something is a new project. You'll have the members of the team from the functional groups involved in the early discovery paths.

> Such as induction, screening, purification, data, the bio group is given the first tasks to come up with a set of binders. As you push down the line [progress the project], people are thinking about the milestones that we've completed. There are key points at which we are incorporating group members from other functional departments, such as regulatory, development, tech ops, clinical, business development. As we advance the project, we draw from these groups, because we know their contributions will be important. […] So the [project team] modifies [its] structure as the project moves further and further down the line.

Project leaders do not always get the members they wish for; several executives mentioned that assignments are based on scientists' expertise, experience, personal interest, development potential, and existing project commitments. There is flexibility associated with project participation, but there are limits. Fiona, a project leader in Aaron's company mentioned that:

> It was always interesting because, when we had a project, it would be the same thing. They would pull one person from each group in lead discovery. For that project leader it was always 'Who am I going to get?" because 'who I get' could really alter the course of this project. […] So much of this is personality-driven. It's so personal that you hope you get the right person that is going to mesh well with the rest of the team. Not just with the project leader, but with everyone else on team because if [team members don't] get along […] it just creates tension

Project leaders have to deal with potentially conflicted or demotivated team members. Larissa, who works at a small biotech as a project leader, when asked what she found challenging about that role, said "The most difficult thing to managing a team is that we all work on multiple projects. To get everyone's full attention at one time can be challenging. There are other problems that can be appear that have priority in different projects at [the same] time." Raymond, who now works for a medium biopharmaceutical company, openly discussed becoming demoralized about working on a project with poor prospects at a large pharmaceutical. He said:

> What was frustrating was you could know from first principles that this wasn't going to work, and yet we spent like three years on it, […] but everybody was ignoring the elephant in the room, which was the fact that it wasn't going to work. […] I wasn't willing to say to my bosses, "No. I don't waste my time like that. Find somebody else to

do it; I'll get another job." I hadn't matured to that point.

The organizational form utilized by biopharmaceutical companies has changed over the past couple of decades to include more project oversight. Raymond supports this idea of a field-wide shift towards active management:

> If you go back into the '60s, '70s, early '80s, it [the biotech field] was very quirky, it was very individual. Scientists were working on their own, they would come up with a good idea, and it was science that was driving those decisions. And then some breakthroughs happened, there was a lot of money being made, and then the business guys figured out, "Hey, this is inefficient, this is quirky; how do we institutionalize this?" [The business guys] started setting up infrastructure to make it more efficient. […] What started happening was decisions were being made by committees that weren't close enough to [the science] […] [If] the chemists are getting measured on how many things they make, and the biologists are getting measured on how many things they test […] then you're guaranteed chemists will make stuff [and] biologists will test stuff. [But] if it made it to the clinic, they really didn't have faith that it was going to work.

Aaron, a senior scientist at a small biotech company notes that detailed planning is widely practiced in the biopharmaceutical field, but relatively new:

> There's [been] a big push since I entered the business ten years ago. The way things are done now – I know this from conferences – is to really address these issues [research obstacles] as early as possible in the discovery process. Because the later you do it, the more time you have wasted because you have to go back to the beginning in order to fix it. Or, you have to play around with your product at the end of the line to get rid of those certain characteristics identified late in the game.

Despite the possibility of having to contribute to less-exciting projects and formal project oversight, many respondents spoke about the collaborative and supportive environment of their work. When I spoke with Travis about the culture at the small biotech where he worked, he said, "The first word that would come to mind is 'collaborative.' That's a bit of a cliché, in this industry; many companies will say that." Tabitha, a core scientist for a large multinational biotechnology company said:

> The project teams that we work on are really great. I love them. Because there's one person there from [each] different division – like a different discipline. So you're constantly learning from the different people because this is not your area of expertise. You're there to provide your area of expertise. But everybody else is providing theirs and

so you get to learn from them. And I really like it.

Many interviewees reported that their work brought them into contact with personnel at other biopharmaceutical organizations, often in other countries. This increases scientists' awareness of their field. Despite being distributed globally, the field has the feeling of a small world. Sue, a project manager for a small biotech located in the Boston area mentioned this when discussing working with a contract research organization (CRO).

> We always have used CROs. [We] never manufacture our self, but we always use somebody else. In the past we have used a CRO in the European Union. One day [my supervisor] met and said "I did not know you have been just [visiting] this country. If I had known, I would have asked you to visit them [the CRO in the EU]." I said "Oh, I know a bunch of them through the conference[s] in the past. Several of my friends moved [to work for] that company.

Larisa, a project manager, discusses how, since her role has changed from selling her company's technology to purchasing technologies from other companies after a promotion, she has learned more about the biopharmaceutical field. She said:

> I definitely like working with collaborators. Before this project, I was a project manager for external projects. I did a lot of work for clients on the other side. Right now, we're hiring all these technologies [for a project]. So I'm managing these meetings, but they are reporting to me. Where before, I would report to our client. I'm learning about all these new technologies that are out there

These accounts of the formal structure of biopharmaceutical organizations appear to support the idea that many features of the network organizational form outlined by Powell (1990) to describe the early biotechnology field remain in the biopharmaceutical field, with some qualifications. While biopharmaceutical organizations appear to be less hierarchical in their formal structure than the large pharmaceutical organizations described by Powell (1990), the formal structure is more pronounced and hierarchical than expected. This supports the boundary-management perspective. In particular, the matrix structure that links scientists, projects, and functional teams develops scientists' depth – as well as breadth – of expertise that supports

organizational learning. Scientists' project participation is not as flexible as expected, but they are not without the capability to negotiate their way into exciting research opportunities and external collaborations.

Research Obstacles

Earlier, I defined the concept of a 'research obstacle' as a challenge that must be overcome in order to fulfill specific research aims pursued by individuals, teams, or other social units. These challenges are a common aspect of biopharmaceutical research and development and, I argue, reveal aspects of the biopharmaceutical organizational form not present in the conversations above. I asked scientists whether their projects experience research obstacles. Dwight, who has over 25 years of experience working in several multinational pharmaceuticals, if he could think of any industry project that did not experience a research obstacle, he highlighted the uncertainty and complexity of moving research from an animal model (experiments on mice) and gauging effectiveness in the human body (clinical trials). He said:

> No. I don't think we've ever been on a project where we had everything we needed to know. You are dealing with an *in vivo* system. That's a quantum leap. I'm trying to use an animal model to think about what might be happening in people. Until you get it [the drug] into people, you don't know what's going to happen. You discover all these potential problems. Sometimes, you think you have solved a problem, but you get it [the drug] into people, you [can] discover you didn't have all the right information. You got the wrong model.

Amit, an associate scientist at a large biotech company, when asked a similar question, stated, "But to that question, I'll try to be brief. I think research obstacles always happen." Parker, who works in chemical manufacturing and control, said, "there can be all sorts of problems. There can be – oh, where to begin?" Tabitha, who works on clinical trials said, "I mean, honestly, in our business there's always something bad going on." Landon, a senior manager working in

development at a large pharmaceutical agrees, saying “I guess every project has them but what’s interesting is that they’re always slightly different.”

When I asked these scientists to describe their research obstacle in general terms, many gave responses like Dwight. Research obstacles often stem from the fact that the science being developed is novel and therefore prone to failure (Firestein 2016); it is simply difficult to have ideas pan out. In some situations, the science is new enough that determining the difference between negative results and poor execution is problematic. Sahil, the director of discovery research for a biopharmaceutical company, said “We’re coming up with a new technology. Even if that technology works, if your target gene is not behaving as it should, you don’t know whether your technology is working or not, or whether you did something wrong. Phillip, a staff scientist working at a small biopharmaceutical, described how difficult it is to understand some worthwhile targets, even in the absence of negative findings.

> For some diseases – especially for cancers – people thought, “Aha! If you look at a normal cell, versus a cancer cell, you notice a cell-wall receptor – basically, a protein sticking off the cell. In a normal cell, there’s maybe a hundred molecules. In a cancer cell, it may be a thousand or ten thousand of these proteins. A hundred versus ten thousand. In many cases, you can block [receptor A] and you think that should lead to a curative effect. But what happens in that there’s another receptor B that’s also indicated in cancer cell growth. Well, receptor A is blocked, but the cancer cells are still growing. What you’ll find is that receptor B is [now has] ten thousand [of these proteins].

Although research obstacles come from a variety of sources, the scientists I interviewed consistently used the same evaluation criteria to explain their perceptions of the seriousness of a research obstacle and decide how to proceed. Comments from Parker summarize these criteria well. When I asked him how scientists understand if a research obstacle is serious, he said “If it's going to affect timeline, cost or quality.” Shortly after, he elaborated “If it's something where I'm not sure that we can proceed with what we've got, or it's going to cost a lot more to fix something [or] if I see an opportunity to speed something up or add value, we'll bring that up, too.”

Timeline, cost, and quality are scarce resources for some biopharmaceutical companies. Dwight, who has decades of experience as a CEO of a multinational pharmaceutical working in discovery and strategy, mentioned how scientists working in small biopharmaceutical companies may get desperate when facing research obstacles because they trigger an existential threat.

> They [small biopharmaceutical companies] may have more drive because they have more to lose. They have a portfolio, in many cases, of one product. They approach risk, risk-management, and risk-mitigation very differently than a mid-size pharmaceutical company. […] In a small company, you have a different mentality. You get a little more creative and a little more desperate trying to find additional collaborators and other ways of getting things done.

Such a sense of desperation bleeds into research obstacles at the later phases where the cost of conducting research – and the costs of failure – are extraordinarily high. When I asked Parker, whose work at a large pharmaceutical focuses on clinical trials, about whether he faces work pressure associated with research obstacles, he explained how being on the patent clock influences the potential impact of a research obstacle. The situations he describes pertain to filing a New Drug Application, which completes the bulk of clinical trial research. In order to start these clinical trials, the company had to have filed an Investigative New Drug Application years earlier, which starts the patent-clock.

> Any delay in filing means [that] every day that you're late is one less day that you have to market the drug before you lose exclusivity. So a six-month delay on – a six-month delay means you're losing six months of peak sales because you're going to be at peak just before it goes generic. I've been in situations where, if we have to delay this three months and it's going to be a billion dollar drug, that's $250 million that we're throwing away. No pressure.

This section establishes that research obstacles are present within the biopharmaceutical field. As expected in a knowledge-intensive context fraught with project failure, research obstacles must be overcome in order for projects to move forward. Many of these obstacles stem from the fact that cutting-edge science is simply difficult. Thus, scientists engage in problem-solving, the process of which is described in the next section.

Problem-Solving

Scientists' accounts of their efforts to deal with a research obstacle reveal more characteristics of the organizational form of biotech companies, especially the social norms associated with advice-seeking. The following presentation begins with individuals and their jurisdictions (Abbott 1988), passes through the intermediate social units of functional areas (Burt 2011, Burt 2005) and project teams (Mortensen and Gardner 2017, Somech and Khalaili 2014), before ending at the level of organizational capability (Kogut and Kulatilaka 2001) and the interorganizaitonal environment (Powell, Koput and Smith-Doerr 1996). The first jump, from the personal jurisdiction of a scientist to a functional area that he or she is affiliated with, represents increasing depth of specialization (Leahey 2007, Leahey and Hunter 2012) in that scientists are seeking advice from scientists with similar expertise. The second jump, from functional areas to the cross-functional team, represents increasing breadth of expertise in that a more interdisciplinary group of scientists (Boix Mansilla, Lamont and Sato 2016, Fiore 2008, National Academy of Sciences 2005) is called for to deal with an issue beyond the scope of the original functional area. Should the cross functional team fail to address the obstacle, the project may fail or be set aside unless sufficient external resources are secured, which may involve a formal collaboration with another organization (Powell, Koput and Smith-Doerr 1996).

Individual Jurisdictions

Many research obstacles can be dealt with by individual scientists. Amit, an associate scientist whose work for a large biotechnology company in the Greater Boston area focuses mostly on the development phase, noted how, for his project, he was assigned to complete work for a project at an intermediate project phase. In this account, Amit references his personal responsibility to solve research obstacles, potential support from his colleagues and manager, and the evaluative

criteria of quality and timeline, which factor into a judgement about how scientists ought to address research obstacles in general based on experience. He said:

> I will be the only one working on it [a particular project goal]. I have to come up with new ways to solve a certain kind of situation. Sometimes people will help if they have time, but I will have to do that by myself. My manager said that if it gets [to be] too much effort, they will get someone to help me. If it is a most-focused kind of work, then it is a bit more intense, but it is more interesting. Because I am responsible for that area of the work, all my team members will be depending on me. I want to do it properly and within time.
>
> Some people seek help earlier and some don't. If you don't and if you don't know what's going on and you try to solve it [a research obstacle] on your own, you kind of – you fight your way through [the obstacle]. That can be good, but it can also lead to a delay [when] you're not [ably] solving it on your own. And then, because you kind of kept everybody waiting, that's not necessarily such a good approach, right?
>
> As a scientist, one of the things you learn relatively early, especially when you did projects completely on your own, you know that you always reach a point where you need extra help, right? Whether it's reading through the literature or finding your peer or your supervisor or whoever, you know that you're not going to be able to solve that problem on your own. And a couple of those experiences normally tells you when to pull the trigger on that. And it's not viewed negatively at all, you know.

In discussing scientists' understandings of their expertise, strengths, and weaknesses, Franklyn mentioned the boundaries he draws around his expertise, which allows him to identify when an issue is beyond his reach. He said, "I do have a certain level of arrogance – it might be arrogance. I prefer that it be confidence. I know what I know and I know what I'm good at. [But] I'm not afraid to ask for help."

The Intraorganizational Structure

Scientists have options of whom to turn to when their individual expertise and experience are insufficient to address a problem. Typically, the first person they would turn to is the scientist who happens to be working close by. These are individuals are likely to be working on similar projects within the same functional background. After this, many respondents expressed that the normal course of action is for scientists to notify the project manager and seek out advice from

within their functional area. The boundaries of the project expand rapidly, but remain within the organization. As Travis mentioned, after applying one's own efforts:

> Usually, that's followed by interaction with their supervisor and the supervisor attempts to assist. Can they define the problem better? Are there work-arounds or alternative strategies? Usually, it is within a functional area that the problem is further worked on. If the obstacle cannot be solved within that functional area, obviously, that's reported out to the project team. If it can't be resolved, then very often, the supervisor or the research scientist will involve cross-functional team mates to help define the problem. Now you've gotten into a bigger scope.

Jim describes how increasing the scope of the response pulls in experts from functional areas that normally remain peripheral. When cross-functional teams hit a wall, the project's boundaries expand yet again:

> For the unanticipated problems the project team is more involved. It actually expands when there's unanticipated problems, because it will often include – operations is kind of included in the project team but usually not until absolutely necessary. But as soon as you get a serious problem and you need to have everybody on board then they're included, some of the higher level people, and quality assurance is included where, often, in the project team they're not a big part of it. Groups are there – I don't want to call them support groups because I don't want to minimize their role – if they weren't there, we'd miss them. [It's a] 'When we need them, we really need them' kind of thing.

Fiona, a leader of project that is close to filing for an Investigative New Drug, which is a major cornerstone occurring prior to most clinical trials, describes a similar process when dealing with a challenging research obstacle

> At this point, we had settled on a lead molecule, and now we're looking at it saying 'this might not be the one that we want to go with.' When this happens, the first thing I do is find out, for sure, if this is going to be a problem. You go to the purification and development people because they're the people who would deal with an issue like this downstream [and] talk to them. "I want to know, from you, is this a big deal? What are your thoughts on it? Is this something that we could deal with? Is it something that we couldn't deal with? How big of a red flag is it, basically?" […] It will take a couple of weeks to get that information, but that doesn't hold us up from moving forward with some research tasks that can ameliorate the problem.

The accounts of Travis, Jim, and Fiona were chosen because they provide a rich overview of the problem-solving process described by others only in part. Moreover, these three quotes,

while they describe a similar process, come from both biotechnology and pharmaceutical organizations of large and small size. They all describe a process that is designed to solve research obstacles at the individual level where coordination and communication costs are minimized, but culminates when the breadth and depth of expertise of the organization are leveraged against these challenges. Again, every effort is made to keep problem solving within organizational boundaries. When these actions fail, interorganizational networks ties are activated.

The Interorganizational Structure

One of the most striking points of conversation with these scientists occurred when they were asked about utilizing their personal networks to acquire advice from scientists in other organizations. Proponents of the network organizational form emphasize the benefits gained from informal governance of interorganizational ties. Because research is complex and complementary organizational capabilities can be found in other organizations, promoting more permeable boundaries is beneficial for organizational learning (Powell 1990, Smith-Doerr 2005). If this holds in the present biopharmaceutical field as it did when the biotechnology field was emerging, biopharmaceutical scientists will have a great amount of control over utilizing interorganizational network ties (Smith-Doerr 2004), even in the case of core R&D projects (Smith-Doerr 2005).

When asked what he and his biotech contacts talk about when they get together, Harrison, whose work at a medium-sized biopharmaceutical company in the Greater Boston area focuses on the business aspects of his organization, mentioned the sense of social monitoring experienced while socializing with scientists from other companies. He said:

> Things like industry news, so deals and that sort of thing. My friends and peers that I talk to, we tend more than anything else to talk about organizational challenges, and career

> paths and stuff that is not proprietary by any means, because there is a nervousness and you are kind of looking over your shoulder talking about propriety or competitive information in a public place in [the Greater Boston Area]. At least you should be and a lot of people certainly are.

When I asked Ned, the CEO of a small biotech company, what advice he gives to his professional contacts, he balked at the idea of freely-exchanging information with anyone but the strongest of network ties. Again, his small company is gearing up to push a small number of projects through the development phase towards filing an Investigative New Drug application, which is a particularly sensitive time.

> Because everything's proprietary, you can't just call your buddy up. I mean, you can, and people do. You got to know the person pretty well, to break that protocol. You don't just do that. As part of your agreement that you sign when you work at a company, you typically can't consult because you're already up to your neck in proprietary information from one company. I've had people email me with general questions and I can provide them with general answers, but we can't consult. I've been approached on a number of occasions, 'Can we hire you on as a consultant?,' and I say, "It's part of my agreement that I can't do that." […] That's why people consult them [the consultants] because you can [talk freely].

How do organizations react when their in-house capabilities are insufficient to deal with a research obstacle? As Ned mentions, when external contacts are utilized for advice, it is through a formal consulting agreement, which protects the intellectual property of the company. Ned continues:

> If it's outside your area of expertise, then you bring in a consultant. If the odds are that you're going to make a bad decision because it's outside your area of expertise, you hedge your bets and you bring a consultant in. […] That's why the consultant business in pharma is huge, because most consultants are people who worked in the industry for a number of years and got sick of […] a nine-to-five job. If you look at all [the people] that I used to work with, I'd say fifty percent are consulting. Most consultants have worked in industry for twenty-plus years, have been around the block, have seen a bunch of stuff, and they're the people that you bounce things off of and say "Wow. Look at this funny thing."

The legal boundaries that protect the intellectual property of one company from escaping also make intellectual property from entering.

From these conversations, I suspected that consultants might link biopharmaceutical organizations, allowing rich exchanges of detailed information. I asked Franklyn if that was the case. He laughed. In his experience, consultants provide guidance towards new knowledge in the field that is being exploited by other companies, but not the new knowledge itself. He said:

> All the consultants that you have will have confidentiality agreements in place with the companies that they're working with. They'll be talking in general terms about best practices. They tip-toe very carefully around any confidential information. I must admit that all the people that I've worked with have all been really good about not telling me anything that I could find to be useful, which is disappointing. [laughs] They've all been very good about managing confidential information from one company to another, being able to abstract the essence of whatever the activity was without couching it in any real-world terms.

Organizational Size

To explore how the structure of biopharmaceutical organizations, research obstacles, and the process of problem solving may differ between organizations of different types, I utilized the co-occurrence feature of ATLAS.ti8 that creates a crosstabulation of chosen variables and counts of each cell. Codes associated with organizational form, research obstacles, and problem solving were rows; each organizational variable (#type and #size) were entered as rows. It became apparent that the two organizational variables are related in this sample. The vast majority (90%) of interviews with scientists working in small organizations (less than 125 employees) were working in biotechnology organizations, most (72%) interviews with scientists working in medium-sized organizations (less than one thousand employees) happen to be biopharmaceutical companies, but interviews with scientists working in large organizations (more than one thousand employees) were almost evenly split between biotechnology companies (43%) and pharmaceutical companies (57%). This overlap between #size and #type is likely due to the sample, which includes scientists working at a small biotech company and scientists working at a medium-sized biopharmaceutical organization.

When the list of quotations associated with each co-occurrence were exported from ATLAS.ti8 and compared, few differences were found in the organizational form, research obstacles, or problem solving process as described by these scientists. However, scientists working in small organizations tended to describe the ease with which they are able to meet and share ideas, creating a generalized awareness. As mentioned by Aaron, who works for a small (less than one hundred employees) biotechnology company:

> we're a very small company. We eat lunch with our executive VP. That's so cool because, immediately, we have access to these people who, either through their contacts or their experience, can offer their suggestions and a path forward, which is extremely important and a lot of fun, really. […] You have access. You have daily input and daily contact with people that you can really learn a lot from.

Artur, who works for the same company adds:

> Nobody is off in a corner, doing their own thing and not involved and aware of everything else that's going on. There is a pretty good face-to-face transfer in meetings. We all carry that around with us as we go to the next project. […] Even if [it's] not the full set of people involved in projects, there's enough overlap that people can raise potential solutions.

When these types of quotations are compared to those of scientists working in medium-sized organizations (between one hundred and one thousand employees), which are mostly biopharmaceutical organizations in this sample, organizational boundaries are mentioned more often. Clayton, who works at Pinory, a small biotech, said the following about his organization's physical and functional boundaries:

> We do have like this other satellite office that we work with routinely and their main objective is to do a bunch of our molecular stuff in gene editing, so they deal with a lot of RNA and DNA and engineered proteins, where we're more on the cellular base and more of a macro level. So sometimes there is that disconnect there. So sometimes, when we see data from them or they see data from us, you've just got to know that you're coming from a different angle.

Carl, who works at a medium-sized biopharmaceutical company, experienced greater organizational boundaries between research teams and management than Aaron or Artur, when dealing with a research obstacle. Carl said:

> We were able to glean some information what could have been the reason and we could confirm it. We actually begin to understand why that experiment failed, that key experiment, why it didn't work out. With this information and knowledge, we're able to propose to the management team a plan to come back and revisit this objective and maybe get it solved. And the management team actually looked at that and were very supportive. Very, very supportive. Nobody blamed anyone. And they said, "Yes, guys, that's important enough. Keep pushing. Go back and try to figure it out."

When I spoke with Jim about how cross-functional teams function, above, I also asked if he experienced any difficulties communicating or meeting with scientists affiliated with other functional areas. He said:

> Some people. A lot of people that are just strictly in commercial operations have a hard time – it's just difficult to communicate with somebody in development and going back and forth without – I don't know. I don't know if they feel intimidated by us or we feel intimated by them or what, but sometimes it's hard to get on the same page. We think so differently about how to solve problems and things like that.

Scientists working in large organizations, those with more than one thousand employees, provided more descriptions of organizational boundaries. When I asked Dwight, whose work for a large pharmaceutical company demanded travel to company sites in other countries, about the advantages of face-to-face communication, he said:

> Face-to-face is very important at the beginning [of working together] for establishing trust so you know who you are working with. [There are] Things that you just can't do over the video. […] Once you've established that trust, then you may not need to go over there as frequently because everybody knows everybody else. [But] For that initial phase – as trivial as it sounds – go out and drink! […] Trust is a big part of project teams and sometimes it's really difficult to do trust over teleconference or videoconference lines.

Another difference is that scientists in larger organizations mentioned having more resources at their disposal. When Dwight compared the resources at his disposal with his friend, who is involved with a start-up in the biopharmaceutical field, he said "I've got a friend who's

got a company up in the Midwest. He just got seed funding; $24 million dollars. You know what? I've spent close to that buying animals in six months." Nandi, who works for a large biotechnology company, mentioned that other project teams may be available to take over problem solving efforts.

> The best case is if you have something to do, they'll just collaborate with another team, cross-functionally. This one team is working on this aspect and now the (inaudible) is showing promise, so they give the molecule to a different kind of group to do their own study. […] They will analyze [it] and give you the results. You have an experienced person doing it [that work] […]

Scientist working in small biopharmaceutical organizations (those withfewer than one hundred employees) thrive on intimacy provided by continuous face-to-face interactions that, consistent with Powell (1990) and Smith-Doerr (2004), are associated with flatter intraorganizational networks. These quotations suggest that as biopharmaceutical organizations increase in size, formal boundaries increasingly enter the picture. Scientists working in medium-sized biopharmaceutical organizations mention traveling between buildings, tensions with the goals of other functional areas, and relationships with managers that, while certainly supportive, are more formal. The scientists I interviewed who work at large biopharmaceutical companies (those with more than one thousand employees) seek out face-to-face interaction when dealing with research obstacles, even if doing so involves international travel. As biopharmaceutical organizations grow, they become more compartmentalized, which strips away the organic nature of interaction enjoyed by small biopharmaceutical companies. This is offset, somewhat, by a claim that larger biopharmaceutical organizations have more resources to put towards problem solving.

DISCUSSION

In this study, I examine how scientists' problem solving efforts reveals important features of the organizational form (Hannan and Freeman 1977) of biopharmaceutical companies. Because R&D is a core activity of the biopharmaceutical field (Powell, Koput and Smith-Doerr 1996), examining this interplay provides a stress-test that reveals patterns of activity associated with scientific problem solving within an innovative field. Interestingly, two broad theoretical perspectives provide different expectations about these patterns. Proponents of the network organizational form (Powell 1990, Smith-Doerr 2005) set expectations that scientific problem-solving depends relies on the informal organizational structures, particularly less-formal relationships between scientists working in different organizations. Although formal collaborations between biotechnology firms were plentiful throughout the emergence and development of the field, each formal contact was just "the tip of the iceberg" that was supported and motivated by numerous informal collaborations between scientists, many of which involved their colleagues working in other organizations (Powell, Koput and Smith-Doerr 1996: 120). In contrast, a boundary-management perspective predicts that distinct boundaries are drawn around core activities, especially when these activities are threatened (Felin and Zenger 2014, Heydebrand 1989, Nickerson and Zenger 2004, Santos and Eisenhardt 2005). Interorganizational ties, while important for problem solving, are activated through – and governed by – the formal organizational structure.

The results of my interview conversations with 36 core scientists about how they deal with research obstacles support the idea that biopharmaceutical organizations have a form that still retains many features of the network form described by Powell (1990) and Smith-Doerr (2005), yet has drifted away from this ideal type. In particular, the formal structure plays a more

active role throughout the problem solving process. This structure still empowers scientists; they remain fascinated with – and able to conduct – cutting-edge science. But learning comes attached with less-exciting projects require their input, too. Consistent with the network organizational form, the core scientists I interviewed frequently engaged in interorganizational collaborations as part of their work. However, these collaborations appear largely structured through their formal obligations. Consistent with Paruchuri (2010), the substrate of interorganizational collaborations has changed since the seminal work of Powell, Koput and Smith-Doerr (1996).

When biopharmaceutical scientists engage in problem-solving to overcome research obstacles, the informal organizational structure – the patterns of activity that are under the control of scientists as opposed to their respective organizations – plays a lesser role than expected. Every effort is made to protect the organization's intellectual property. By the time network ties to scientists in external organizations are activated for the purpose of problem solving, the research obstacle has exhausted the efforts of individual scientists, functional area teams, and multidisciplinary teams of core scientists. The organization's internal capability is exhausted. Utilizing interorganizational network ties requires legal scaffolding. In the current context, it is formal contracts and legal protections, not informal norms, that safeguard these relationships. Here, the behavior of biopharmaceutical organizations and their core scientists is more consistent with the boundary-management perspective.

These differences are likely due to the growth and development of the biopharmaceutical field. Paruchuri (2010) notes the integration of the biotechnology and pharmaceutical fields through a long series of mergers and acquisitions. This is likely to facilitate the blending of the forms of these two fields (DiMaggio and Powell 1991). In addition, fields create pressures through a process that Bouncken et al. (2015), Tsai (2002), and others call 'coopetiton' that

changes the logic of interorganizational collaboration based on the development of a field or product lifecycle (Bouncken et al. 2017). In the earlier phases of development of a new type of product, collaborations aim to develop the technology, reduce uncertainties, and grow the market and value of the product. Later, when the uncertainty has been reduced and the market for the product has grown, collaborators tend toward competing with each other. The organizations studied by Powell, Koput and Smith-Doerr (1996) appear to be embedded in the earlier, cooperative phase of field development where organizational learning through knowledge diffusion is most important. The biotechnology, pharmaceutical, and biopharmaceutical organizations studied here are likely in a later phase of field development that is more competitive. As such, the organizations where the interviewees of this study work are likely to be more concerned with retaining the value of their R&D projects than increasing the learning capability of their organization. Thus, the interviewees in this study have to work with more formal organizational boundaries

This research is not without its limits. First, in designing this project, I made a deliberate choice to focus on the Greater Boston Area in order to control for geographic region. While efforts were made to broaden the scope of research beyond the Greater Boston Area, this geographic region is over-represented. It may be the case, consistent with Saxenian (1994), that biopharmaceutical organizations in other regions, like the Bay Area of California, utilize a different problem-solving process because their organizational form remains closer to the network form described by Powell (1990). With only two cases from The Bay Area, comparing geographic regions is not feasible with these interviews; future research is required to establish the generalizability of these findings beyond the Greater Boston and adjacent Tri State areas.

A second limitation is that the discovery phase, which is the earliest R&D phase, is over-represented. Because project failure is more common and less expensive in the discovery phase compared to later R&D phases, it may appear as if research obstacles are less threatening and less likely to trigger tight project boundaries than later R&D phases, like clinical trials (Timmermans 2011). However, despite focusing on the earlier R&D phases that are much more likely to fail, all the scientists I interviewed attended to legal boundaries when activating interorganizational networks.

These findings push our understanding of knowledge-intensive work and organizational problem solving forward. It is conventional knowledge that social networks aid innovation, in part, because they connect actors to the right information to solve complex problems. The process of problem-solving that actors go through remains as an unexamined mechanism that links social networks to desired outcomes, e.g. Cross and Cummings (2004). Part of the purpose of this research is to open up problem solving as a process – an active process – fundamental to innovation that is actively shaped by organizational structures in order to leverage in-house knowledge (Arora, Belenzon and Rios 2014).

Although the organizational form of biopharmaceutical organizations in the Greater Boston and Tri-State Areas has changed since theorized by Powell (1990) and investigated in detail by Smith-Doerr (2005) and Whittington and Smith-Doerr (2008), organizational learning remains as a core competency. This study suggests that problem solving is another organizational capability that has been formally developed by biopharmaceutical organizations. Dual network structures (Breiger 1974, Lazega et al. 2008) link scientists, organizations, functional areas, and project teams. Why and how the biopharmaceutical field developed such a formal structure remains an open question. Recent literature suggests institution- and field-level trends of

increasing R&D costs combined with diminished R&D capability pushed biopharmaceutical organizations to focus more on protection and knowledge-exploitation than organizational learning and exploration (Arora, Ceccagnoli and Cohen 2008, Arora, Belenzon and Rios 2014, Rafols et al. 2014). Future research is needed to establish the trajectory and possible applications of this trend.

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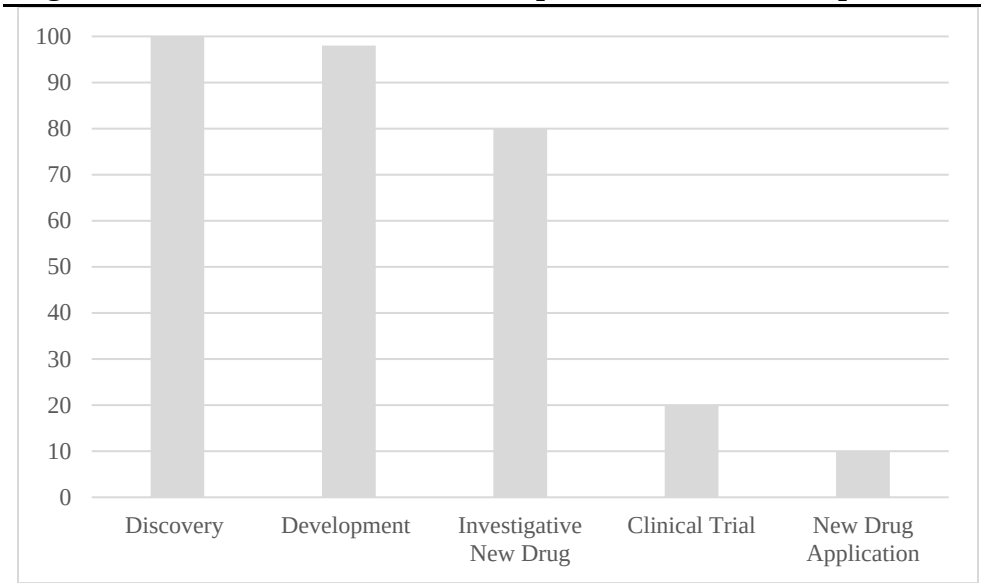
TABLES AND FIGURES

Table 1. Central Themes

Code/ Variable	Definition/Criteria
ORG, Form	The formal structure, informal norms/culture, or field-position of an organization.
P-SOLVE	How research obstacles are dealt with; problem-solving phases
RO	Descriptions of research obstacles
BOUND	The drawing, redrawing, or bridging of social, epistemic, or organizational boundaries; the permeability, saliency, or visibility of boundaries
NORMS	The norms of their organization/ field
NETWORK	Contacts; the process of utilizing contacts; seeking advice; giving advice; support; reputation; repeated interactions; trust; negative experiences;
LEAD	Formal leadership/authority is exercised or informal leadership is performed
TEAM	Mention of a team, team members, or functioning/performance of a team
EVAL	Respondent performs/describes some type of evaluation
#type	The type of organization respondents are affiliated with (Biotech, Biopharmaceutical, Pharmaceutical, Other)
#size	The number of employees in respondents' organizations (Small < 100, Medium < 1,000, Large > 1,000
	Codes are designated by all caps
	Qualitative variables are designated by hashtags and lowercase words

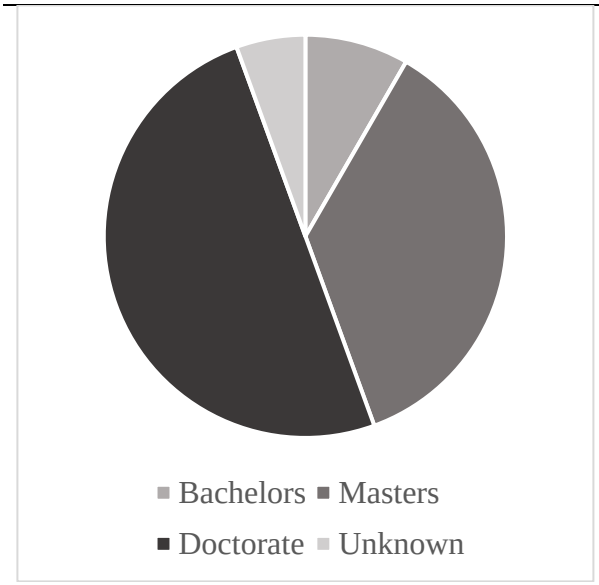
Figure 1. Failure rates in different biopharmaceutical R&D phases



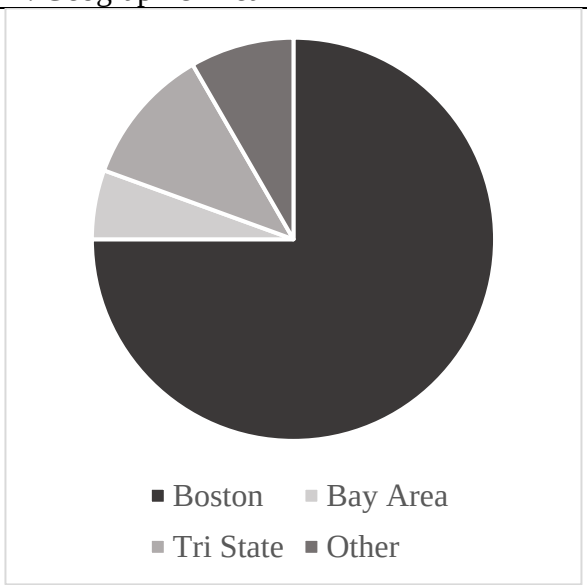
Sources: Bartfai and Lees (2006), DiMasi, Hansen and Grabowski (2003), DiMasi, Grabowski and Hansen (2014), and Firestein (2016)

Figure 2. Respondent Characteristics

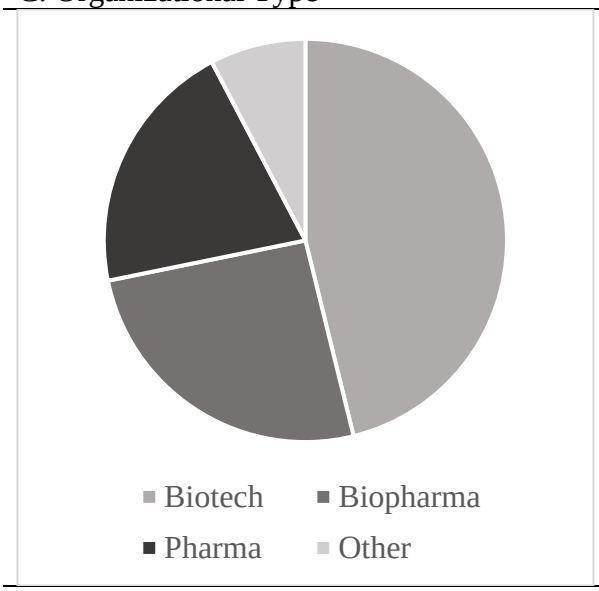
A. Educational Attainment



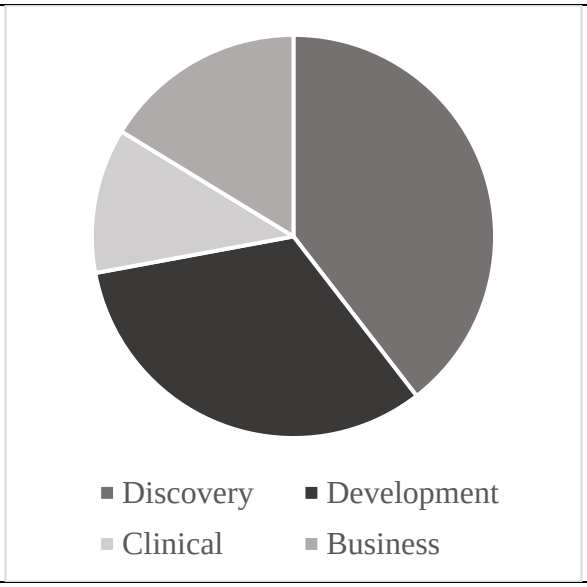
B. Geographic Area



C. Organizational Type



D. Research Phase



APPENDIX C

Path Dependence, Social Networks, and Scientific Problem Solving

ABSTRACT

In this chapter, I study what types of social network contacts biopharmaceutical scientists find useful during two problem solving phases and whether those phases are connected via path dependence. Interestingly, two lines of research have different expectations regarding whether path dependence exists between different problem solving phases. The "needs perspective" argues that the contacts that prove useful at one phase have characteristics that are distinct from the characteristics of the contacts that prove useful at the other phase. Thus, because these two problem solving phases call for different types of contacts, they should be independent from each other. In contrast, several lines of social network research posit path dependence between problem solving phases; scientists will tend to utilize contacts that prove useful for one purpose at the other problem solving phase. To test these hypotheses, I survey members of the American Association of Pharmaceutical Scientists who engage in biopharmaceutical R&D about a research obstacle their project encountered and the network contacts they utilized to address their problem. Survey items encapsulate respondents' involvement with several problem solving phases and characterize their network contact using measures from research on strength of ties, knowledge networks, and formal authority within organizations. A multi-level path model with a rich set of control variables tests several hypotheses regarding which specific types of network contacts will prove useful at two problem solving phases expected to be facilitated by different types of network contacts. Further, the model test for path dependence of contact-use between these two phases. Limitations, directions for future study, and implications of results for the study of problem solving, creativity, and other parts of the innovation process are discussed.

INTRODUCTION

Social networks facilitate innovation in many ways. Social networks bolster creativity and the generation of good ideas through recombinant innovation and boundary-spanning (Perry-Smith and Mannucci 2017, Phelps, Heidl and Wadhwa 2012, Powell, Koput and Smith-Doerr 1996). Whether researchers examine organizations (Powell 1990, Powell, Koput and Smith-Doerr 1996), teams (Fiore 2008, Gardner, Staats and Gino 2012, Gardner 2017), individuals (Burt 1992, Burt 2005, Granovetter 1973) – or virtually any other social unit – social networks provide individuals with access to diverse information and new knowledge that facilitates the generation of new ideas. Social networks also help good ideas become useful. Actors utilize their social networks to mobilize support, frame ideas to gatekeepers, generate interpersonal trust, and manipulate the social environment to their advantage (Burt 2005, Fligstein and McAdam 2012, Grosser et al. 2017, Obstfeld 2017, Perry-Smith and Mannucci 2017). Social networks help these phases of innovation. They also facilitate problem solving, which is an important part of innovation.

The Importance of Problem Solving

The road from a good idea to its final destination is long and difficult; creative innovators often experience setbacks, false-starts, and many other types of problems before their ideas ever see the light of day (Obstfeld 2017, Perry-Smith and Mannucci 2017). This is especially true in the context of biopharmaceutical research and development (R&D); despite having an innovative reputation, this field is characterized by high rates of project failure (Bartfai and Lees 2006, DiMasi, Grabowski and Hansen 2014, Firestein 2016) where research project typically face several obstacles (Powell, Koput and Smith-Doerr 1996). Like other types of people working in

innovative fields, biopharmaceutical scientists must engage in problem solving to keep their R&D projects on track (see appendix B).

Problem solving is a process that moves through several phases. It begins when an individual identifies that a goal cannot be achieved from their current situation (Duncker 1945, Novick and Bassok 2005, Obstfeld 2017, Rittel and Webber 1973). After this identification phase, individuals proceed by establishing an understanding of the problem, evaluating its impact, formulating a plan of action, executing the plan, and communicating about the problem to their organization (Collins and Evans 2007, National Research Council 2013, Novick and Bassok 2005, Reiter-Palmon and Illies 2004). Fortunately, problem-solvers do not have to go through this difficult process in isolation. Just like in the case of creative innovation, individuals rely on their social network contacts to access new knowledge, gain interpersonal support, and mobilize other types of resources when they go about solving problems if they cannot solve it themselves (Burt 2005, Cross and Cummings 2004, Obstfeld 2017, Perry and Pescosolido 2012).

However, not all social network contacts are equally useful for problem solving. Recent research on social networks and creative innovation has identified that different types of social network contacts facilitate different innovation phases (Perry-Smith and Mannucci 2017, Phelps, Heidl and Wadhwa 2012, Reagans and McEvily 2003). As argued by Perry-Smith and Mannucci (2017), creators rely on weak ties to generate their initial ideas because weak ties provide new knowledge and fresh perspectives. Afterwards, creators rely on their strong ties for trust and other types of interpersonal support when they seek to elaborate their ideas. This argument ought to apply to problem solving because many problem solving phases call for different types of network contacts. For instance, given the interpersonal risks associated with admitting mistakes, assigning implicit blame, and seeking advice; calling attention to a problem requires trust and

commitment from their network contacts (Borgatti and Cross 2003, Cross and Cummings 2004, Lazega and Pattison 1999). Understanding the nature of that same research problem may require scientists to branch out by discussing matters with less familiar network contacts who bring fresh perspectives and new knowledge (Collins and Evans 2007, Cross and Cummings 2004, Novick and Bassok 2005). Thus, *different types of network contacts are expected to facilitate different problem solving phases*.

More specific claims about which types of network contacts are expected to facilitate each problem solving phase can be made. I am particularly interested in comparing two critical earlier phases of problem solving: problem identification and problem understanding. Of the six phases of problem solving, the identification phase and understanding phase are critical to the problem solving process; one risks returning to these phases later if they are not successful (Gardner 2017, Perry-Smith and Mannucci 2017, Reiter-Palmon and Illies 2004). I also restrict my focus to three broad characteristics of network contacts: the strength of network ties (Granovetter 1973), the knowledge that inheres in networks (Contractor and Monge 2002, Phelps, Heidl and Wadhwa 2012, Yuan et al. 2010), and the formal authority positions of network contacts (Oldenhof, Stoopendaal and Putters 2016, Sorenson and Rogan 2014). As I detail in the following sections, the identification and understanding phases of problem solving are expected to be facilitated by very different types of network contacts.

Strength of Ties

Strong and weak network ties provide different types of support. Strong ties are expected to facilitate the identification phase of problem solving; weak ties are expected to facilitate the understanding phase. As conceived by Granovetter (1973: 1361), "the strength of a tie is a (probably linear) combination of the amount of time, the emotional intensity, the intimacy

(mutual confiding), and the reciprocal services which characterize the tie." Strong ties are linked to emotional support (Perry-Smith and Mannucci 2017), interpersonal trust through social closure (Granovetter 1973, Phelps, Heidl and Wadhwa 2012), cooperation (Melamed and Simpson 2016), and knowledge-sharing (Levin and Cross 2004, Uzzi and Lancaster 2003). Strong ties are likely to facilitate the identification phase because they reduce the interpersonal risk associated with disclosing one's ignorance to another (Borgatti and Cross 2003, Collins and Evans 2007, Lazega and Pattison 1999). Weak ties have been shown to enhance creativity through accessing diverse knowledge in other social circles (Perry-Smith and Mannucci 2017, Phelps, Heidl and Wadhwa 2012). This is likely to facilitate the understanding phase by enhancing the search for new information necessary for a comprehensive understanding.

H_1: Strong ties are helpful for identifying the presence of a research obstacle

H_2: Weak ties are helpful for understanding the nature or characteristics of a research obstacle

Knowledge Networks

As argued by Phelps, Heidl and Wadhwa (2012), properties related to knowledge are an important dimension of social network ties. Three network properties are especially salient for problem-solvers. First, actors are better able to seek knowledge the more they are aware of the expertise of their contacts (Borgatti and Cross 2003). With high awareness of the expertise of others in their network, actors develop a transactive memory – an informal sense of who does what and whom to turn to when facing complex problems (Cross and Cummings 2004, Hirst and Echterhoff 2012, Wegner, Erber and Raymond 1991). Second, competence-based trust – trust in the skills, knowledge, and experiences of others – facilitates knowledge-transfer (Levin and Cross 2004). Third, knowledge-transfer and knowledge-integration are enhanced when network

actors' expertise overlaps (Reagans and McEvily 2003, Rulke and Galaskiewicz 2000). Because they facilitate searching, transferring, and integrating knowledge; these three knowledge network properties are expected to facilitate the utilization of higher levels of expertise and diverse knowledge associated with the understanding phase (Collins and Evans 2007, Levin and Cross 2004). While these three knowledge network properties are not as essential for the identification phase that utilizes lower levels of expertise when compared to the understanding phase (Collins and Evans 2007), it is likely that knowledge network properties also facilitate the identification phase.

As discussed in Appendix B, biopharmaceutical scientists typically work in multidisciplinary or multifunctional teams (Nakagawa and Lehman 2015, Smith-Doerr 2005). While many of the research obstacles encountered by scientists fall within their professional jurisdiction, they typically turn to other scientists whose expertise is within – or close to – their own professional jurisdiction before broadening the range of expertise by engaging their multidisciplinary teammates. In other words, biopharmaceutical scientists typically increase the specialization (Leahey, Keith and Crockett 2010, Leahey and Hunter 2012) and depth (Collins and Evans 2007) of expertise in the network of scientists affiliated with the research obstacle before increasing the breadth of expertise and interdisciplinarity (Fiore 2008, Leahey, Beckman and Stanko 2017, McBee and Leahey 2016, National Academy of Sciences 2005) in the same network. This process presupposes that scientists have high levels of awareness and overlap – if not trust – in regard to the expertise and experiences of many of their network contacts.

> *H_3: Network ties with higher levels of knowledge network properties are helpful for identifying the presence and understanding the nature or characteristics of research obstacles.*

One of the reasons biopharmaceutical scientists follow this pattern of advice-seeking is that, by exploiting (March 1991) their in-house expertise, biopharmaceutical companies maintain tight boundaries around their intellectual property. Thus, formal authority is expected to play a role.

Formal Authority

Early work into the nature of innovation in the field of biotechnology describes contexts where scientists have a great deal of personal freedom regarding the network contacts they utilize for R&D purposes (Powell 1990, Smith-Doerr 2005). However, the biotechnology field has largely merged with the pharmaceutical field in recent decades (Nerkar and Paruchuri 2005), paving the way for formal authority to shape how scientists utilize network contacts for the purpose of dealing with problem solving. Acquiring support from individuals of higher organizational standing or leadership positions can facilitate problem solving because these positions are associated with greater amounts and varieties of resources (Erickson 2003, Lin 2001). However, there are interpersonal costs associated with seeking advice; one is disclosing one's ignorance to another, which can be risky (Borgatti and Cross 2003, Lazega and Pattison 1999). These risks are amplified when contacts occupy a leadership position or a position with higher levels of formal authority. Thus, individuals are expected to avoid contacts during the identification phase if those contacts occupy a higher formal position, are associated with project leadership, or are affiliated with the project team. As a result,

> *H_4: Contacts that occupy lower formal positions, are not associated with project leadership, or are not affiliated with the project team are helpful for identifying the presence of a research obstacle*

In contrast to the identification phase, biopharmaceutical scientists are likely to find that the more that their contacts are associated with formal authority, the more helpful these contacts

will be for the purposes of the understanding phase. Within the biopharmaceutical industry, scientists often turn to more experienced contacts and core members of their multidisciplinary teams to understand more complex problems. They may need permission from their organization to cross organizational boundaries when activating distant contacts that bring fresh knowledge (see Appendix B). Moreover, because understanding the nature of a problem is more abstract, it calls for higher levels of expertise (Abbott 1988, Collins and Evans 2007, Collins 2010) than identifying the presence of a problem. Seeking advice from contacts associated with formal authority carries less stigma. Further, scientists are fascinated by what is not understood in their field, which makes such conversations points of interest between competent scientists (Firestein 2012). Thus:

> *H_5: Contacts that occupy higher formal positions, are associated with project leadership, or are affiliated with the project team are helpful for understanding the nature or characteristics of a research obstacle.*

Path Dependence

Many theorists would agree that different types of network contacts will be utilized for different problem solving phases. There are disagreements regarding whether or not using contacts for one phase is expected to influence whether those contacts are utilized for another phase. The "needs perspective", put forth by Perry-Smith and Mannucci (2017), argues that creative innovators are able to move through different phases only when their networks fit the needs of their current phase. Further, relations that facilitate one phase are detrimental to other phases. By making analogies with problem solving, it follows that problem solving phases ought to be independent from each other in terms of the type of social network contacts utilized to facilitate each phase.

H_{6a}: Problem solving phases that call for different types of network contacts are independent in terms of their associated contacts.

In contrast to the "needs perspective," most other theorists posit mechanisms that suggest path dependence and lower network turnover between problem solving phases. Feld (1984) argues that network contacts originate within social contexts that are designed to guide certain types of network contacts towards particular purposes. Within the context of a biopharmaceutical organization, one's selection of network contacts may be very similar or limited (see Appendix B) creating path dependence between the identification phase and the understanding phase. Perry and Pescosolido (2012) add that when individuals face daunting circumstances, they form a dense core of trusted network contacts which they use for several purposes. Moreover, the idea of path dependence between phases is consistent with several lines of research that demonstrate individuals' interactions with network contacts is based, in part, on expectations formed by previous interactions (Burt 2005, Granovetter 1985, Molm, Whitham and Melamed 2012, Uzzi 1997) and familiarity with the problem (Feld and Grofman 2009, Perry and Pescosolido 2012). Having proven useful at one phase of problem solving, a network contact is more likely to be perceived as potentially useful for other phases of problem solving. Thus:

H_{6b}: Network contacts utilized at one problem solving phase are more likely to be utilized at other phases of problem solving even when those phases are facilitated by different types of network contacts.

DATA AND METHODS

To test these hypotheses, I collected data from members of the American Association of Pharmaceutical Scientists (AAPS) about the contacts they utilized when dealing with a serious research obstacle. The AAPS is the largest professional organization of pharmaceutical scientists

with 11,000 members worldwide in industrial, academic, government, and other research organizations. Their stated mission is to advance "the capacity of pharmaceutical scientists to develop products and therapies that improve global health" (American Association of Pharmaceutical Scientists 2016). As part of this mission, the AAPS organizes large annual conferences, such as their Annual Meeting and Exposition that draws over 7,000 registrants annually; provides workshops on such topics as Future Advances in Nanotechnology; and publishes a news magazine focusing on scientific and management issues and four research journals. As such, it maintains an important position in the field of pharmaceutical science.

The survey was distributed by InFocus Marketing, a marketing company that contracts with AAPS for list management, data services, and email fulfillment (InFocus Marketing 2016). Survey invitations follow the basic tailored design method (Dillman, Smyth and Christian 2008, Dillman, Smyth and Christian 2014) and include an anonymous link to an online survey developed in *Qualtrics*. In August 2015, InFocus emailed the invitation to 8,065 people which includes individuals with current AAPS memberships, those who had canceled their membership within one year, or had registered for the 2015 AAPS Annual Meeting. A reminder was sent two weeks later. The invitation had a delivery rate of 95.4%, an open rate of 35.6%, an overall completion rate of 5.37%, and a click-to-open rate of 15.1%; the reminder message had a delivery rate of 96.8%, an open rate of 38.2%, an overall completion rate of 4.34%, and a click-to-open rate of 11.3%. In total, the survey yielded 661 completed responses (more than 50% of the survey was completed), yielding a response-rate of 9.1%[1].

[1] A facsimile of the survey can be accessed through the following hyperlink: Survey on Research Obstacles FACSIMILE. This facsimile is a complete copy of the survey sent out to AAPS members. Moving through it efficiently will require entering responses that *Qualtrics* will record automatically. These responses will be kept entirely separate from the original survey and never examined.

The survey collected information about a wide variety of factors related to working in the biopharmaceutical field, research obstacles, and social network ties. The survey comprises eight question-blocks and generates a multi-level data structure. After establishing informed consent, the survey solicited background information and asked about respondents' work histories and biopharmaceutical organization (Level II). The next two blocks of questions surveyed respondents about a de-identified ongoing pharmaceutical science project and a de-identified research obstacle that they encountered in the past year. Because many biopharmaceutical scientists work on multiple R&D projects (Nakagawa and Lehman 2015), respondents were asked to focus on the project that occupied the greatest amount of their time in the past year. To facilitate recall, respondents were asked to nickname that project (Callegaro, Manfreda and Vehovar 2015). This nickname was then inserted into future question prompts, as appropriate, by *Qualtrics*. In a later question, respondents were given the following prompt that includes a definition of 'research obstacle' and then asked if their project experienced any research obstacles in the past year.

> *Many pharmaceutical science projects experience research obstacles. A research obstacle is a challenge that must be overcome in order to meet specific research aims that individuals, teams, or other social units seek to fulfill. Some obstacles are very serious; others are much easier to deal with.*

Because some projects may have had multiple research obstacles, respondents were asked to think of the most serious research obstacle that came up in the past year and give it a nickname to aid recall on future survey questions. The final sets of survey questions cover respondents' social network contacts (Level I) and the problem-solving process associated with their de-identified research obstacle, including which social network contacts they found most helpful at each problem solving step.

Of the survey respondents, 184 met the scope conditions (Walker and Cohen 1985) of the research question: their biopharmaceutical R&D project had experienced a serious research obstacle within the past year, they had utilized network contacts for the purpose of attempting to solve that obstacle, and they had been involved in the identification and understanding phases. Of these 184 responses, 142 included complete information on all variables associated with this study. These 142 respondents constitute the analysis sample used in statistical models. Control variables were selected based on their theoretical importance and lack of missing values. A summary view of missing data revealed that most missing data values were embedded in the question-block related to characteristics of respondents' organization. Accordingly, control variables that measure organizational size (18 missing values), formal organizational authority (24 missing values), and income (13 missing values), were omitted from the set of control variables[2]. Additionally, a measure of the project's phase was omitted (27 missing values). Occupying a leadership position on the project team (17 missing values) was retained because project leaders are more likely to be involved with problem solving on their biopharmaceutical R&D projects and have great latitude when interacting with core project members (see appendix B). The 142 respondents with complete information are similar to the 184 respondents meeting the scope conditions with the small exception that the research obstacle they encountered was further beyond their expertise (4.4 compared to 3.7).

Because each survey respondent utilized one or more network contacts to help solve a serious research problem, the data are hierarchical (Raudenbush and Bryk 2002); network contacts (level I) are embedded within survey respondents (level II). The 184 respondents

[2] None of these variables were found to influence either outcome in exploratory statistical models.

meeting the scope conditions of this study listed a total of 828 network contacts; the 142 respondents with complete data listed a total of 636 network contacts. Fortunately, both sets of network contacts are very similar, with one small exception. The 142 respondents with complete information reported communicating with their 636 network contacts an average of 13.7 days per month while they dealt with the research obstacle, compared to an average of 15.9 days per month for the184 respondents who met the scope conditions. Table 1, below, reports descriptive statistics for both sets of respondents.

[Table 1]

Key Measures

Outcomes: problem-identification and problem-understanding

The main outcomes of interest involve whether or not respondents' network contacts facilitated specific problem-solving steps, namely whether each network contact facilitated the identification of the presence of a research obstacle and/or facilitated the understanding of the nature of a research obstacle. Data on network ties were collected using a typical two-step name generator/interpreter sequence of survey questions (Knoke and Yang 2008). The first step of this combination of survey questions asked respondents to generate a list up to eight network contacts who provided assistance in dealing with their research obstacle. Consistent with prior research (Cross and Cummings 2004), the question wording of the name generator encouraged respondents to name contacts outside of the normal social circle of the project, outside organization, another scientific field, or another field outside of science. Having generated a list of up to eight helpful network contacts, respondents proceeded to the second step of the generator/interpreter combination. Here, respondents "interpreted" each contact by answering questions that provide information about the characteristics of each of their contacts and aspects

of the relation between them and each of their contacts. As part of these name interpreters, respondents indicated which, if any, of their contacts were especially helpful toward identifying the presence of the research obstacle (1/0) and which, if any, contacts were especially helpful for understanding the nature or characteristics of that same research obstacle (1/0). Other name interpreter questions capture independent variables associated with tie strength, knowledge networks, and formal authority.

Tie strength

Three items captured tie strength. Relationship duration (in years) of the network tie between respondent and contact was measured with a seven-point scale (1 = less than one year; 2 = 1-2 years; 3 = 3-4 years; … 7 = 10 years or more), and midpoints were used. As a substitute for emotional intensity, emotional closeness was measured using a six-point scale that ranged from very distant (1) to very close (6). Frequency of communication is aggregated from two questions that ask respondents to indicate the monthly face-to-face and electronic communication averages for each contact, inclusive of scheduled meetings. With the growing realization that electronic communication augments, rather than replaces, face-to-face interactions (Phelps, Heidl and Wadhwa 2012, Rainie and Wellman 2012), an overall communication frequency was set to equal the maximum value of either type of communication. Thus, this measure ranges from 0 (no communication) to 30 (daily communication).

Knowledge networks

Aspects of knowledge networks are measured with three name-interpreter questions. Following Borgatti and Cross (2003) and Cross and Cummings (2004), respondents were asked to indicate the extent to which they were aware of the expertise of each contact when they first began assisting with the research obstacle on a five-point scale that ranges from very unaware (1) to

very aware (5). Asking respondents to recall their awareness of each contact from an earlier point in time is important because awareness of expertise likely develops as problem-solving progresses and collaborative relationships develop (Hirst and Echterhoff 2012, Reagans, Argote and Brooks 2005, Wegner, Erber and Raymond 1991). Thus, this measure includes more network contacts with less awareness. Building off of Rulke and Galaskiewicz (2000), knowledge overlap was measured with a five-point scale that ranges from No overlap (1) to Complete overlap (5). Finally, respondents indicated the amount of competence-based trust – the extent to which they found the expertise and experiences of a contact to be adequate and reliable (Levin and Cross 2004) – using a seven-point scale that ranges from Completely distrust (1) to Completely trust (7).

Formal authority

Three survey items capture the sense of formal authority associated with each network contact. To better capture resource differentials between respondents and their contacts that are embedded in formal positions (Fu 2008, Lin 2001, Lin and Erickson 2008, van der Gaag, Snijders and Flap 2008), respondents were asked if the formal position of their contact was lower, the same, or higher than the respondent. Options ranged from 'Two or more positions lower than me' (-2) to 'Two or more positions above me' (+2). Because project leaders are tasked with formal oversight and have access to resources embedded in their formal positions (Carson, Tesluk and Marrone 2007, Martin, Liao and Campbell 2013, Somech and Khalaili 2014), respondents indicated whether each contact had taken a leadership role on the project at any time during the past year (1/0). With the realization that respondents are likely to turn to their team members as part of the problem-solving process, in part because team affiliations give members the expectation that they ought to assist each other (Katzenbach and Smith 2003,

Nakagawa and Lehman 2015, National Research Council 2015, Walsh and Maloney 2007); respondents were asked to indicate whether each contact had been a part of the R&D project at any time during the past year (1/0).

Control Variables

The survey a rich set of control variables that captures various aspects of human capital, social capital, and the rich context of biopharmaceutical research and development work that could influence how respondents' utilize their network contacts for the purpose of problem solving. Older respondents and those with more experience in the biopharmaceutical field are likely to have additional experience to call upon when solving problems (Collins and Evans 2007, Reagans, Argote and Brooks 2005). Respondents' biological age (twelve 5-year age-categories) and professional age (number of years engaged with biopharmaceutical science, inclusive of time spent in graduate school) are included as control variables.

Individuals with an interdisciplinary background (Andreasen 2005) or cross-functional experience (Burt 2005) are thought to be better problem solvers. To measure the extent to which respondents' backgrounds are interdisciplinary, I asked them to indicate the broad fields in which they had earned one or more degrees.[3] To measure cross-functional experience, I calculated the index of qualitative variation (IQV) of the percentage of respondents' career time spent working in each of nine areas of pharmaceutical research.[4]

[3] I used the fields provided by the National Science Foundation's 2012 *Survey of Earned Doctorates*: business; computer science; engineering; agricultural sciences; biological sciences; health sciences; mathematics; chemistry; social science; the arts and humanities; law; medicine; and any other area.

[4] The AAPPS areas are: Analysis and Pharmaceutical Quality; Biotechnology; Clinical Pharmacology and Development; Drug Discovery and Development; Formulation Design and Development; Manufacturing Science and Engineering; Physical Pharmacy and

Two control variables capture productivity. Productivity is linked to human and social capital (Leahey 2007). More productive respondents are likely to have better capabilities when it comes to solving research problems. Moreover, more productive respondents are likely to have engaged with a greater number of projects, giving them more experience solving research problems. To measure productivity, respondents were asked to indicate both the number of peer-reviewed articles they had published and the number of patents that list them as an inventor. Finally, respondents reported the number of work hours they spent on their focal project, under the assumption that respondents associate a sense of interest or importance with projects that occupy more of their time, increasing their awareness and interest in the state of the project (Broschak, Davis-Blake and Block 2008, Katzenbach and Smith 2003, Nakagawa and Lehman 2015).

Respondents also reported on items related to time spent affiliated with their organizations. Because spending more time at the same organization allows one to develop more organizational-specific social capital (Sorenson and Rogan 2014) and transactive memory (Fiore and Salas 2007, Hirst and Echterhoff 2012, Reagans, Argote and Brooks 2005, Wegner, Erber and Raymond 1991), organizational tenure – the number of years a respondent had spent in their focal organization – could influence the type of contacts respondents utilize to solve problems. Likewise, the number of alters utilized for problem solving by each respondent is a basic measure of degree centrality, which is linked to power, centrality, social capital, and many other network benefits (Bonacich 1987, Knoke and Yang 2008, Wasserman and Faust 1994). Respondents were also asked if they occupied a leadership role (0/1) on the focal R&D project as

Biopharmaceutics; Pharmacokinetics; Pharmacodynamics; and Drug Metabolism; Regulatory Sciences; and ‘Any other area.’

this indicates a level of accomplishment, control, and access to resources that typical project team members lack (Balkundi and Harrison 2006, Carson, Tesluk and Marrone 2007, Denis, Lamothe and Langley 2001, Fleming and Waguespack 2007, Hackman and Wageman 2009, Martin, Liao and Campbell 2013, Reiter-Palmon and Illies 2004). Respondents indicated their gender (Male = 1) because males often have increased status (Erickson 2003, Etzkowitz, Kemelgor and Uzzi 2000), even in more gender-balanced biopharmaceutical organizations (Smith-Doerr 2004). Similarly, respondents were asked to report whether each network contact was male or female.

Organizational context and team size are utilized as control variables because they are thought to influence social networks. Because academic and industrial science organizations often have different organizational forms (Hong and Walsh 2009, Walsh, Cohen and Cho 2007), respondents were asked to indicate the sector of their organization (Academic, Industrial/ Private, Government, or Other). Because the vast majority of respondents (97%) worked within an academic or an industrial sector, a dummy-variables for working within academia was utilized to measure this aspect of respondents' organizational context. Teams facilitate problem-solving, especially smaller, moderately sized teams (Katzenbach and Smith 2003, Nakagawa and Lehman 2015, National Research Council 2015, Walsh and Maloney 2007). Thus, respondents were asked to indicate the size of the focal project team (ranging from 1 to More than 20).

Finally, respondents were asked to report on some characteristics of the research obstacle they faced. To capture whether or not the research obstacle fell within their realm of expertise and experience (Collins and Evans 2007, Collins 2010), respondents were asked to indicate their agreement with the statement "It was beyond my personal expertise" and "It was familiar to me"

on a seven-point scale that ranges from ‘Completely disagree’ (1) to ‘Completely agree’ (7). The latter measure was reverse-coded to measure unfamiliarity.

Analytic Strategy

To determine what type of network contacts facilitate the identification and understanding phases of problem solving, and to test for path dependence between these two phases, I utilize a multi-level path model. Multi-level (i.e., hierarchical) approaches are called for when data are nested (Rabe-Hesketh and Skrondal 2012, Raudenbush and Bryk 2002), as is the case here; multiple network contacts (Level I) are nested within each individual respondent (Level II). Beyond control variables, a multi-level model accounts for unobserved heterogeneity at the respondent level (Level II) that may influence the utilization of network contacts (Level I).. A multi-level model can generate a variance component to control for these respondent-level differences. Ideally, it would be possible to utilize more than two levels to fully control for additional levels, such as project teams. While desirable, this approach is not feasible because specific affiliations with higher level social units were kept anonymous to project human subjects’ confidentiality.

A path model approach was combined with the multi-level approach described above. Path models are ideal for exploring the presence and influence of complex relations between variables (Acock 2013, Kline 2015) to gain a fuller sense of how social processes play out. In this case, using a path model provides the means to determine whether two dependent variables are related; that is whether or not respondents find the contacts that they found useful during the problem identification phase increases the chance that they find those same contacts useful during the problem understanding phase.

I use the generalized structural equation modeling (gsem) feature of Stata 15 to specify and estimate statistical models. Because the outcomes are dichotomous and the independent

variables and control variables are a mix of continuous and dichotomous variables, I utilize a binomial logit distribution (Agresti 2002, Long and Freese 2014) for each dependent variable. As shown in Table 2, three models were estimated. The first model includes both dependent variables and all nine independent variables that represent network characteristics. The second model introduces a causal pathway between 'Identify' and 'Understand' – the two variables that measure whether respondents' social network contacts were helpful at these phases. Because these two models are nested, testing for incremental model fit improvement is possible by comparing log likelihood statistics. The third model adds all control variables. Because the gsem family of commands in Stata 15 does not permit most absolute model-fit statistics utilized in SEM (Acock 2013, Hooper, Coughlan and Mullen 2008), the final model was rerun as a path model using commands for a structural equation model as if the outcomes were continuous and data were not nested. These results indicated the model fit well ($p = .90$, RMSEA = 0.00, CFI = 1.0, TLI = 1.0, CD = .25), although the applicability of these fit statistics to the final model is uncertain and should therefore be interpreted with caution.

As discussed above, missing data were handled through listwise deletion. An approach that utilizes maximum likelihood or multiple imputation would offer the possibility to retain cases with missing data (Allison 2002) but these features are unavailable for the gsem family of commands in Stata 15. It is possible to approximate a control function using a latent variable approach, akin to Heckman (1979), that corrects parameters and standard errors (StataCorp 2017) as though missing data is a selection process. Because the number of observations is relatively small, because the latent control function variable failed to exhibit a significant effect on either dependent variable and did not change any parameter or standard error etimate to an

appreciable degree, and because of known risks (Stolzenberg and Relles 1997) and limitations (Tucker 2010) under these circumstances, these models are not reported.

RESULTS

Descriptive Statistics

Most respondents are male (66%) who earned a PhD (68%) and began working in the biopharmaceutical field when they were around 30 years old (average age is 44.9 and average professional age is 15.5 years). Although the PhD denotes a high level of specialization within an academic discipline, many of these individuals have broad exposure, both in the sense of having an interdisciplinary background (average number of degree-areas is 1.48) and in the sense of having cross-functional exposure (average IQV scores for cross-functional exposure is .53, SD = .24).

Respondents tend to work for private organizations (67%) or in academia (32%). It would seem as if most also work for large organizations because the average number of biopharmaceutical scientists employed by their organization is 2,396, but there is a lot of variability surrounding this number (SD = 5,478). Tabulating this variable shows that 19.6% of respondents work in very large organizations which employ 15,000 or more individuals whose work involves some aspect of biopharmaceutical science. However, most respondents (59%) work in small organizations that employ 125 or fewer such individuals. Because respondents' average organizational tenure (7.01) is less than their professional age (15.5), it follows that many respondents have worked for more than one company associated with biopharmaceutical science.

By all measures, respondents appear to have successful careers. Their average salary is $122,000 (SD = $72,500). They have worked their way up the hierarchy of their organization, to

an extent; the average self-reported score for the position of their job title within their organization is 6.04 (range 1-9, SD = 2.09). Tabulating this variable shows that only 29% of respondents are at or below the middle of their organizational hierarchy. While most respondents (52%) report having no patents, the average number of patents is 2.61 (SD = 4.77). In contrast, the vast majority of respondents (92%) have published one or more articles in peer-reviewed journals (25% have published 25 articles or more). On average, respondents have 12.6 publications (SD = 10.4).

Respondents reported devoting many hours, 29.6 on average (SD = 14.9) per week, to the biopharmaceutical science project that occupied the greatest amount of their time over the past year. Perhaps this is because they tended to lead their project teams; 90% of respondents indicated that they occupied a formal leadership position or took on informal leadership roles on their project. Their project teams averaged 8.1 members (SD = 6.41). Tabulating the team size variable shows that most (55%) respondents worked in teams of between two and five individuals; a few (13.5%) worked in teams with more than 20 members.

When it comes to research obstacles, respondents tended to agree that the most serious research obstacle they encountered was familiar to them; the average Likert agreement score is 5.3, out of 7 (SD = 1.54). About half (51%) of respondents disagree to an extent that the obstacle their project faced was beyond their expertise; almost half (45%) similarly agree that it was beyond their expertise. (The average agreement score for this statement is 4.4; SD = 1.9.) Research obstacles occurred across all research and development phases (the average phase, from 0 to 100 is 19.7, SD = 26.7)[5].

[5] Although biopharmaceutical R&D projects are broken into well-known phases in industrial or private contexts, there was no reason to expect that corresponding phases would be found in

Respondents utilized several (4.67) network contacts (SD = 2.4) to help them deal with their research obstacle, most of which (66%) are male. Generally, respondents have more strong ties than weak ties (Granovetter 1973). On average, respondents had known their contacts for 4.66 years (SD = 3.53) before the research obstacle occurred. Many (53%) of these contacts were relatively new in the sense that they were known for between 1.5 and 3.5 years. Nevertheless, respondents were emotionally close (average score is 3.99 on a scale from 1-6, SD = 1.27) to their contacts and communicated with them a self-reported average of 13.65 days a month while the research obstacle was ongoing. The network ties respondents have with their contacts have high levels of the components of knowledge networks (Contractor and Monge 2002, Phelps, Heidl and Wadhwa 2012, Yuan et al. 2010). Respondents were very aware of the expertise and experiences of their contacts (the average awareness scores were 4.37 out of 5, SD = 1.0) and trusted their expertise greatly (6.05 out of 7, SD = 1.12). Respondents reported that their expertise and the expertise of their contacts overlapped to an appreciable extent (3.01 out of 5, SD = 1.0). Interestingly, respondents' network contacts have a mix of characteristics associated with formal authority. On the one hand, most (75%) are affiliated with the biopharmaceutical science project team. More than a third (39%) are also affiliated with a formal project leadership position or informal project leadership role. However, contacts tended to have positions that place them at a level of organizational hierarchy that is equivalent to respondents; the average difference between the hierarchical position of respondents and their contact is -0.1 (range = -2 to +2, SD = 1.42).

academic contexts. Therefore, project phase was measured with a continuous variable that ranged from 0 (the earliest point in the project) to 100 (the final point in the project).

Statistical Analysis

Table 2 reports results of the multilevel path models that test hypotheses. The first model tests hypotheses regarding which types of network contacts facilitate which phases of problem solving. There is support for the idea that strong ties facilitate the problem identification phases (H_1), but no support for the complementary idea, that weak ties facilitate the problem understanding phase (H_2). Emotional closeness positively influences the log-odds that a network contact utilized for the purpose of dealing with a research obstacle will prove helpful during the identification phase (coefficient = .22, p = .03). When the log-odds of network contacts that are 'Very Distant' (1) are compared to network contacts that are 'Very Close' (6), the odds increase from 1.2 to 3.6, which translates into an increase of 44%. Communication frequency, although not significant, is suggestive (p = .08) and its impact (.02) is meaningful when the range of this measure is taken into consideration; increasing communication with a network contact from one day a month (1) to daily (30) increases the log odds by .58, which translates into an increase of 28%. Curiously, the durations of network ties, which have been shown to be the strongest component of tie strength (Marsden and Campbell 2012, Melamed and Simpson 2016) are not significant (p = .33). Weak ties do not facilitate the understanding phase (H_2); the coefficients of these variables are positive or effectively neutral and non-significant.

[Table 2.]

The first model also supports the idea that components of knowledge networks facilitate both the problem identification phase and the problem understanding phase (H_3). The more trust respondents place in the expertise and experiences of network contacts, the more likely respondents are to find those network contacts helpful towards identifying and understanding a research obstacle. In both cases, the parameters are strong (.53 and .60, respectively) and

significant ($p < .05$). Running from 'Completely Distrust' (1) to 'Completely Trust (7) increases the log-odds of respondents will find their network contact helpful towards identifying the presence of a research obstacle by 3.18 and that same contact helpful towards understanding the obstacle by 3.6, increases of 55% and 53% respectively. Neither of the other knowledge network variables are significant for either outcome, but awareness is suggestive ($p = .10$); respondents who are 'Very Aware' (5) of a contact's expertise and experiences find that contact to be especially helpful towards identifying the presence of a research obstacle 42% more often than contacts whose expertise they are 'Very Unaware' (1).

Results from this model contradict some expectations regarding how respondents utilize network contacts for the purpose of problem solving when those contacts hold positions of formal authority. It was expected that biopharmaceutical scientists would shy away from contacts associated with formal authority when they needed help identifying the presence of a research obstacle (H_4), but would find these types of contacts especially helpful when trying to understand the nature of their research obstacle (H_5). With a strong (.60) and significant ($p = .04$) parameter estimate, biopharmaceutical scientists found that their network contacts who are also their project teammates to be especially helpful more than non-teammates when needing help with the identification phase. Contacts associated with a leadership position had an even stronger (1.35) significant ($p = .00$) parameter estimate; respondents find these contacts to help with the identification phase more than non-leaders. Especially because the relative standing of network contacts within organizational hierarchies had a minimal (-0.04) and non-significant ($p = .60$) influence, H_4 is not supported. Conversely, contacts in a leadership position tended to provide quality assistance when it came to understanding the nature of respondents' research obstacles. This influence is strong (1.03) and significant ($p = .00$); project leaders helped respondents

understand the nature of their research obstacle more than contacts not associated with a project leadership role. This provides some support for H_5, although the influence of project affiliation (Teammate) and organizational status (Hierarchy) were not even suggestive ($p > .10$).

To test whether path dependence exists between the problem solving phases of identification and understanding, I added a path between 'Identify' and 'Understand' in Model 2. The "needs perspective" (Perry-Smith and Mannucci 2017) argues that these two phases ought to be independent (H_{6a}). Thus, this path should not reach statistical significance. In contrast, other theories hold that network contacts that are helpful at one problem solving phase are more likely to prove helpful at other problem solving phases (H_{6b}). Thus, the influence of 'Identify' on 'Understand' that is represented by this path should be strong and significant. Contrary to the "needs perspective," the latter turns out to be closer to reality, at least in this context. The coefficient of this pathway is strong (2.72) and significant ($p = 0.00$). Given that a respondent's network contact is useful for identifying the presence of the research obstacle, that contact will prove useful for understanding that same obstacle 94% more often. This disconfirms hypothesis H_{6a} and lends support to H_{6b}.

Table 3 presents fixed effects, variance components, and fit statistics[6] from the final multi-level path model. It adds control variables that cover respondents' (Level II) demographics, career achievements, the organizational and project team contexts in which they work, and the characteristics of their research obstacle. In addition, a variable is added to control

[6] The gsem family of commands does not allow the same range of goodness of fit statistics as commands associated with conventional structural equation models (sem). To generate the RMSEA, CFI, and TFI, the multi-level path model that utilizes logistic regression was run as a typical structural equation model with the option of clustering standard errors by respondents' identification codes. As mentioned above, these absolute fit statistics should be interpreted with caution as they merely fail to be inconsistent with good model fit.

for the gender of respondents' network contacts (Level I). Complete results are presented in Table 3. Figure 1 shows the essential features of the path model. Each of the two problem solving phases is presented in a rectangle that labels the variable, its associated distribution, and intercept. Network contact variables (Level I) are represented by white rectangles; respondent variables (Level II) are encapsulated in a gray rectangle. Statistically significant pathways are represented by bold arrows; suggestive pathways are represented by regular arrows. Coefficients appear alongside their associated paths. All other features – non-significant variables and elements associated with the multilevel aspects of this model – have been removed for ease of presentation.

[Table 3]

[Figure 1]

Adding control variables does change the results for hypothesized effects. In particular, some network variables (Level I) have become less significant. Contacts' project team affiliation (Teammate) no longer has a statistically significant influence on problem identification, but remains suggestive ($p = .07$). Awareness no longer has a suggestive influence on problem identification ($p = .13$). Interestingly, knowledge overlap has a suggestive influence ($p = .09$) on problem understanding when these control variables are introduced.

None of the Level II control variables are statistically significant, but a few have a suggestive influence ($p < .10$) on problem identification. Male biopharmaceutical scientists (coef = .51), scientists working in larger teams (coef = .04), and scientists facing unfamiliar research obstacles are more likely to receive useful help from network contacts when identifying the presence of a research obstacle. Biopharmaceutical scientists that utilize more social network contacts to deal with their research obstacle in general (Network Centrality) appear less likely

(coef = -0.11) to find any particular contact especially helpful towards identifying the presence of the obstacle.

DISCUSSION

In this chapter, I seek to provide a better understanding of how social networks help biopharmaceutical scientists further their problem solving efforts when facing challenges that crop up during the course of research and development. In the context of biopharmaceutical R&D, as in many types of knowledge-intensive work, a lot goes wrong during the journey of an idea between its moment of creative insight and final destination. Biopharmaceutical scientists must engage with problem solving to keep their R&D projects from failing. As argued above, this type of problem solving is a process that begins when scientists identify that an obstacle is present and then attempt to understand the nature of that problem. This is a social process; social networks provide scientists with informal support, access to other experts, and the organizational backing necessary to overcome these challenges. Because different types of social network contacts provide different types of resources, numerous social network theories suggest that different types of network contacts would be most useful at different problem solving phases. For example, strong network ties provide social support for scientists when they need help identifying that a research obstacle is present and weak ties provide diverse information later, when scientists struggle to understand those same obstacles. While appealing, this depiction fails to fully consider influences between problem solving phases. A recent argument by Perry-Smith and Mannucci (2017) argues that problem solving phases are expected to be independent from each other in terms of the types of social network contacts they attract; the strong ties that prove useful towards identification are replaced by weak ties when the process moves into the understanding phase. This claim of independence between phases contradicts several lines of

social network research that sets an expectation that the contacts that biopharmaceutical scientists find useful for the purpose of identification will not only remain, but prove useful for the purpose of understanding. That is, there is path dependence between these two problem solving phases.

The main finding is that path dependence plays a strong role in determining which social network contacts prove useful for different problem solving purposes. This directly contradicts expectations set forth by the "needs perspective" of Perry-Smith and Mannucci (2017) who argued for a strong type of independence between phases associated with innovation, but it is consistent with several lines of social network research (Feld 1984, Feld and Grofman 2009, Melamed and Simpson 2016, Perry and Pescosolido 2010, Perry and Pescosolido 2012). When a network contact proves useful, she is drawn into the larger problem solving effort. Timeline differences may account for this path dependence. Whereas the creative innovation process described by Perry-Smith and Mannucci (2017) may take longer than the problem solving process in the realm of biopharmaceutical science. With additional time between phases, project turnover may be greater and path dependence minimalized or absent. This is plausible, yet biopharmaceutical R&D often has high levels of turnover built into their project teams; as projects move through the innovation cycle, project team members are replaced by new types of experts appropriate to that R&D phase (Bartfai and Lees 2006, Nakagawa and Lehman 2015). This ought to create an environment conducive to short term network turnover is tolerated, if not normalized. Future research ought to examine the interrelations between activity timelines, organizational contexts, and innovation phases in greater detail.

Beyond the main finding of path dependence between problem solving phases, several findings about network characteristics stand out. As expected, scientists find their strong ties –

those associated with emotional closeness and trust – to be more useful during the identification phase. Unexpectedly, weak ties are not especially useful during the understanding phase. The ineffectiveness of weak ties may be due to path dependence; having been drawn into the problem solving process, stronger ties supplant later contributions from weaker ties. It may also be due to a prevalence of strong ties; on average, respondents had known their contacts for about a third of their careers (4.66 years out of an average professional age of 15.5 years), were emotionally close with their contacts, and enjoyed frequent communication with their contacts as well. Although there is substantial variability associated with these averages (see Table 1), respondents tend to have utilized stronger ties more than weaker ties.

Higher levels of trust in the expertise and experiences of network contacts are associated with their being useful at both the identification and understanding phases. This was expected as all components of knowledge networks were expected to increase the usefulness of contacts at both problem solving phases. Curiously, awareness of contacts' expertise and experiences, which is thought to facilitate problem solving (Cross and Cummings 2004) in general, did not influence whether contacts were useful at either phase. This may be because awareness facilitates the development of the other network components; one must be aware of another's expertise before one can find it trustworthy. The influence of formal authority ran counter to expectations. Scientists find contacts associated with leadership roles helpful during the identification phase, not the understanding phase. This is likely due to the large percentage of respondents who are associated with project leadership roles. Descriptive statistics in Table 1 show that 90% of respondents are associated with a leadership role. Researchers who study less-elite respondents than AAPS members may discover that these findings about formal authority do not generalize to contexts where shared leadership is less common.

Although the statistical models presented here are consistent with many theoretical expectations, this study has several limitations. By design, the survey utilizes retrospective cross-sectional data. Utilizing more objective measures and adopting a longitudinal approach would allow better validation that these expectations have been met. Further, the survey asked respondents about their social network contacts. A better approach would have been to adopt an ego network approach that collects data on relationships among contacts (Borgatti, Everett and Johnson 2013, Knoke and Yang 2008). With an ego network approach, additional network measures would be available that better capture characteristics of respondents' networks and an approximate understanding of respondents' positions within their wider networks. These benefits would have come with the cost of lengthening survey response times considerably, which may have increased demoralization among survey respondents (Fowler 2014, Groves et al. 2009). Nevertheless, with an ego network approach, it would have been possible to capture network relations between project leaders, to better understand if weak ties provided access to disparate knowledge, and to attain structural measures of awareness, which originated in whole-network studies (Cross and Cummings 2004). Similarly, with greater organizational access, project teams and member affiliations could be examined in greater detail both as an additional level in a multilevel process and as another type of influential network connection through the duality of persons and groups (Breiger 1974), as examined by Lazega et al. (2008). Finally, this study examines the biopharmaceutical field, which is well known for relying on collaborations and team work to support its innovation process (Firestein 2016, Powell, Koput and Smith-Doerr 1996, Smith-Doerr 2005). Many engineering fields appear more confrontational and guarded (Etzkowitz, Kemelgor and Uzzi 2000, Obstfeld 2017). Social networks are likely to operate very differently in these contexts.

Despite these limitations, this study provides insight into how biopharmaceutical scientists utilize social network contacts to solve problems that occur during the innovation process. These findings should be especially interesting to those studying creativity (Koppman 2014, Koppman 2016) and innovation. Conceptually, creativity and problem solving are related in that each depends on the other; to an extent, problem solvers need to be creative and creatives need to engage with problem solving (Holyoak and Thagard 1995, Novick and Bassok 2005, Reiter-Palmon and Illies 2004, Sternberg et al. 2005). Moreover, these two processes have isomorphic phases. When the six-phase problem-solving process described here is compared to the creative phases described by Perry-Smith and Mannucci (2017) and phases associated with the problem-solving view of the firm (Nickerson and Zenger 2004, Reiter-Palmon and Illies 2004), all have generation, evaluation, and implementation phases. Researchers in these areas interested in social networks may do well to consider how path dependence and network turnover influences their part of the innovation process.

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TABLES AND FIGURES

Table 1. Descriptive Statistics

	Respondent Variables (Level II)	Mean/ Percentage	SD
Demographic	Male Respondent (1/0)	66%	
	Age (years)	44.90	12.93
	IDR (1 - 13)	1.48	0.74
	PhD (1/0)	68%	
Career	Professional Age (years in biopharma)	15.50	6.17
	Publications	12.60	10.40
	Patents	2.61	4.77
	Cross Functional (IQV)	0.53	0.24
Organization	Academia (1/0)	33%	
	Org Size (25 - 10,000+)	2,396	5,478
	Org Tenure (years at org)	7.01	4.67
	Organizational Hierarchy (1-9)	6.04	2.09
	Income	$122,000	$72,500
	Network Centrality/ Contacts (1-8)	4.67	2.40
Project	Project Leader Respondent (1/0)	90%	
	Team Size (0 - 21+)	8.10	6.41
	Project Phase (0 -100)	49.70	26.69
	Weekly Project Hours (0 - 100)	29.59	14.90
Research	Beyond R's Expertise (1-7)	4.40	1.88
Obstacle	Unfamiliar (1-7)	1.90	1.54
	N	142	
	Network Variables (Level I)	Mean/ Percentage	SD
	Male Contact (1/0)	66%	
Tie Strength	Duration (years known)	4.66	3.53
	Emotional Closeness (1-6)	3.99	1.27
	Communication Frequency (0-30)	13.65	8.71
Knowledge	Knowledge Awareness (1-5)	4.37	0.98
	Krowledge Overlap (1-5)	3.01	0.99
	Knowledge Trust (1-7)	6.05	1.12
Formal	Teammate (1/0)	75%	
Authority	Project Leader Contact (1/0)	39%	
	Hierarchy of Contact (-2 to +2)	-0.07	1.42
	N	636	

Table 2. Statistical Models without Control Variables

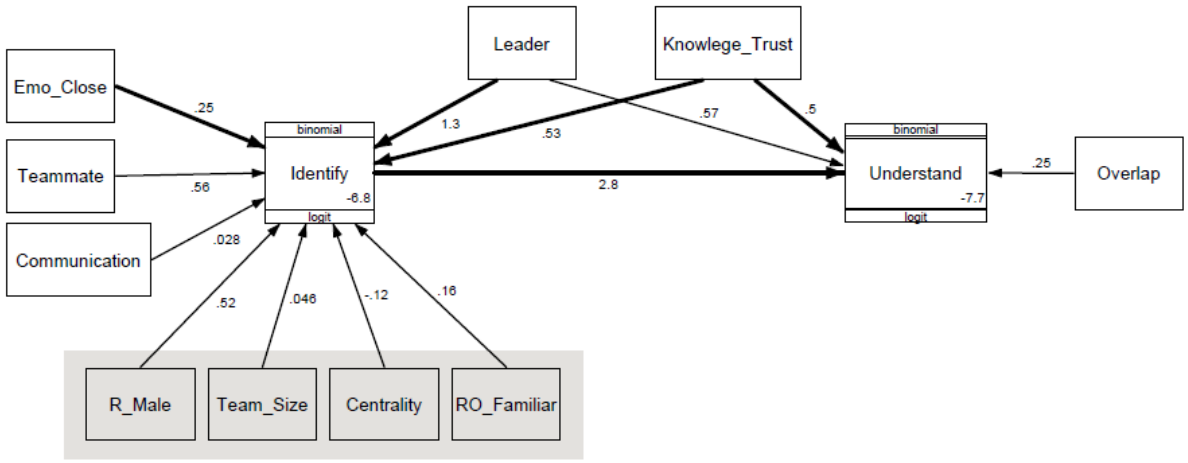
	Model 1: Independent Outcomes			Model 2: Path Dependence		
	Outcome: Identify			Outcome: Identify		
Network Variables	Coef	SE	p	Coef	SE	p
Duration	-0.03	0.03	0.33	-0.03	0.03	0.33
Emotional Closeness	0.23	0.10	0.03	0.23	0.10	0.03
Communication Freq	0.02	0.01	0.09	0.02	0.01	0.09
Awareness	0.23	0.14	0.10	0.23	0.14	0.10
Overlap	0.00	0.12	0.98	0.00	0.12	0.98
Trust	0.54	0.14	0.00	0.54	0.14	0.00
Teammate	0.60	0.30	0.05	0.60	0.30	0.05
Contact Leader	1.36	0.26	0.00	1.36	0.26	0.00
Hierarchy	-0.05	0.09	0.60	-0.05	0.09	0.60
	Outcome: Understand			Outcome: Understand		
Network Variables	Coef	SE	p	Coef	SE	p
Duration	0.03	0.03	0.45	0.05	0.04	0.25
Emotional Closeness	0.12	0.10	0.26	0.02	0.12	0.86
Communication Freq	-0.01	0.02	0.56	-0.03	0.02	0.15
Awareness	0.06	0.14	0.69	-0.02	0.17	0.90
Overlap	0.12	0.12	0.32	0.18	0.15	0.23
Trust	0.61	0.14	0.00	0.48	0.16	0.00
Teammate	0.26	0.30	0.40	0.04	0.36	0.91
Contact Leader	1.03	0.26	0.00	0.54	0.31	0.08
Hierarchy	-0.09	0.09	0.31	-0.07	0.10	0.50
Path						
Identify				2.72	0.31	0.00
N	636			636		
Log Likelihood (rounded)	-737 (22)			-681 (23)	Δ = 57 (1)	
AIC (rounded)	1519			1407	Δ = -112	
BIC (rounded)	1617			1509	Δ = -108	

Results are from one-tailed tests

Table 3. Fixed Effects of Path Model with Control Variables

		Outcome: Identify			Outcome: Understand		
Networks (Level I)		Coef	SE	p	Coef	SE	p
Tie	Duration	-0.05	0.03	0.15	0.04	0.04	0.32
Strength	Emo Closeness	0.25	0.10	0.02	-0.03	0.12	0.76
	Comm Freq	0.02	0.01	0.07	-0.02	0.01	0.16
Knowledge	Awareness	0.21	0.14	0.13	-0.08	0.17	0.63
Networks	Overlap	-0.04	0.12	0.71	0.24	0.15	0.09
	Trust	0.53	0.13	0.00	0.50	0.15	0.00
Formal	Teammate	0.55	0.31	0.07	0.01	0.36	0.96
Authority	Contact Leader	1.34	0.26	0.00	0.57	0.31	0.06
	Hierarchy	-0.00	0.09	0.92	-0.05	0.11	0.64
Control	Male Contact	-0.05	0.22	0.82	-0.18	0.26	0.48
Path Dependence (Level I)							
Identify					2.77	0.31	0.00
		Outcome: Identify			Outcome: Understand		
Respondents (Level II)		Coef	SE	p	Coef	SE	p
Demographics	Male Respondent	0.51	0.29	0.08	-0.38	0.38	0.32
	Age	-0.10	0.10	0.30	0.01	0.13	0.89
	Interdisciplinary	0.01	0.17	0.92	0.34	0.23	0.15
Career	Professional Age	0.01	0.04	0.80	0.04	0.05	0.38
	Publications	-0.00	0.01	0.69	0.00	0.01	0.88
	Patents	-0.00	0.02	0.96	0.04	0.03	0.20
	Cross Funct IQV	-0.34	0.55	0.53	0.59	0.72	0.41
Organization	Academia	0.29	0.38	0.43	0.40	0.50	0.42
	Org Tenure	0.03	0.03	0.34	0.00	0.04	0.88
	Net Centrality	-0.11	0.06	0.06	0.02	0.08	0.75
Project	R Leader	-0.00	0.49	0.99	0.07	0.66	0.91
	Team Size	0.04	0.02	0.07	-0.02	0.03	0.45
	Project Hours	0.00	0.01	0.96	0.01	0.01	0.16
Research	Beyond Expertise	-0.00	0.07	0.95	0.04	0.10	0.63
Obstacles	Unfamiliar	0.16	0.10	0.10	0.01	0.13	0.88
	Variance	.70			1.85		
	Intercept	-6.80	1.45	0.00	-7.70	1.79	0.00
	R^2	0.20			0.26		
	N				636		
	AIC				1444.14		
	BIC				1689.17		
	1-RMSEA				1.00		
	CFI				1.00		
	TFI				1.00		

Figure 1. Simplified Path Model with Controls



Significant pathways ($p < .05$ one-tailed tests) are in bold
Marginal pathways ($p < .10$ one-tailed tests) are black
Outcomes (Identify and Understand) are in special boxes (distribution family and constant).
Network contact variables (level I) are in white boxes
Control variables (level II variables) are encased in the gray box
Error terms, variances, and non-significant paths have been omitted for clarity

APPENDIX D

Social Networks and Problem Solving Effectiveness

ABSTRACT

In this chapter, I study the factors that explain why some biopharmaceutical scientists are more effective at problem solving than others. Innovators often experience obstacles between conceiving of a good idea and its ultimate implementation. The biopharmaceutical field is one such area where biopharmaceutical scientists engage in problem solving to keep their research and development projects moving forward. Fortunately, their team members and other types of social network contacts bolster their problem solving efforts. To answer this question about problem solving effectiveness, I survey members of the American Association of Pharmaceutical Scientists who engage in biopharmaceutical research and development about a research obstacle their project experienced, their problem solving effectiveness, the social network contacts they utilized to help them deal with the problem, and the context of their work. Because many of these factors are multifaceted and expected to relate to each other through the problem solving process, I utilize structural equation modeling. Results suggest that the knowledge components of networks mediate the relationship between strong ties and problem solving effectiveness. In addition, scientists' individual job performance inreases problem solving effectivess and is supported by the performance of their project teams. Limitations, directions for future study, and implications of these results for the study of innovation are discussed.

INTRODUCTION

The 'Problem' Problem

Problem solving is an important part of the innovation process, yet remains curiously understudied. Research on innovation and creativity focuses on the process by which novel ideas are generated (Perry-Smith and Mannucci 2017). But because they delve into unknown areas or generate products that are difficult to evaluate (Firestein 2012, Hsu, Hannan and Koçak 2009, Lamont 2012), many novel ideas fail to become useful innovations. In fact, innovative fields like biopharmaceutical science are characterized by high failure rates (Firestein 2016, Murmann 2003, Saxenian 1994). The road to innovation is fraught with challenges, false-starts, setbacks, and obstacles (Firestein 2016, Obstfeld 2017, Powell, Koput and Smith-Doerr 1996) – what I call 'research obstacles' as scientists and their research teams attempt to realized what was considered impossible only a few years prior. In these circumstances, biopharmaceutical scientists engage in problem solving to keep their projects on track (see Appendix B). Given that problem solving is essential to biopharmaceutical science, it is appropriate to ask *why are some biopharmaceutical scientists more effective at problem solving than others?*

To ask this question about problem solving, it is important to first clarify the meaning of the word 'problem'. That problem solving is a fundamental component of science is taken as given (Gieryn 1978, Gieryn and Merton 1978, Kuhn 1962). Yet the concept of a 'problem' varies greatly across research lines. In the words of Tez (2016), there is a 'problem' problem. In the sociology of science and knowledge, a 'problem' often means 'research area.' Researchers ask why scientists choose to work in certain fields or pursue particular research lines (Gieryn 1978, Grit and Jana 2018, Gross 2002, Rushforth, Franssen and de Rijcke 2018). Often, scientific problems are framed as Grand Questions, like how to edit the functionality of human genes or

cure cancer. This conception of 'problem' bleeds into the concept of expert jurisdictions where professionals or academics specialize and defend control over their "turf," which can be thought of as the problems for which they are qualified to diagnose, treat, or address (Abbott 1988, Anteby, Chan and DiBenigno 2016). In the burgeoning research on the problem-solving view of the firm (Baer, Dirks and Nickerson 2013, Felin and Zenger 2014, Nickerson and Zenger 2004), organizational leaders struggle with the strategic issue of dealing with an uncertain environment and a plethora of poorly-defined problems. Their burden is to evaluate, clarify, prioritize, and focus efforts on the greatest problems. The conception of 'problem' can carry a positive connotation of a creative challenge and growth opportunity (Lepine et al. 2016, Reiter-Palmon and Illies 2004).

These conceptualizations of 'problem' do not fit many of the research obstacles experienced by biopharmaceutical scientists. Consider the following description given by a CEO of a small biotech company in the Greater Boston Area whom I interviewed (see Appendix B for details). In this excerpt, Ned (a pseudonym) explains how the contract research organizations used by his company make small changes to the chemicals. Taken by itself, each small change does not appear to cause an issue, but these changes add up over time to the point that the experiment being conducted is essentially different from the experiment that they intended.

> We had an assay that we used to detect the drug in the blood. The [contract research organization] that we used made a number of changes, but they were always scientifically justifiable. They used bugger A, [then] buffer B. They liked buffer B. They went with buffer B. But they did it on a number of steps in the recipe so at the end of the day, they weren't making cookies, they were making brownies. You didn't realize that until you stepped back and realized the totality of the changes that had gone on. Like "Holy shit, you're making brownies now. You're supposed to be making cookies." So the assay wasn't performing as it should because they were making brownies.

Consider also the following quote from a division manager for a large pharmaceutical company. In it, Arnie (a pseudonym) describes how efforts to understand human biology by utilizing mice

and other types of animals often fails. This is a common problem in biopharmaceutical research (Firestein 2016). Arnie says:

> All of a sudden, we started seeing some elevated enzymes and getting enlargement of [something] in the liver. We never saw it in animals because animals responded differently. We stepped in and went forward […] with a structurally-different molecule that works fine. Sometimes, until you get it [the drug] into people, you don't understand that [their reactions]. So you need to use computer simulations. You use all your best animal models but it ain't going to happen.

While "Ned" and "Arnie" are presented with opportunities to apply their expertise and thereby gain recognition for having fixed the issue, there can be no doubt that these two scenarios are obstacles in the sense that their projects could not have moved forward as planned unless they were dealt with.

When 'problem' carries the connotation of an obstacle, it is assumed that actors have goals, but do not know how those goals are to be reached (Duncker 1945, Novick and Bassok 2005, Rittel and Webber 1973). This conception of 'problem' fits the context of biopharmaceutical research and development (R&D) projects well because these projects are planned in advance, but experience disruptions, setbacks, and hinderances (Firestein 2016, Nakagawa and Lehman 2015). Scientists do not choose to pursue these problems like they choose a line of research and they do not typically require engaging in the sense-making process of problem formation that is required by strategic organizational issues. Rather, the process for dealing with these obstacles begins when actors identify that their current situation does not fulfill their desired situation. Ned and Arnie become aware that their research plans were thwarted. Additional problem solving phases show actors establishing an understanding of the problem, evaluating its impact, generating a solution or plan to address the problem, executing the solution or plan, and communicating about the problem to others (Collins and Evans 2007,

National Research Council 2013, Novick and Bassok 2005, Obstfeld 2017, Perry-Smith and Mannucci 2017, Reiter-Palmon and Illies 2004).

Individual scientists attempting to solve problems associated with R&D projects face a daunting challenge that calls for a multifaceted array of expertise and experiences. To be more effective in dealing with these obstacles, these scientists must be effective at each problem solving phase. Being proficient in their realm of expertise only goes so far; many of the problem solving phases deal more with experience (Collins and Evans 2007), fostering collaborative relationships with other scientists (Leahey 2016) or important figures in other parts of their organization (Burt 2005, Obstfeld 2017), and establishing interpersonal trust that defrays the difficulties of admitting mistakes or calling attention to problems (Borgatti and Cross 2003, Firestein 2016). Moreover, being at one effective at one phase in the problem solving process may call for certain types of expertise and experiences that undermine other problem solving phases (Perry-Smith and Mannucci 2017). It seems unlikely that an individual scientist can accomplish all this.

Networks

Fortunately, individual scientist are not required to address research obstacles in isolation. Social networks provide access to diverse knowledge that is critical for creativity, innovation, and problem solving (Levin and Cross 2004, Perry-Smith and Mannucci 2017, Phelps, Heidl and Wadhwa 2012). Social networks help individuals mobilize support for their ideas and activities (Burt 2005, Fligstein and McAdam 2012, Grosser et al. 2017, Obstfeld 2017). In the context of biopharmaceutical R&D, scientists utilize their contacts to facilitate problem solving when dealing with research obstacles (Smith-Doerr 2004, Smith-Doerr 2005) (see also Appendix B and Appendix C). Different characteristics of social network contacts provide different types of

support and different resources in knowledge-intensive contexts like the field of biopharmaceutical science.

Researchers often characterize social network contacts in terms of the strength of the relationship (network tie). In the words of Granovetter (1973: 1361), "the strength of a tie is a (probably linear) combination of the amount of time, the emotional intensity, the intimacy (mutual confiding), and the reciprocal services which characterize the tie." Famously, Granovetter argues for the unexpected utility of weak ties, which are thought to connect individuals to unfamiliar knowledge that is often more useful than the familiar knowledge provided by strong ties. This insight has held up; weak ties have been shown to enhance creativity through accessing diverse knowledge in other social circles (Perry-Smith and Mannucci 2017, Phelps, Heidl and Wadhwa 2012), but strong ties still have their place. They promote emotional support (Perry-Smith and Mannucci 2017) and foster cooperation (Melamed and Simpson 2016), both of which support knowledge-sharing (Levin and Cross 2004, Uzzi and Lancaster 2003). Both types of ties would appear to support problem solving. However, research in Appendix C shows that biopharmaceutical scientist find that their strong ties are especially useful during the earliest phases of problem solving. Moreover, once they prove useful at an earlier phase, these strong ties are likely to prove useful at later problem solving phases. Therefore:

H_1: Strong ties increase scientists' problem solving effectiveness

Beyond the strength of a network tie, networks in knowledge-intensive contexts like biopharmaceutical R&D are often characterized by their knowledge components. These components relate the expertise and experiences of individuals and their network ties (Cross and Cummings 2004, Phelps, Heidl and Wadhwa 2012). These knowledge components of networks

(Phelps, Heidl and Wadhwa 2012) culminate in a transactive memory system (Wegner, Erber and Raymond 1991) that provide scientists with an awareness of the expertise and experiences of their network contacts (Borgatti and Cross 2003) as well as an indirect sense of who knows who the expertise and experiences of others (Yuan et al. 2010), which aids problem solving (Cross and Cummings 2004). Transferring knowledge through social networks is more likely to occur when the competence of the sender is high. That is, there is trust in the competency of the sender's expertise or perspective (Contractor and Monge 2002, Levin and Cross 2004). Moreover, individuals find that their network contacts are more effective collaborators and easier to work with when they have shared expertise and experience. This knowledge overlap bolsters problem solving through complementary skills and facilitates communication (Katzenbach and Smith 2003, Phelps, Heidl and Wadhwa 2012, Reagans and McEvily 2003, Rulke and Galaskiewicz 2000). All of these knowledge components of networks – awareness, competence-based trust, and knowledge-overlap – are expected to facilitate problem solving.

H_2: Knowledge components of networks increase scientists' problem solving effectiveness

Both tie strength and the knowledge components of networks are expected to increase scientists' problem solving effectiveness directly, but these two types of network ties are not expected to be independent. The longer the two individuals know each other, the more frequently they interact, and the close they are emotionally – the stronger their tie, the more they become embedded in a common transactive memory system and come to be aware and trust the expertise of others (Cross and Cummings 2004, Hirst and Echterhoff 2012, Wegner, Erber and Raymond 1991), especially if their work is interactive and their tasks interdependent (Reagans, Argote and Brooks 2005, Yuan et al. 2010), which is the case with biopharmaceutical R&D work

(Nakagawa and Lehman 2015). Thus, two scientists are more likely to have greater awareness, competency-based trust, and overlapping knowledge when their ties are stronger. Thus:

H_3:Strong ties increases the knowledge components of networks

Two performance factors – scientists personal job performance and the performance of their project teams – are expected to directly influence problem solving effectiveness. Indirect pathways are also expected because these performance factors are related and because they are thought to support the generation of strong ties and the knowledge components of networks, as argued below. Figure 1 diagrams these factors and their expected influences. Because each major factor is multifaceted, ovals are utilized to indicate that they are conceptualized as latent variables that are labeled in all caps. These ovals have the same labels as Figure 7, which is a simplified diagram of results from a structural equation model. These latent variables and their labels are 1) Problem solving effectiveness (P Solve); 2) Tie strength (STR TIES); 3) The knowledge components of networks (KNOW NET); 4) Individual performance (I PERF); and 5) Team performance (TEAM PERF).

[Figure 1 here.]

Individual Performance

Individual scientists with higher levels of job performance are expected to be more effective at problem solving. As defined by Campbell et al. (1993: 41), job performance is "what people actually do to accomplish organizationally-relevant goals that can be observed and measured." The authors frame this concept as distinct from job effectiveness. Whereas job performance relates to processes, job effectiveness relates to outcomes; for example, in academia adhering to a writing schedule indicates a higher level of job performance (Silvia 2007) whereas publishing

written work indicates a high level of job effectiveness (Leahey, Beckman and Stanko 2017). All else being equal, those who perform their jobs well are expected to be more effective at job-related tasks (Campbell et al. 1993, Erez et al. 2015, Glaser, Stam and Takeuchi 2016, Miron-Spektor et al. 2018, Vogel, Rodell and Lynch 2016). Given that dealing with scientific problems is a core task of biopharmaceutical scientists (Firestein 2016), scientists' individual job performance is likely to improve their problem solving effectiveness.

H_4: Individual job performance increases scientists' problem solving effectiveness

Because the biopharmaceutical field is knowledge-intensive, many of the types of resources that facilitate problem solving also facilitate individual performance. To the extent that strong ties are associated with frequent communication, trust, and cooperation, they facilitate many aspects of job performance because they help overcome communication problems, establish trust, generate a sense of collective action (Granovetter 1973, Yuan et al. 2010). This is especially true for sharing knowledge, communicating with others, and working well with others (Yuan et al. 2010). In addition, components of knowledge networks are expected to increase scientists' individual job performance by making the expertise of others more relevant to their tasks, more understandable, more visible, and more accessible (Contractor and Monge 2002, Cross and Cummings 2004, Yuan et al. 2010). Therefore,

H_5: Strong ties increase scientists' individual job performance

H_6: Knowledge components of networks increase scientists' individual job performance

Team Performance

Project teams are expected to increase scientists' problem solving effectiveness if those teams perform well. Well-performing teams provide individuals with greater amounts of collective

knowledge, complementary skills, and the ability to integrate this knowledge (Börner et al. 2010, Katzenbach and Smith 2003, National Research Council 2015, Wuchty, Jones and Uzzi 2007). Well-performing teams increase the frequency of interaction between their members, especially face-to-face interactions, which coordinates individuals' efforts and helps them navigate conflicting goals when problems arise (Alexander and Van Knippenberg 2014, Hoegl and Proserpio 2004, Hoegl, Weinkauf and Gemuenden 2004, Oldenhof, Stoopendaal and Putters 2016, Walsh and Maloney 2007). Team members are also excellent resources for understanding difficult problems and how do deal with them (Fiore and Salas 2007, Fiore 2008, Salazar et al. 2012). This leads to the expectation that:

H_7: Team performance increases scientists' problem solving effectiveness

Well-performing teams are also thought to bring out the best in their members, in terms of their individual performance (Katzenbach and Smith 2003, National Research Council 2015). By generating a focus on the attainment of goals and establishing a sense of mutual accountability, well-performing teams help individuals reach their peak performance through enhanced coordination and shared expectations (Alexander and Van Knippenberg 2014, Hoegl and Proserpio 2004, Katzenbach and Smith 2003). Thus:

H_8: Team performance increases scientists' individual job performance

Team performance is expected to influence the qualities of scientists' social networks. As noted above, well-performing teams provide many benefits of strong ties, e.g. frequent communication (Hoegl and Proserpio 2004, Yuan et al. 2010), interpersonal trust (Katzenbach and Smith 2003, Walsh and Maloney 2007). High performing teams help individuals bond with each other over shared activities (Balkundi and Harrison 2006, Stokols et al. 2008, Yuan et al.

2010). Teams also provide many of the benefits of the knowledge components of networks, such as generating larger stocks of collective knowledge and facilitating knowledge transfer (Börner et al. 2010, Katzenbach and Smith 2003, Walsh and Maloney 2007, Wuchty, Jones and Uzzi 2007, Yuan et al. 2010). As a practical matter, biopharmaceutical companies encourage their scientists to utilize team members when dealing with research obstacles, in part, to draw protective boundaries around intellectual properties (see Appendix B). Thus, many biopharmaceutical scientists' most useful network contacts are affiliated with the same R&D projects (see Appendix C). As a result, team performance is expected to increase both types of social network ties.

H_9: Team performance increases network tie strength

H_{10}: Team performance increases the knowledge components of networks

DATA AND METHODS

Sample

To test these hypotheses about why some biopharmaceutical scientists are more effective at solving research-related problems than others, I surveyed members of the American Association of Pharmaceutical Scientists (AAPS). The AAPS is the largest professional organization of pharmaceutical scientists with 11,000 members worldwide in industrial, academic, government, and other research organizations. Its stated mission is to advance "the capability of pharmaceutical scientists to develop products and therapies that improve global health" (American Association of Pharmaceutical Scientists 2016). As part of this mission, the AAPS organizes large annual conferences, such as their Annual Meeting and Exposition that draws over 7,000 registrants annually, provides workshops on topics such as Future Advances in

Nanotechnology, and publishes four research journals focusing on scientific and management issues. As such, it maintains an important position in the field of biopharmaceutical science.

The questionnaire I developed was distributed by InFocus Marketing, a marking company that contracts with AAPS for list management, data services, and email fulfillment (InFocus Marketing 2016). Survey invitations followed the basic tailored design method (Dillman, Smyth and Christian 2008, Dillman, Smyth and Christian 2014) and included an anonymous link to an online survey I developed in *Qualtrics*, an online survey software suite. In August 2015, InFocus emailed the invitation to 8,065 people which included individuals with current AAPS memberships, those who had canceled their membership within one year, and those who had registered for the 2015 APS Annual Meeting. A reminder was sent two weeks later. The invitation had a delivery rate of 95.4%, an open rate of 36.5%, an overall completion rate of 5.37%, and a click-to-open rate of 15.1%. The reminder message had a delivery rate of 96.8%, an open rate of 38.2%, an overall completion rate of 4.34%, and a click-to-open rate of 11.3%. In total, 661 individuals provided useable data by completing at least half of the survey, resulting in a response-rate of 9.1%.

The survey collected information about working in the biopharmaceutical field, research obstacles, social network ties, and scientists' self-reported evaluations of their effectiveness at problem solving. The survey comprises eight sets of questions. After establishing informed consent, it solicited background information and asked about respondents' work histories and their current organization. The next two blocks of questions asked respondents about one of their ongoing pharmaceutical science projects and the most serious research obstacle that they encountered in the past year. The final questions generated a list of network contacts that were used to deal with the research obstacle. Name-interpreter questions (Knoke and Yang 2008)

asked respondents to provide information about each network contact and the respondent's relationship with each. The final question-block asked respondents about the problem solving process associated with their research obstacle.

Of these 661 initial respondents, 284 met the scope conditions (Walker and Cohen 1985) for this study. Their biopharmaceutical R&D project that had occupied the greatest amount of their time in the past year experienced a research obstacle and they utilized one or more network contacts to deal with that obstacle. The 284 respondents who meet the scope conditions appear to differ from AAPS members in that some biopharmaceutical functional areas may be overrepresented. AAPS members may affiliate with nine different functional areas of pharmaceutical science, e.g., Manufacturing Science and Engineering. Numbers of section affiliations are listed on the AAPS website (American Association of Pharmaceutical Scientists 2016). In lieu of asking respondents about their affiliations to these sections, members were asked to indicate the percentage of their career they had spent in each of these nine areas. While not equivalent, when the percentages of these two variables are compared, survey respondents spent more time in Drug Discovery and Development (+7%) and Formulation Design and Development (+4%) than AAPS percentages would indicate. These areas are associated with biopharmaceutical science that focuses on pre-clinical R&D.

Key Measures

Problem solving effectiveness

To measure scientists' individual problem solving effectiveness, respondents were asked to evaluate their personal effectiveness in dealing with each of six problem solving steps. These steps are: identifying that the research obstacle was present, evaluating its seriousness or impact, understanding its nature, planning to solve or circumvent it, communicating about it to people

outside of the project, and executing the plan to overcome or circumvent the obstacle. For each phase, they rated their effectiveness using a six-point Likert scale: 1) Ineffective; 2) Mostly Ineffective; 3) Somewhat Ineffective; 4) Somewhat Effective; 5) Mostly Effective; or 6) Effective. As mentioned above and described below in detail, scientists self-evaluations of their effectiveness at these problem solving phases are combined to create 'P Solve' a latent variable.

Networks

To capture respondents' broad range of network support, respondents were given a typical combination of two types of survey questions. First, a name-generator question asked respondents to provide the initials of up to eight contacts who assisted with their project's research obstacle. Capping the number of contacts at eight seemed reasonable given that pervious researchers' network surveys have yielded smaller average network sizes, e.g. Grosser et al. (2017) found an average network size of 5.49 contacts (sd = 2.31), despite utilizing four name-generator questions. The name generator question on my survey was followed by several name-interpreter questions that ask respondents to provide information about each social network contact that they listed in the name-generator (Knoke and Yang 2008). Name-interpreter questions are based on research on strength of ties, the knowledge components of networks, and organizational authority (see Appendix C for additional details).

Four survey items capture the strength of the relationship between each respondent and each respondent's contacts. Although the details provided by Granovetter (1973) are very clear (see above), few researchers measure tie strength as he describes. Instead, researchers often utilize one strong indicator, such as the duration of the relationship between respondents and their contacts, which has been shown to be a strong indicator of tie strength (Marsden and Campbell 2012, Melamed and Simpson 2016). A latent variable approach was chosen because it

is closer to the original mutifacted conception of the concept of Granovetter (1973). Accordingly, I measure the duration of the relationship between respondents and their contacts using a seven-point scale (1 = Less than one year; 2 = 1-2 years; 3 = 3-4 years; … 7 = 10 years or more). As a substitute for emotional intensity, emotional closeness was measured using a six-point scale that ranged from Very distant (1) to Very close (6). Communication frequency, long claimed to the hallmark of good working collaborations (Gardner 2017, Gupta et al. 2009, Katzenbach and Smith 2003, Phelps, Heidl and Wadhwa 2012, Rainie and Wellman 2012), is measured with two questions that ask respondents to indicate the number of monthly face-to-face and electronic communications for each contact, whether these communications were scheduled or impromptu. These indicators are used in 'STR TIES,' a latent variable.

The knowledge components of these network ties are captured with three name-interpreter questions. To measure the awareness of their contacts' expertise, respondents indicated the extent to which they were aware of the expertise of each contact when they were first contacted for the purpose of dealing with the research obstacle that they had identified earlier. Asking respondents to recall their awareness at this point of contact is intended to mitigate against maturation effects that are expected to occur when respondents and their contacts engage in problem solving over time. A five-point Liker scale was used: 1) Very Unaware; 2) Unaware; 3) Somewhat Aware; 4) Aware; and 5) Very Aware. Respondents indicated the extent to which the expertise of each contact overlapped with their expertise using a five-point Likert scale: 1) No Overlap; 2) Little Overlap; 3) Moderate Overlap; 4) Strong Overlap; or 5) Complete Overlap. Finally, respondents indicated the amount of competency-based trust – the extent to which they found the expertise and experiences of a contact to be adequate and reliable – using a seven-point Likert scale: 1) Completely Distrust; 2) Distrust; 3)

Somewhat Distrust; 4) Neutral; 5) Somewhat Trust; 6) Trust; or 7) Completely Trust. These measures are used as indicators for the latent variable 'KNOW NET.'

Individual performance and team performance

The items used to measure scientists' individual job performance and the performance of their project team is based on each respondent's evaluations of work-related processes (Campbell et al. 1993). Following extant research on individual and team performance (Allen et al. 1988, Ancona and Caldwell 1992, Cross and Cummings 2004, Gardner, Staats and Gino 2012), respondents were asked to evaluate their own performance based on whether they worked efficiently, worked well with team members, worked well with team leaders, adhered to the project schedule, kept to the project budget, produced excellent work, were competent, understood project goals, and communicated effectively. To better distinguish respondents' relationships within their project team, respondents were asked to evaluate how well they worked with other team members and project leadership. Respondents were also asked to evaluate the performance of their project teams based on whether their team worked efficiently, adhered to the project schedule, kept to the project budget, produced excellent work, understood project goals, was competent, and communicated effectively. Each item was measured using a seven-point Likert scale: 1) Completely Disagree; 2) Disagree; 3) Somewhat Disagree; 4) No Opinion; 5) Somewhat Agree; 6) Agree; or 7) Completely Agree. The self-reported evaluations from respondents about their own performance are used as items for 'I PERF,' which is a latent variable. Self-reported evaluations of team performance are used as items for 'TEAM PERF,' another latent variable.

Control Variables

Additional survey data allow a rich set of variables that have the potential to influence scientists' problem solving effectiveness to be included. Several control variables measure aspects of human capital that touch upon experience and expertise. The more expertise that a scientist has, the more that he or she is able to solve problems because of exposure to a wide range of situations, contexts, and prior obstacles (Collins and Evans 2007, Novick and Bassok 2005). Thus, respondents indicated the number of years they had worked in the biopharmaceutical field, broadly construed, inclusive of graduate school. Additionally, respondents indicated the number of peer-reviewed academic articles they published and the number of patents they hold (1-5, 6-10, […] 26 or more). Academic publications and patents signal competency, visibility, and generate field-specific social capital (Bourdieu 2004, Leahey 2007, Whittington and Smith-Doerr 2005, Whittington and Smith-Doerr 2008). With the realization that collaboration is becoming more commonplace within academia and industry (Falk-Krzesinski et al. 2011, Wuchty, Jones and Uzzi 2007), publications also represent the capability to collaborate (Leahey 2016), navigate the complexities of interdisciplinary research (Fiore 2008, National Academy of Sciences 2005), and deal with disruptions caused by research obstacles (Obstfeld 2017). Thus, scientists with greater numbers of publications and patents ought to deal with research obstacles more effectively.

To capture greater depths of expertise and specialization, respondents indicated their fields(s) of study in which they had earned any type of college degree. Response options were based on the 2012 Survey of Earned Doctorates (Millar and Dillman 2012, National Science Foundation and National Center for Science and Engineering Statistics 2011) and included: Business, Computer/ Information Science, Engineering, Agricultural Sciences, Biological

Sciences, Health Sciences, Mathematics, Chemistry, Social Sciences, Arts and Humanities, Law, Medicine, and 'Any Other Area.' Having indicated their fields of study, respondents indicated their subfields and the highest degree earned in each subfield. These responses were used to count the number of PhDs earned by each respondent as one measure of expertise. In addition, breadth of expertise (especially interdisciplinarity) should also improve scientists' problem solving effectiveness ((National Academy of Sciences 2005). But whereas interdisciplinarity normally manifests in collaborative teams (Fiore 2008, Leahey 2016, Salazar et al. 2012), some individuals are able to pursue it alone, despite the inherent challenges (McBee and Leahey 2016). All else being equal, these boundary-spanning individuals ought to have higher levels of problem solving effectiveness than their monodisciplinary counterparts. To measure the extent to which respondents have interdisciplinary backgrounds, a variable that counts the number of fields in which respondents have earned degrees is included.

Control variables related to social capital and networks are also included. Although many measures of social capital have been developed (Erickson 2003, Koput and Broschak 2010, Lin and Erickson 2008), the number of social network contacts (degree centrality) remains related to these measures (Freeman 1978, Knoke and Yang 2008). Therefore, the number of network contacts utilized by respondents to deal with their research obstacle is included as a control variable. I also control for the number of years respondents spent working at their current organization (organizational tenure) because it represents firm-specific social capital. Those who have worked in an organization longer are likely to have established more durable ties, retain a better sense of what is possible, and how disruptions to research activities are resolved (Obstfeld 2017). Important resources and organizational power are concentrated in high-status positions (Burt 2005, Erickson 2003, Grosser et al. 2017). One such position is a project leadership role

(Martin, Liao and Campbell 2013, Nakagawa and Lehman 2015), which is often an informal role in many knowledge-intensive contexts (Carson, Tesluk and Marrone 2007, Katzenbach and Smith 2003). Accordingly, respondents were asked if they occupied a leadership role on their project team.

Two variables control for organizational context. First, it is often stated that larger biopharmaceutical organizations are less innovative than small biopharmaceutical companies , in part, because their small size makes aspects of organizational learning and network activation easier (Powell 1990, Powell, Koput and Smith-Doerr 1996, Rafols et al. 2014). Larger organizations may encourage more specialization (Leahey and Hunter 2012), which could make dealing with more complex, multifaceted problems more difficult (National Academy of Sciences 2005). To measure organizational size, respondents were asked to indicate the number of individuals in their organization whose work focuses on some aspect of biopharmaceutical science. The first twenty response-options increase in 50-unit blocks (‘Less than 50,’ ’50 to 99,’ etc.), but gave two additional options for organizations with thousands or ten thousand or more individuals. Second, respondents were asked which sector best characterized their current organization (Academic, Government, Private/ Industry, or Other). Because several researchers have noted organizational differences between academia and industry (Croissant and Smith-Doerr 2008, Shibayama, Walsh and Baba 2012, Walsh et al. 2008), a dummy variable was used to distinguish respondents who work in academe and those who do not.

To measure the severity of respondents’ research obstacles, they evaluated several characteristics of their research obstacle using the same seven-point Likert scale used to measure individual job performance and team performance. Respondents’ evaluations of whether their research obstacle was serious, complicated, beyond their personal expertise, increased work

pressure, intensified over time, and impacted other projects were used as indicators of a latent variable 'SEVERITY.' A latent variable approach was chosen because the severity of a research obstacle is difficult to identify but its associated indicators can be seen as manifestations of such severity (Acock 2013, Bollen 1989, Kline 2015).

In addition to the characteristics of the severity of these obstacles, open-ended descriptions of these obstacles from respondents provided insight into the sources of these obstacles. These short descriptions were coded using a generic coding method described in Saldana (2013) and Strauss and Corbin (1998) that aimed to generate and apply inductive codes during open coding (also known as initial coding). The five codes that were present in the open-ended accounts of 5% or more of respondents are utilized in this model. First, following Firestein (2016), respondents' brief descriptions of their research obstacles are coded 'Novelty' if their obstacle stemmed from the difficulties associated with conducting cutting-edge science. This was the most common code; 21% of respondents' research obstacles stemmed from the novelty of their work. Some examples of 'Novely' include "Developing mathematical models of pharmaceutical processes" and "The animal model we chose to test our compound in did not behave as expected." Second, with Obstfeld (2017) in mind, 9% of respondents' descriptions emphasized difficulties getting technology to work; the cause of their research obstacle was coded 'Tech.' One respondent wrote "I had a crisis where a machine had broken down in the middle of a three-month long experiment." Another stated, "Machine jammed and weights mysteriously increased." If, however, the research obstacle stemmed from a lack of resources – typically time, money, or personnel – the research obstacle was coded 'Resource,' the third qualitative code that pertains to 15% of respondents' obstacles. A number of respondents typed simply 'Budget constraints,' 'Money,' or 'Funding.' Another person elaborated "Need money to

generate preliminary data, but can't get money until preliminary data is available." Fourth, 8% of respondents described dealing with issues relating to regulatory agencies. As one respondent wrote, the difficulty was "Gaining health regulatory acceptance for a change in the site of manufacture." Another wrote that the project experienced "Complications introduced during FDA approval process." Finally, externall collaborators, while an important part of the biopharmaceutical field (Powell, Koput and Smith-Doerr 1996), posed difficulties for 6% of respondents. One stated, "Working with outsource labs." Another wrote "Managing external sources." Many other qualitative codes were generated, but applied to few cases (less than 5%) and were not considered as control variables. Because the sources of research obstacles are often distinct from each other, each is utilized as a dichotomous control variable.

Analytic Strategy

I use structural equation modeling (SEM) to address why some biopharmaceutical scientists are more effective at solving research-related problems than others. This is a good approach because SEM is able to accommodate complex latent variables and multiple causal pathways. (Acock 2013, Bollen 1989, Kline 2015). The analysis proceeded as follows. As a first step, I utilized confirmatory factor analysis (CFA) to specify error covariance structures and determine the best way to measure the latent variables of interest (Acock 2013, Kline 2015). Once good fitting CFA models were achieved for each latent variables, I added the more structural, causal, paths among latent variables – paths that correspond to hypotheses (see Figure 1). Because many respondents have more than one social network contact, the data structure is nested and in long (stacked) format. I therefore used clustered robust standard errors, an approach that increases the magnitude of standard errors based on the standard errors within each cluster (here, individual respondent), the average number of units in each cluster, and the number of clusters (Cameron

and Miller 2015). A maximum likelihood approach to missing values accommodates cases with missing data (Allison 2002), which is widespread across variables (see Table 1). Because of the clustered errors, most model fit statistics cannot be calculated. Despite the maximum likelihood approach to missing values, the variable organizational size generates an increased number of missing cases. Because its influence on problem solving effectiveness was not significant in earlier models ($p = .51$), it was removed to maximize the number of observations in the models.

Model fit was improved utilizing modification indices to help decide which variables' errors to correlate. Because modification indices often suggest "illegal" paths (Kline 2015) that run opposite to theoretical models, they were used primarily in a reductive manner. For instance, most latent variables have items associated with communication. It would appear reasonable to correlate these errors, but this results in several additional paths. Modification indices suggested that none were necessary. Instead, better model fit could be achieved by correlating the errors of similar items team performance and individual performance and by the errors of two items of tie strength with two items of the knowledge components of networks that appear reasonable, given extant research (Contractor and Monge 2002, Phelps, Heidl and Wadhwa 2012, Yuan et al. 2010).

RESULTS

Descriptive Statistics

This section reports descriptive statisics from Table 1 and elaborates on these statistics when necessary. Most of the 284 respondents that provided usable data are male (65%) and have a PhD (65%) and began working in the biopharmaceutical field when they were around 30 years old (the average biological age is 45.9 years and the average professional age is 14.5 years). The prevalence of doctorates suggests a focus on depth of expertise and specialization, but

respondents' average interdisciplinarity score is 1.45 (range = 1 – 4); many respondents have degrees from more than one area.

Respondents tend to to work for private or industrial organizations; just 29% work for academic institutions. It appears as if many respondents' work in large organizations because the average number of biopharmaceutical scientists in their organizations is 2,520, but there is a lot of variation surrounding this figure (sd = 5,463). When this variable is tabulated, it is clear that most respondents (60%) work at organizations with 125 or fewer biopharmaceutical scientists. This tend towards smaller biopharmaceutical organizations is overshadowed by the 16% of respondents who work for massive companies with 15,000+ scientists. The average career age (14.5) is about twice as much as the average organizational tenure (7.15).

Signs of successful careers are present. Respondents' average salary is $125,000 (sd = $77,000). While most respondents (57%) report having no patents, those that do patent have several; respondents average 2.48 patents (sd = 4.84). In contrast, 85% of respondents have published at least once in a peer-reviewed publication and the average number of publications is 11.14 (sd = 10.2). Their success may stem from good job performance. When respondents evaluated various aspects of their personal performance using a seven-point Likert scale, there was widespread agreement that they were efficient (6.11), produced excellent work (6.28), were competent (6.42), communicated well (6.24), worked well with other project members (6.47), and worked well with project leaders (6.43).

Most respondents (84%) occupy either formal leadership positions or have taken the mantel of an informal leadership role on the biopharmaceutical R&D project. Their teams average 7.15 members (sd = 2.34). When asked to evaluate various aspects of the performance of their teams using a six-point Likert scale, respondents voiced strong agreement with the claims

that their teams were efficient (4.95), produced excellent work (5.26), focused on project goals (5.32), communicated well (5.11) and were competent (5.33).

The research obstacles encountered in their projects tended to stem from issues related to the difficulties of conducting novel science (21%) or a lack of resources (15%); fewer (9%) involved technological issues. Several obstacles (15%) involved dealing with regulatory agencies and another 6% involved various aspects of collaboration. When it comes to the characteristics of these research obstacles, respondents tended to characterize them as serious (5.86 on a 7-point Likert scale) and as increasing pressure (5.73). Evaluations of their obstacles' ability to impact other projects (4.44) or intensify over time (4.90) were closer to neutral. Despite being complicated (5.74), respondents tended to disagree that these obstacles were beyond their expertise (3.96).

Respondents gave themselves high evaluations for their effectiveness at problem solving through all phases of problem solving. On a six-point Likert scale, respondents' evaluations all averaged close to 'Mostly Effective' (5). Only modest amounts of variations (the standard deviation of each ranges from .85 to .98) are associated with this measure; the majority of respondents ranked themselves between 'Somewhat Effective' and 'Effective.' On the one hand, high levels of problem solving effectiveness are expected because respondents have several years of experience working in a project-based, knowledge-intensive field; respondents who had low levels of problem solving effectiveness would be less likey to survive and thrive in this context. On the other hand, because problem solving is expected to be a core competency in this field, it would be socially desirable (Fowler 1995, Groves et al. 2009) for respondents to indicate high scores, even with the anonymity of a web-based survey (Callegaro, Manfreda and Vehovar 2015).

As expected, these biopharmaceutical scientists did not deal with their research obstacle in isolation. On average, they mobilized 4.68 contacts to assist them (sd = 2.50). When the indicators of tie strength are considered, many of these ties appear stronger than weaker. The duration of these relationships averages 4.48 years (sd = 3.58), which is about 30% of respondents' average career length and 63% of respondents' average organizational tenure. Emotional closeness was more subdued, about 'Somewhat Close' (3.99 on a six-point scale), but communication with contacts while the research obstacle was being dealt with is very frequent. On average, respondents report meeting their contacts face-to-face 11.45 times a month and communicating electronically 13.31 during the same period of time, inclusive of scheduled meetings and planned communications. It is worth noting that these idicators have high variability (sd = 9.16 and 9.06 respectively) and that these indicators are positively correlated to an appreciable degree (.60). Respondents were 'Aware' of the expertise of their contacts (4.21 on a five-point scale), but indicated only a 'Moderate Overlap' (2.97 on a five-point scale) with their respondents' expertise, on average. Interestingly, respondents placed a lot of trust (6.05 on a seven-point scale) in the competence of their contacts' expertise and experiences.

Confirmatory Factor Analysis

As mentioned above, confirmatory factor analysis was utilized to gauge the fit of latent variables' indciators prior to running structural equation models (Acock 2013, Kline 2015). When applicable, modification indices were utilized to improve model fit within each latent variable. Scientists' self-reported evaluations of their problem solving effectiveness across all six problem solving phases (Identify, Understand, Evaluate, Plan, Execute, and Communicate) did not result in good model fit until most indicators' errors were correlated with the errors of Plan. As recommended by Acock (2013), this indicator was removed and the model respecified, which

resulted in excellent model fit (see Figure 2) once the errors of Evaluate and Execute are correlated. These five indicators are retained for P SOLVE, the latent variable that measures biopharmaceutical scientist' problem solving effectiveness across problem solving phases.

Networks

The latent variables associated with strength of ties (STR TIES) and the knowledge components of networks (KNOW NET) were difficult to asses because of their multilevel nature. As mentioned above, multiple network contacts (Level I) are embedded within each respondent (Level II). Adopting a multilevel approach to confirmatory factor analysis, while perhaps possible through a multilevel factor analysis (StataCorp 2017) or through clustered standard errors (Cameron and Miller 2015), if possible, but appropriate model fit statistics cannot be calculated. Utilizing regular standard errors resulted in conflicting fit statistics. While RMSEA and CFI were exceptional (0.00 and 1.00 respectively), the CD measures were below acceptable standards (.69 and .62 respectively). Yet even modification indices failed to improve the latter fit statistics. Therefore, these latent variables' confirmatory factor analysis models should be interpreted with caution. As an alternate strategy, these two latent variables were covaried, essentialy replacing the path in the conceptual model with a covariance relationship between STR TIES and KNOW NET, which improved the model fit. When the errors of awareness were correlated with those of relationship duration and then competency-based trust, model fit generally improved ($p = .00$, RMSEA = .04, CFI = .99, and CD = .80). Allowing STR TIES and KNOW NET to covary and the error correlations between these indicators are consistent with research on tie strength, the knowledge components of networks, and professional trust (Contractor and Monge 2002, Levin and Cross 2004, Levin, Whitener and Cross 2006, Yuan et al. 2010), so they were retained in the final model.

Tie strength (STR TIES) and the components of knowledge networks (KNOW NET) have a moderately strong correlation (.65). The strongest indicators of the latent variable tie strength (STR TIES) is involve communication. Face to face communication (2.5) and electronic communication (2.4) are the strongest indicators (see Figure 3). Because in-person communication frequency is generally expected to correlate to electronic communication frequency (Rainie and Wellman 2012, Wellman 2004), the errors for these two indicators are correlated. Relationship duration (1.0) and emotional closeness (.67) are far behind. Consistent with Borgatti and Cross (2003) and Cross and Cummings (2004), awareness is a strong indicator (.95) of KNOW NET, but competency-based trust (Levin and Cross 2004, Levin, Whitener and Cross 2006) is the strongest (1.0). Knowledge overlap is also strong (.85).

Individual performance and team performance

Scientists' self-reported evaluations of aspect of their own performance (producing excellent work, being competent, being efficient, working well with leaders, working well with team members, and communicating) comprise the latent variable I PERF. (See Figure 4.) Modification indices indicated that Excellence ought to have correlated errors with Competent. In addition, the errors of 'w/Members' should correlated with 'w/ Leaders' and 'Communicate.' These correlated errors resulted in excellent model fit. Working efficiently (Efficient) and communicating with others (Communicate) were the strongest indicators, but producing excellent work (Excellence) and being competent (Competent) were not far behind (.96 and .95 respectively).

The latent variable TEAM PERF captures scientists' evaluations of their project teams. Modification indices suggested that the errors of communicating well with each other (Communicate) shold be correlated with those of working efficiently (Efficient) and focusing on team goals (Goals). This resulted in good model fit (see Figure 5). Producing excellent work

(Excellence) is the strongest indicator (1), but working efficiently (Efficitent) and focusing on team goals (Goals) are also very strong (.92 and .90 respectively).

Research Obstacles

The latent variable SEVERITY measures the severity of the research obstacles experienced by biopharmaceutical scientists. It is worth mentioning again that a latent variable approach was utilized for these indicators because they are all thought to be manifestations of the same unobserved research obstacle. In contrast, the dichotomous variables that characterize the *sources* of research obstacles do not have the same unmeasured cause as these indicators and are modeled separately from these indicators. Modification indices suggested that the errors of the extent to which the obstacle was complicated (Complicated) should be correlated with the seriousness (Serious) of the obstacle and whether the obstacle was beyond the expertise of the respondent (Beyond). In addition, the errors of the sense in which the obstacle intensified over time (Intensify) and whether the obstacle impacted other projects (Impact) should also be correlated. These suggestions appeared reasonable and resulted in acceptable model fit (see Figure 6). Of the six indicators of SEVERITY, intensifying over time (Intensify) was the strongest (1) with causing performance pressure (Pressure) a close second (.95).

Results from Structural Equation Modeling

Table 2 reports results from two structural equation models. The first model is used to test hypotheses; the second model add all control variables. As Table 2 reveals, standard errors are calculated using a robust cluster option to account for the fact that there are 1,319 network contacts embedded within 284 respondents. Significance is determined via one-tailed tests. Because this approach was coupled with a maximum likelihood approach for missing data (Allison 2002), Stata 15 could not calculate most model-fit statistics typical for structural

equation modeling (Hooper, Coughlan and Mullen 2008). Simplified results from the second model are diagrammed in Figure 7 which includes only significant and marginal pathways between independent variables; all indicators, error covariances, and control variables are omitted for simplicity.

There is no support for the claim (H_1) that tie strength increases scientists' problem solving effectiveness. As indicated in Table 2, the associated coefficient is close to zero and far from significant (p = .76) in the conceptual model and the saturated model. The expected influence of the knowledge components of networks on scientists' problem solving effectiveness (H_2) fares much better. The magnitude of its coefficient changes from .26 to .30 and its significance changes from marginal (p = .07) to significant (p = .03) with the addition of control variables. The hypothesis that strong ties influence the knowledge components of networks (H_3) is fully supported. The path from tie strength (STR TIES) to the knowledge components of networks (KNOW NET) is meaningful (.27) and significant (p = .00). Because of these influences, tie strength has an indirect influence on scientists' problem solving effectiveness that is mediated through the knowledge components of networks, consistent with Contractor and Monge (2002) and Yuan et al. (2010).

[Figure 7]

As expected, scientists' individual job performance promotes their problem solving effectiveness (H_4). Its influence is strong in both models (.50 and .47 respectively) and significant (p = .01). Scientists' job performance is expected to be influenced by tie strength (H_5). This hypothesis is not fully supported, but tie strength does have a marginally signficiant (p = .07) effect of a meaningful magnitude (.08). Hypothesis H_6 that set an expectation that the

knowledge components of networks support scientists' individual job performance is not supported. In fact, the direction of influence is negative (-.22).

Team performance meets few of its associated expectations. Contrary to expectations (H_7), scientists' team performance does not increase scientists' problem solving effectiveness (p = .57). Team performance does have a large (.89) and significant (p = 0.00) influence on scientists' individual performance, as expected (H_8). Team performance has only a marginaly significant (p = .098) and modest (.28) influence on tie strength. Thus, H_9 is not fully supported. Similarly, team performance has a marginally significance (p = .052) influence on the knowledge components of networks that is modest (.27) in its magnitude.

In addition to the latent variables, some control variables had significant influences on problem solving effectivess. Contrary to all expectations about interdisciplinary and problem solving (National Academy of Sciences 2005), biopharmaceutical scientists reported being *less* effective at problem solvling the more subject-areas in which they had earned academic degrees. This influence is significant via a two-tailed test (p = .02) and meaningful in its magnitude (-.23). Further, the numbers of publications in peer-reviewed journals has a marginal (p = .04) negative (-.02) influence on problem solving effectiveness. Conversely, patenting activity has a significant (p = .02) and positive (.02) influence on problem solving effectiveness. These results appear counterintuitive, especially given that these two productivity variables have a slight positive correlation (.16). A possible explanation is that academic scientists, who may be more likely to hold interdisciplinary backgrounds, are pushed to publish more in academic journals. Their industrial counterparts are pushed towards patenting. These results may be due to differential support structures.

An exploratory set of regressions (not reported) give limited support to this idea. When numbers of patents is regressed onto numbers of publications, interdisciplinary backgrounds, and working in academia; academic scientists have 1.25 fewer patents ($p = .029$) but publications numbers have a positive (.08) and significant ($p = .002$) influence on patenting activity. Conversely, when publications are regressed onto numbers of patents, interdisciplinary backgrounds, and working in academia; there is marginal support ($p = .095$) that academics have more (2.02) peer-reviewed journal articles than their industrial peers. In addition, biopharmaceutical scientists receive an additional publication for roughly every third (.36) of their patents. While academics are pushed to publish more and patent less than their industrial peers, this relationship is complicated by the fact that patents and peer-reviewed publications appear to influence each other.

Having an interdisciplinary background did not significantly influence either productivity measure. Perhaps it is the case that biopharmaceutical scientists with interdisciplinary backgrounds are drawn to specialize less, thereby working less efficiently (Leahey 2007, Leahey and Hunter 2012), yet interdisciplinarity had no influence on self-reported work efficiency, one of the indicators of scientists' job performance. A bivariate regression failed to show significant results ($p = .32$) on this aspect of job performance or any other.

DISCUSSION

In this chapter, I seek to provide a better understanding of why some biopharmaceutical scientists are more effective at solving research obstacles – the problems that crop up during the course of biopharmaceutical R&D – than others. This question is important to address because it fits witin a line of innovation research that seeks to elaborate and understand the processes which occur between the generation of an idea and its ultimate implementation (Perry-Smith and

Mannucci 2017). The biopharmaceutical field is particularly interesting and fitting context to ask this question because it is reputed to be an innovative field (Powell 1990, Powell, Koput and Smith-Doerr 1996) that experiences high project failure (Bartfai and Lees 2006, Firestein 2016, Philippidis 2016) on the other. To bridge this gap, scientist must regularly engage in problem solving in order to keep their R&D projects from failing (see Appendix B).

The main finding, apparent in Figure 7, is that biopharmaceutical problem solving is supported through two complementary pathways. The first path concerns social networks. Tie strength, while it does not influence problem solving directly, has an indirect influence through the knowledge components of networks, which directly influences problem solving effectiveness. This is consistent with the work of Contractor and Monge (2002) and Yuan et al. (2010), who argue for an intuitive relationship between tie strength and the knowledge components of networks; the strength of strong ties is that they support a rich exchange of knowledge (Phelps, Heidl and Wadhwa 2012). This appears to support biopharmaceutical scientists' problem solving efforts. This makes sense. After all, scientist engaging in problem solving are likely to encounter obstacles that fall within their professional jurisdiction (Abbott 1988, Abbott 2001, Anteby, Chan and DiBenigno 2016, Feyereisen, Broschak and Goodrick 2017). Given this, it follows that scientist push their networks to become more specialized and efficient (Leahey 2007, Leahey, Keith and Crockett 2010, Leahey and Hunter 2012), perhaps to avoid the difficulties, costs, and penalties associated with the exploration and integration of very unfamiliar knowledge (Borgatti and Cross 2003, Gardner 2017, McBee and Leahey 2016).

The second pathway begins with team performance, runs through scientists' individual performance, and ends with problem solving effectiveness. Consistent with expectations (Campbell et al. 1993), scientists who perform their job well are better problem solvers. They do

not just go through the motions, they deliver. But their efforts are supported by others. Beyond the influence of their network contacts (many of whom happen to be team members), well-performing teams have a strong influence on problem solving by boosting the performance of their members, likely by providing a support environment conducive to establishing trust nad exchanging knowledge (Börner et al. 2010, Contractor and Monge 2002, Gardner, Staats and Gino 2012, Katzenbach and Smith 2003).

Results failed to provide anything more than marginal support for multiple hypotheses (H3, H6, H9, and H10). This is likely due to the limited ability of the data to capture network contacts who are not affiliated with project teams. More than two-thirds (68%) of respondents' network contacts are affiliated with their project teams. This is expected, given the context of biopharmaceutical R&D and its concerns with protecting intellectual property (see Appendix B). However, team performance and social network characteristics are likely conflated in ways that cannot be understood through this model. Sorting this issue out is important for future research.

While this study gives insight into scientific problem solving, it has several limiations. By design, the survey asked respondents about their social network contacts without soliciting information about the structure of relationships between these contacts. That is, this study utilizes network ties which provide less information than approaches that utilize egonetworks or full networks (Borgatti, Everett and Johnson 2013, Knoke and Yang 2008). Either alternative approach would provide additional network measures that could better capture respondents' network and their positions within those networks. While such benefits would come with associated costs like increasing survey length and demoralization (Fowler 2014, Groves et al. 2009, Paik and Sanchagrin 2013), the benfits would have been significant. Similarly, with access to an organization, rich interrelations between scientists' project teams could be examined in

greater detail to fully model a multilevel process and/or to get at affiliation ties and the duality of persons and groups (Breiger 1974, Lazega et al. 2008). The structural equation models presented here are consistent with many theoretical expectations. Yet the data come from scientists' retrospective accounts and are cross-sectional in nature. Further, as mentioned above, scientists' self-reported evaluations of their problem-solving effectiveness are very high, likely because of social desirability bias. Collecting panel data and using more objective measures would strengthen confidence in the validity of these models.

Despite these limitations, this study makes several important contributions to the study of social networks and innovation. Other researchers are encouraged to utilize the approach taken here that utilizes structural equation modeling to capture more of the multifaceted nature of social network concepts and their interrelated social processes. It is strange that more researchers have not attempted to capture the richness of Granovetter's (1973) conception of tie strength through latent variables or utilized factor scores (Acock 2013) in other types of statistical models. Further, the knowledge components of networks formulate a coherent latent variable as well, one that is related to tie strength in predictable ways. This approach may be adopted by other researchers who seek to answer the call to better understand the knowledge components of networks, particularly their relation to other types of social network characteristics (Phelps, Heidl and Wadhwa 2012).

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TABLES AND FIGURES

Table 1. Descriptive Statistics

	Variables	N	Mean	SD
Demographic	Male Respondent	278	65%	
	Age	274	45.90	14.22
Education	Educ IDR (1-13)	279	1.45	0.66
	PHD (1/0)	279	65%	
Career	Professional Age (years in biopharma)	277	14.50	6.83
	Income	259	$125k	$77k
	Publications	279	11.14	10.20
	Patents	278	2.48	4.84
Organization	Academia (1/0)	279	29%	
	Organizational Size	256	2,520	5,463
	Organizational Tenure (Years)	276	7.15	2.34
	Income ($10,000)	259	$125	$77
	Network Centrality/ Contacts (1-8)	279	4.68	2.50
Project	Project Leader (1/0)	254	84%	
	Team Size (0 to 21+)	277	7.55	6.44
Ostacle Variables	Novelty (0/1)	279	21%	
	Technology (0/1)	279	9%	
	Resources (0/1)	279	15%	
	Regulatory (0/1)	279	8%	
	Collaboration	279	6%	
Latent Variables	P SOLVE (Level II)			
	Identify (1-6)	192	5.29	0.85
	Evaluate (1-6)	210	5.13	0.97
	Understand (1-6)	219	5.09	0.98
	Plan (1-6)	223	5.09	0.98
	Communicate (1-6)	181	5.18	0.95
	Execute (1-6)	201	5.13	0.95
	STR TIES (Level I)			
	Duration (.5-11.5)	1,307	4.48	3.58
	Closeness (1-6)	1,289	3.99	1.26
	Face-to-Face (0-30)	1,151	11.46	9.16
	Electronic (0-30)	1,247	13.31	9.06
	KNOW NET (Level I)			
	Awareness (1-5)	1,283	4.21	1.07
	Overlap (1-5)	1,279	2.97	0.99
	Competence-Trust (1-7)	1,259	6.05	1.09
	I PERF (Level II)			
	Efficient (1-7)	279	6.11	0.97

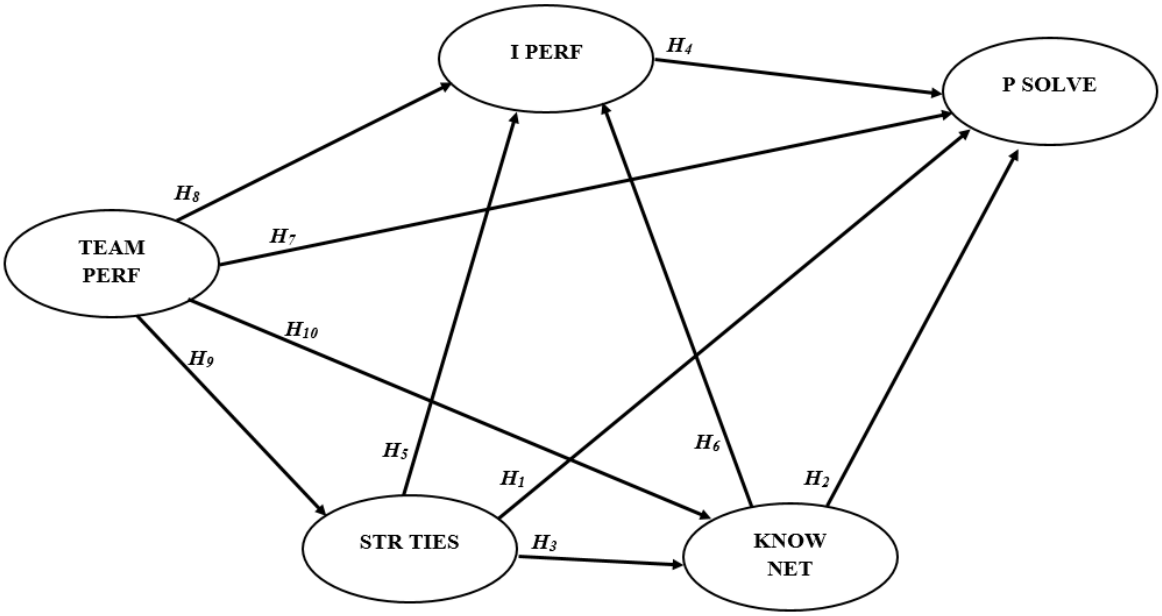
Excellence (1-7)	279	6.28	0.78
Competent (1-7)	277	6.42	0.75
Communicate (1-7)	253	6.24	0.82
Worked with members (1-7)	254	6.47	0.66
Worked with leaders (1-7)	253	6.43	0.79
TEAM PERF (Level II)			
Efficient (1-6)	238	4.95	0.81
Excellence (1-6)	245	5.26	0.74
Goals (1-6)	246	5.32	0.73
Competent (1-6)	249	5.33	0.68
Communicate (1-6)	244	5.11	0.81
SEVERITY (Level II)			
Serious (1-7)	222	5.86	1.22
Pressure (1-7)	222	5.73	1.34
Intensify (1-7)	220	4.90	1.72
Impact (1-7)	221	4.44	1.95
Complicated (1-7)	221	5.74	1.43
Beyond R's Expertise (1-7)	222	3.96	1.95

Table 2. Results from Structural Equation Models

Variable	Conceptual Model			Full Model		
Effects on Problem Solving Effectiveness	Coef	SE (Cluster)	p	Coef	SE (Cluster)	p
STR TIES	-0.02	0.05	0.76	-0.03	0.05	0.48
KNOW NET	0.26	0.14	0.07	0.30	0.14	0.03
I PERF	0.50	0.20	0.01	0.47	0.19	0.01
TEAM PERF	-0.13	0.22	0.57	-0.17	0.21	0.41
PhD				0.11	0.07	0.11
Educational IDR				-0.23	0.10	0.02
Career Tenure				0.02	0.01	0.19
Income				0.00	0.00	0.73
Publications				-0.02	0.01	0.04
Patents				0.02	0.01	0.02
Academia				0.25	0.20	0.21
n/Network Contacts				-0.01	0.03	0.80
Organizational Tenure				0.00	0.01	0.73
Project Leader				0.09	0.14	0.53
Team Size				0.01	0.01	0.62
SEVERITY				-0.11	0.11	0.31
Novelty				0.18	0.12	0.12
Technology				0.19	0.16	0.26
Resources				-0.03	0.18	0.87
Regulatory				0.22	0.20	0.26
Collaboration				0.10	0.22	0.65
R^2	0.15			0.28		
Effects on Knowledge Components						
STR TIES	0.27	0.05	0.00	0.27	0.05	0.00
TEAM PERF	0.20	0.10	0.05	0.20	0.10	0.05
R^2	0.46			0.46		
Effects on Tie Strength						
TEAM	0.28	0.17	0.10	0.28	0.17	0.10
R^2	0.01			0.01		
Effects on Individual Performance						
STR TIES	0.08	0.04	0.07	0.08	0.04	0.07
KNOW NET	-0.22	0.12	0.06	-0.22	0.12	0.06
TEAM PERF	0.89	0.11	0.00	0.89	0.11	0.00
R^2	0.56			0.56		
	N	1,319 (284 Clusters)		N	1,319 (284 Clusters)	

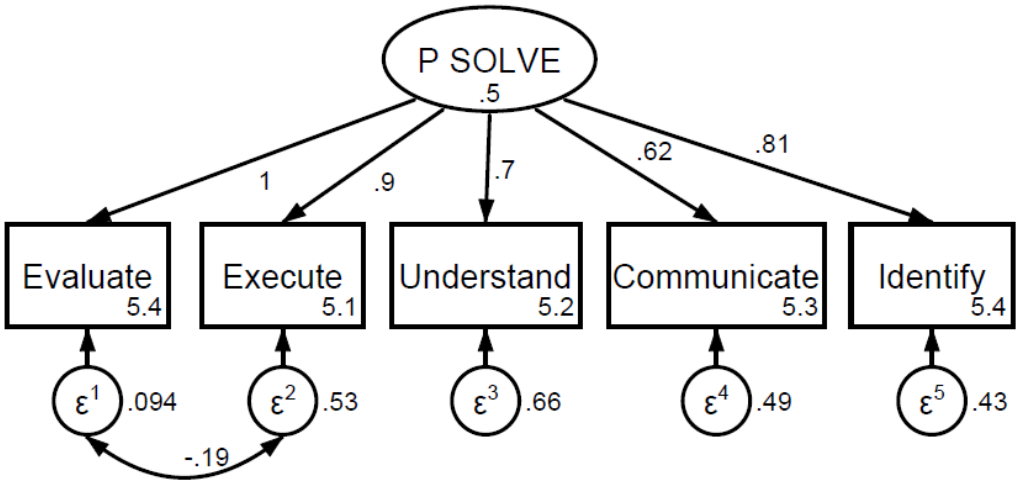
LL	-36856 (91)	LL	-83904 (270)
AIC	73,894	AIC	168,347
BIC	74,366	BIC	169,747
CD	0.89	CD	0.98

Figure 1. Conceptual Model



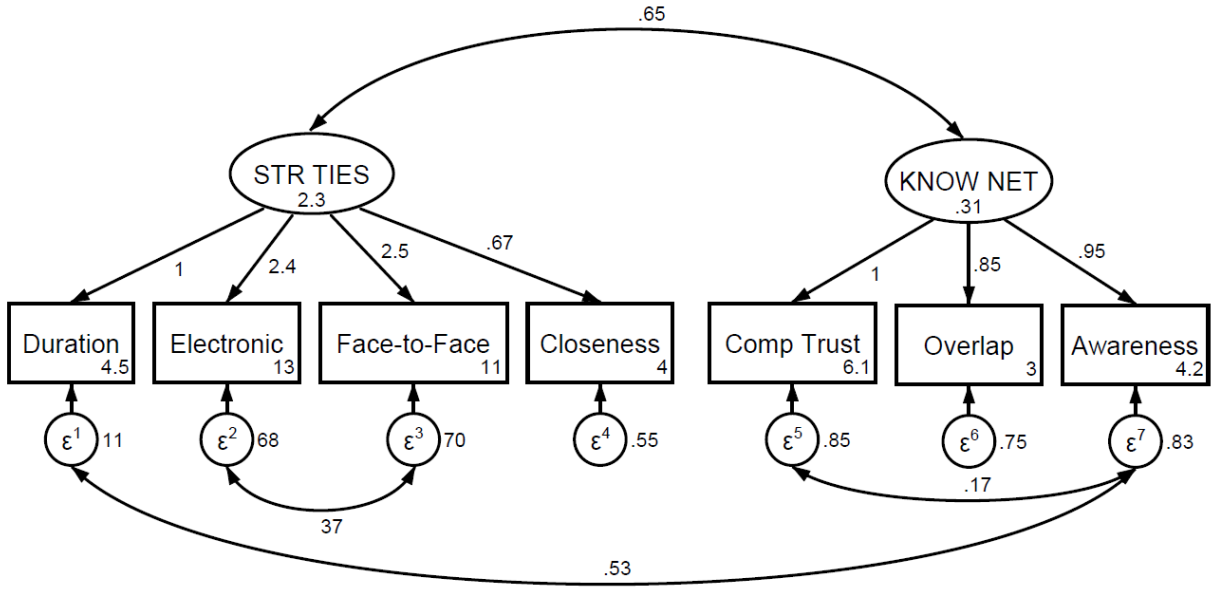
Latent variables related to hypotheses are presented in ovals
Significant influences between latent variables are solid lines
All indicators, control variables, and error covariance stuctures are omitted for simplicity

Figure 2. Problem Solving Effectiveness



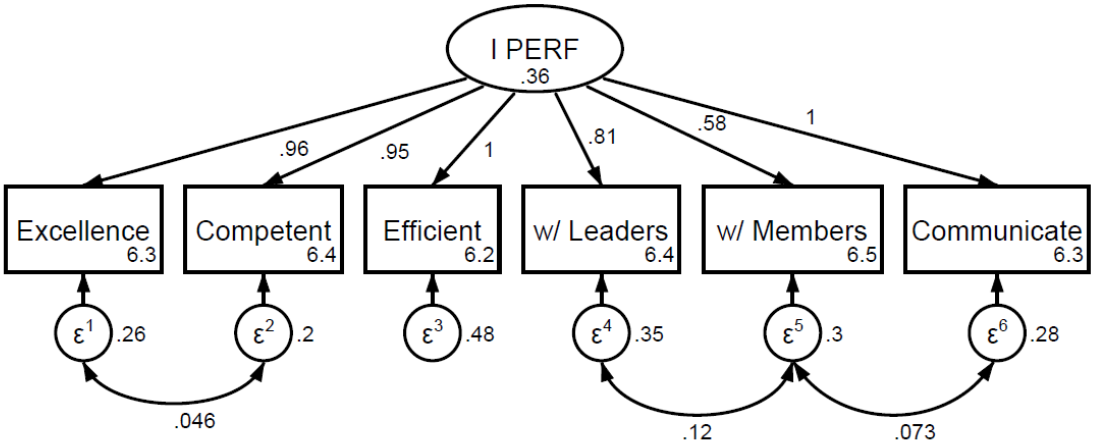
p = .45
CD = .98
RMSEA = .00
CFI = 1.00

Figure 3: Tie Strength and Components of Knowledge Networks Confirmatory Factor Analysis (Level I)



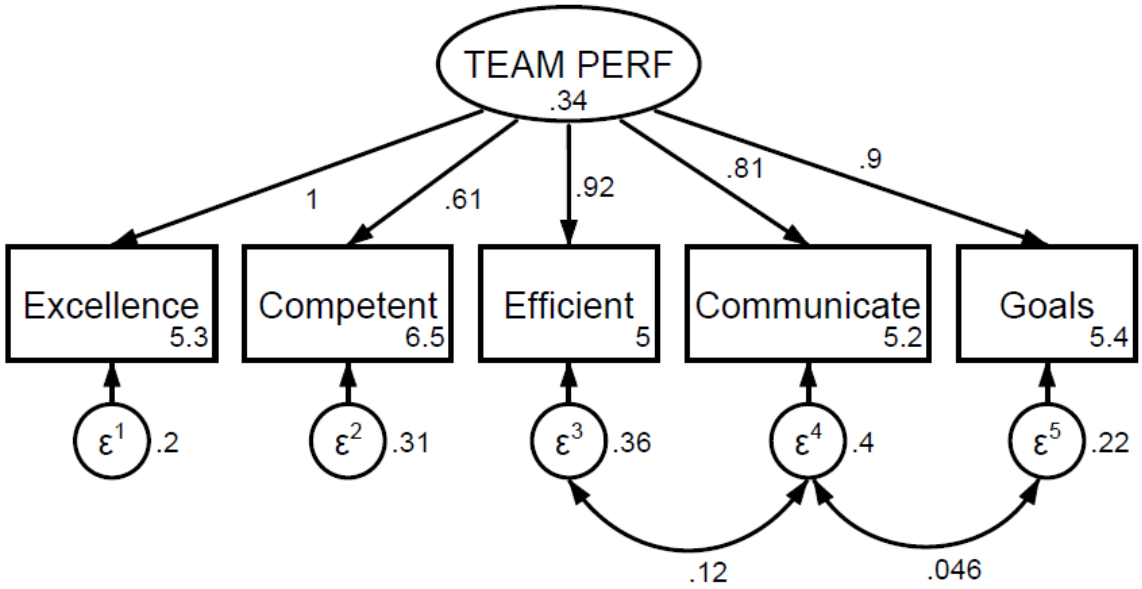
p = .00
CD = .80
RMSEA = .04
CFI = .99

Figure 4. Individual Job Performance Confirmatory Factor Analysis (Level II)



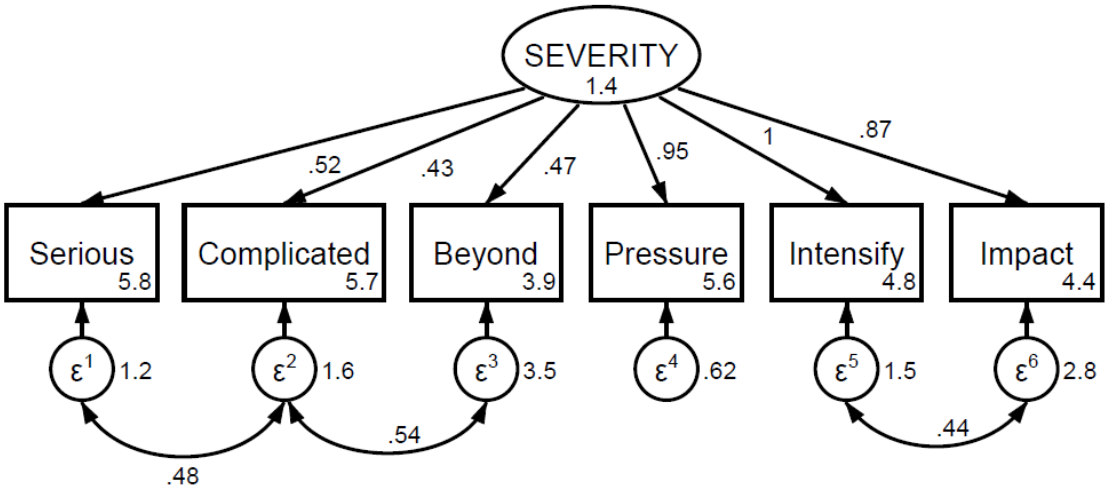
p = .20
CD = .84
RMSEA = .04
CFI = .99

Figure 5. Team Performance Confirmatory Factor Analysis (Level II)



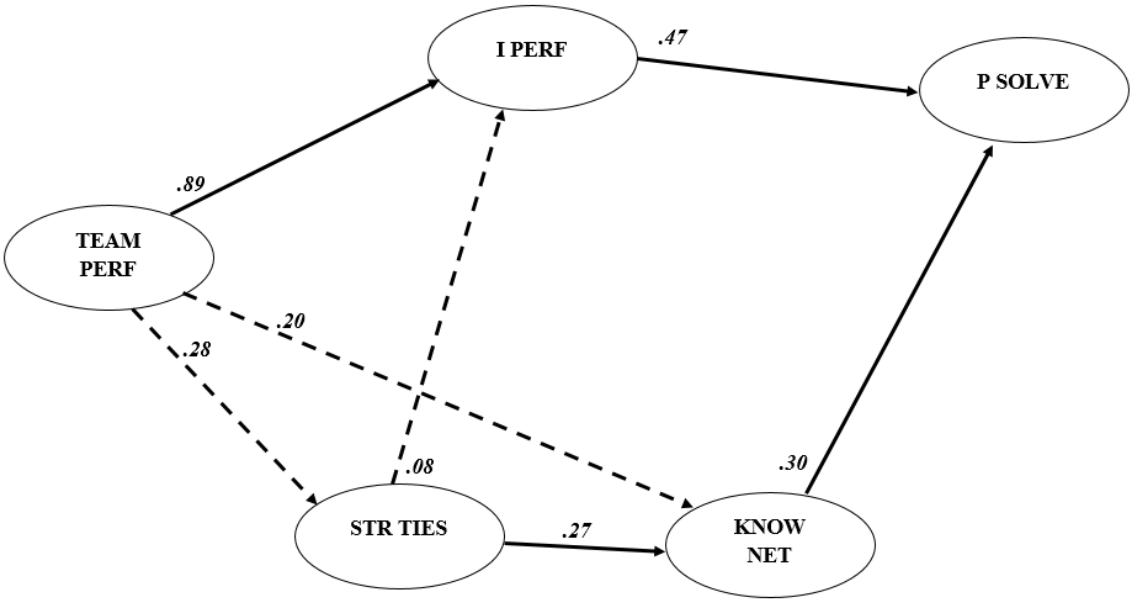
p = .22
CD = .81
RMSEA = .04
CFI = .99

Figure 7. The Severity of Research Obstacles Confirmatory Factor Analysis



p = .16
CD = .79
RMSEA = .05
CFI = .99

Figure 7. Diagram of Simplified Results from Structural Equation Model



Latent variables related to hypotheses are presented in ovals
Significant influences between latent variables are solid lines
Marginal influences between latent variables are dashed lines
Effect sizes are presented adjacent to the path of influence
All indicators, control variables, and error covariance stuctures are omitted for simplicity