Essays on Knowledge Networks, Scientific Impact and New Knowledge Adoption

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Document Version
Final published version

Publication date:
2021

License
Unspecified

Citation for published version (APA):
Jeppesen, J. E. (2021). *Essays on Knowledge Networks, Scientific Impact and New Knowledge Adoption*. Copenhagen Business School [Phd]. PhD Series No. 12.2021

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Download date: 04. Jul. 2025

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WWW.CBS.DK

ISSN 0906-6934

Print ISBN: **978-87-7568-000-9**
Online ISBN: **978-87-7568-001-6**

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PhD Series 12.2021

Jacob Emil Jeppesen

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HANDELSHØJSKOLEN

Title: Essays on Knowledge networks, scientific impact and new knowledge adoption

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Essays on Knowledge networks, scientific
impact and new knowledge adoption

1st edition 2021
PhD Series 12.2021

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ISSN 0906-6934

Print ISBN: 978-87-7568-000-9
Online ISBN: 978-87-7568-001-6

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ENGLISH SUMMARY

Knowledge creation are the crux of economic development. However, an increase in the speed of which knowledge is created has resulted in a knowledge burden in which the time it takes to become specialized in a knowledge field is increasing at an increasing rate. Thus, creators of new knowledge employ new strategies to reduce these costs, specifically through collaborating more. Collaboration entails both opportunities and constraints. Opportunities in the form of an increased influx of new knowledge, or a better division of labor, but constraints in the form of increases in coordination costs and increasing reliance on individual network embeddedness to draw upon resources. A continuously growing stream of literature explores how network positions drive an increase in knowledge network outcomes and impact, which in turn has created an emergent literature of network antecedents. Findings in these streams of literature indicate that certain positions are more likely to be associated with increases in performance and higher likelihood of becoming central in a network.

Thus, it is of increasing importance to understand the interrelatedness of knowledge and networks, individuals and teams, to disentangle the question on how high impact new knowledge is created.

The purpose of this dissertation is therefore to contribute to the stream of literature revolving around how knowledge is created and adopted through the influence of collaboration – the result of which is knowledge networks. More specifically the dissertation explores how both individuals and their direct connections are utilizing their network positions to achieve higher impact, become more central or adopting new knowledge. Further, I explore individual level characteristics that can change the impact of such network positions. The empirical analysis is done through a bibliometric study of all scientists at a Large Scale Research Facility (LSRF) in the US – specifically the Spallation Neutron Source (SNS) at Oak Ridge Tennessee. Through the full bibliometric mapping I gain the insights of the development, production and network aspects of scientific work conducted there, which provides a unique opportunity to gaze into a somewhat isolated knowledge network. I utilize new techniques derived from simulation and machine learning to construct measures of network evolution and knowledge focus at the individual level.

In the first essay I explore the antecedents of network evolution and the likelihood of creating high impact science, and question how the network characteristics influence these outcomes. In the second I pose the question how centrality gains of collaborators influence the creation of impactful science. Specifically, I look into how centrality increases of alters, lead to decreased impact of individuals, and further how knowledge overlap moderates this relationship. In the third, I look into the drivers for new knowledge adoption. Specifically, I investigate the direct impact of scientists' structural holes and tie strength distribution on, for

them, the adoption of new knowledge. I further argue that the degree to which the scientist has a diverse knowledge portfolio, positively moderates this relationship.

This provides insights into how individuals can structure their network, for optimal impact. It also provides insights into the social underpinnings for large scale research infrastructure, in which the essays provide guidance on how to ensure the highest impact from these very large investments.

DANSK SAMMENDRAG

Videnskabelse er kernen i økonomisk udvikling. En stigning i hastigheden, hvormed viden skabes, har dog resulteret i en vidensbyrde, hvor den tid det tager at blive specialiseret i et vidensfelt I øges med stigende hast. Således bruger skabere af ny viden nye strategier til at reducere disse omkostninger - især gennem at samarbejde mere. Samarbejde indebærer både muligheder og begrænsninger. Muligheder i form af en øget tilstrømning af ny viden eller en bedre arbejdsdeling, men begrænsninger i form af stigninger i koordinationsomkostninger og øget afhængighed af individuel netværksindlejring for at trække på ressourcer. En kontinuerligt voksende strøm af litteratur udforsker hvordan netværkspositioner driver en stigning i viden-netværksresultater og -udvikling, hvilket igen har skabt en åbnet for et felt omhandlende hvad der ligger forudgående dette. Resultater i disse områder indikerer, at visse positioner mere sandsynligt er forbundet med ydeevne og større sandsynlighed for at blive central i et netværk.

Det er derfor endnu vigtigere nu at forstå sammenhængen mellem viden og netværk, individer og teams, for at belyse spørgsmålet om hvordan ny viden bliver dannet.

Formålet med denne afhandling er at bidrage til strømmen af litteratur, der omhandler hvordan viden skabes og tilegnes gennem indflydelse af samarbejde – der ultimativt er struktureret i form af vidensnetværk. Mere specifikt undersøger afhandlingen, hvordan både enkeltpersoner og deres direkte forbindelser udnytter deres netværkspositioner for at opnå større indflydelse, blive mere centrale eller tilegne sig ny viden. Desuden udforsker jeg karakteristika på individniveau, der kan ændre virkningen af sådanne netværkspositioner. Den empiriske analyse udføres gennem en bibliometrisk undersøgelse af alle videnskabsfolk på en Large Scale Research Facility i USA - specifikt Spallation Neutron Source ved Oak Ridge Tennessee. Gennem en fulde bibliometriske kortlægning får jeg indsigt i udviklings-, produktions- og netværksaspekter af videnskabeligt arbejde, der udføres der, hvilket giver en unik mulighed for at observere et forholdsvist isoleret vidensnetværk. Jeg bruger nye teknikker, der stammer fra simulering og maskinlæring til at konstruere mål for netværksudvikling og videnfokus på individuelt niveau.

I det første essay undersøger jeg hvad der ligger forud for netværksudvikling og sandsynligheden for at skabe viden med stor indflydelse og sætter spørgsmålstegn ved, hvordan netværkets egenskaber påvirker disse resultater. I det andet essay stiller jeg spørgsmålet, hvordan centralitet får videnskabsfolkenes samarbejdspartnere til at påvirke oprettelsen af en videnskab med høj indflydelse. Specifikt ser jeg på, hvordan centralitetsforøgelse, fører til nedsat indflydelse fra enkeltpersoner, og, videre, hvordan individer hvis viden overlapper modererer dette forhold. I det tredje, undersøger jeg egernskaber for ny videnoptagelse. Specifikt undersøger jeg den direkte indflydelse fra forskernes strukturelle huller og binder styrkefordelingen på for dem vedtagelsen af ny viden. Jeg argumenterer endvidere for, at den grad, som forskeren har en divers videnportefølje, modererer dette forhold.

Dette giver indsigt i, hvordan enkeltpersoner kan strukturere deres netværk for optimal effekt. Det giver også indsigt i de sociale grundlag for stor forskningsinfrastruktur, hvor disse essays giver vejledning i, hvordan man sikrer størst mulig virkning fra disse meget store investeringer.

ACKNOWLEDGEMENTS

It has been a long (some would say way too long!) ride. This dissertation marks the completion of what I, at the very least consider eye opening, but, in reality, has been life changing. Nonetheless, I am incredibly thankful to have ventured down this path that has been simultaneously murky, clear, straight and crooked. I am grateful to have had the opportunity to meet so many inspiring, knowledgeable, passionate people during my Ph.D. – thanks a lot to you all.

I'm particular grateful of the patience and guidance given from my supervisors. Marie Louise Mors as well as Kristina Vaarst Andersen. Louise, for gently pushing for completion when it looked bleak, for always giving constructive comments, and basically paving the way. Kristina, for the many hours you spent in the office discussing networks, SIENA, and not least your many quarrels with building your house. Your ongoing support has been invaluable.

During the long range of my Ph.D. I had the pleasure of starting out alongside. The many great conferences and hours of late study wouldn't had been as fun without my Ph.D. Cohort, Anders, Giulio and Cecilie. If it's sailing 4 hours in a boat to see orcas, going to little Italy in NYC or Christmas dinners, it wouldn't have been as fun without you. The helpfulness and friendliness of other, at the time, 'old' Ph.D. students, Solon, Arjan, Karin, Virgilio, Maria, Milan, Karin and Gouya inspired me a lot, and it was a pleasure sparring, working and laughing with you all.

I'm also grateful to have been given the opportunity to work closely with so many talented scholars both at INO and SMG (now SI). From Dana Minbaeva and the introduction into the HRM world, to Francesco and Valentina and working with the mobility of scholars.

I was fortunate enough to receive a scholarship to SCANCOR and given the opportunity to stay and study at Stanford. This gave me great opportunities to show and tell and receive invaluable feedback. The stay was made truly enjoyable by the other SCANCORIANS present, and their friends that joined us for amazing wine trips, surrealistic hotel cult experiences, and great conversations. Thank you, Simone, Ulrik, Linda and Charlotta in specific.

I also want to thank Francesco Di Lorenzo and Valentina Tartari for taking the time to read my work and serve in my pre-defense committee.

I'm fortunate to have such great friends that are always willing to listen (or sometimes pretend to) about the quarrels of a PhD face – and in the end problems sometimes only needs a beer and cheese to get solved. Thank you Sune, Allan, Mark, Nickels and André.

The support received from my brothers, Jimmi and Jonas, and parents, Lisa and Sven, means everything to me. You made everything possible. Finally, I want to thank my future wife Sonia. With you I feel everything I possible.

TABLE OF CONTENT

CHAPTER 1. INTRODUCTION

This dissertation consists of three chapters, in which I explore how knowledge networks are formed over time, as well as how these affect the creation, impact and adoption of new knowledge. The underlying assumption is, that the way in which individuals are embedded in an, often unobserved, social network provides both opportunities and constraints that, when analyzed in depth, enables to disentangle the process of creating new knowledge.

Chapter two focuses on network evolution and finds that the context in which a tie is formed influences the impact on the evolution of a scientists position and impact in a knowledge network. Chapter two zooms in on the knowledge creation process and finds that the increase of alter average centrality has a negative effect on the knowledge creation of the individual scientist in focus. Chapter three shows that knowledge diversity, tie skewness and structural holes impacts new knowledge adoption and that degree of knowledge diversification moderates the impact of the occupied network position.

Extensive literature has dealt with the role of knowledge networks in science, both from a scientific collaboration perspective and with other innovative units as focus. Under the assumption that the premises for collaboration are similar, empirical findings show e.g. that diversity of knowledge can facilitate innovation through recombination (Henderson & Clark, 1990), that structural positions and increasing the number of co-authors result in increased scientific production and impact (Wuchty et.al., 2007; Abbasi et.al., 2011), that the number of organizational boundaries crossed are negatively related to innovation unless the collaborators taken together spans otherwise distant units (Bercovitz & Feldman, 2011), that the type of connections that are formed, i.e. tie, influences the creativity (Lee, Walsh, and Wang 2015; Mannucci and Yong 2018) and impact (Wang 2016) of knowledge producers. Extant literature has thus shown that the impact of knowledge networks on knowledge related outcomes can be synthesized in three different buckets (Phelps, Heidl, and Wadhwa 2012). *Creation* pertains the generation of new knowledge in the form of e.g. ideas, practices and research papers. *Transfer* pertains the efforts of an ego to share information and knowledge, or the efforts of an ego to acquire and absorb said knowledge. *Adoption* refers to the ability or decision to implement a discrete element of knowledge (Ibid.). A common factor characterizing these studies are thus an emphasis on how knowledge networks facilitates the creation, transfer or adoption of knowledge (Phelps et.al., 2012). At the same time less attention has been paid to understanding the endogenous nature of network emergence and evolution, and even more so how this translates into performance.

The role of generalists and knowledge overlaps

Below table gives a brief overview of the three chapters and their main components.

Contributions to extant research

The literature on knowledge networks and how they impact innovativeness, knowledge creation, adoption and transfer is vast. However, even though many mechanisms have been uncovered, there are still conflicting results with regards to many of these. In this dissertation, I contribute to the stream of knowledge network literature, by arguing that with regards to network evolution a contingency approach, in which the context for tie creation matters for the predicted outcomes, is needed. From a knowledge creation perspective, I contribute by expanding the egocentric view, and argue that it is not only an individual’s own centrality seeking behavior that influences knowledge outcomes. In contrast, the network seeking behavior of alters provides both opportunities and strengths that needs to be considered, as well. I show that the cost of alters' centrality seeking behavior can be lowered in certain situations, e.g. when knowledge domains are overlapping. This emphasis on alter behavior and the influence this has on ego is largely still an unexplored area.

Further, with the aforementioned increase in knowledge burden, the role of scientific archetypes, with an emphasis on the generalist, has started to emerge (Phelps, Heidl, and Wadhwa 2012; Furman and Teodoridis 2018; Nagle and Teodoridis 2017; Teodoridis 2018; Teodoridis, Bikard, and Vakili 2018; Teodoridis, Vakili, and Bikard 2017). The dissertation aims to contribute to this literature by adding a network-based approach, effectively showing that generalists, measured by their knowledge diversity, seems to be able to utilize the opportunities given through favorable network positions.

The final area of contribution is within the absorptive capacity literature. Originally thought of as an individual level construct much absorptive capacity literature is focusing of whole organizations and their capacity to internalize new knowledge. I add to further our individual level understanding of this and argue that the diversity of an individuals’ knowledge space, is a conduit for absorbing new knowledge, as shown by a positive and significant effect of knowledge diversity on new knowledge adoption.

Empirical Setting

The contributions mentioned above are made by analyzing a large data set created for the purpose, involving the creation of publications at a scientific laboratory. Specifically, I leverage full publication history of scientists at a Large Scale Research Facility (LSRF) – a facility that enables neutrons to collide with different material types at speeds nearing the speed of light, at the Oak Ridge National Laboratory, specifically the Spallation Neutron Source.

The Oak Ridge National Laboratory was established in 1943 and is the largest research laboratory under the US Department of Energy. Both basic and applied science activities are conducted in the areas of neutron science, biological systems, energy and high-energy physics, material science, supercomputing, and national security. The Neutron Sciences Directorate (NSD) has managed the research program in neutron science since 2006. Our analysis focuses on scientists affiliated with the Spallation Neutron Source (SNS), which came into operation in 2006, and the High Flux Isotope Reactor (HFIR), which underwent a major renovation in 2007. Affiliation with SNS and HFIR are available to scientists of all nationalities based on evaluation of research proposals by an independent council of scientists. The facility offer a multitude of instruments all connected to the main reactor core.

All peer-reviewed publications affiliated with SNS and HFIR are publicly listed on the NSD website. From SCOPUS, we retrieved the full bibliographic records of the publications produced at the facility in the period from initiation and restart after renovation of the facilities in 2006/2007 until 2011. Based on this list of publications, we identified all scientists affiliated with the facility. I then utilized SCOPUS's unique author identifier to retrieve a full bibliographic record of each scientist, cleaning out potential wrong name assignments and other potential confounding elements in the process. To build scientists' track record and collaboration networks, I further collected information on 196,302 off-site publications.

I thus use bibliometric and machine learning techniques to identify individual level performance, citations, productivity, cognitive overlaps, as well as the social networks through co-authorships. All methods commonly used in the scientific literature (Newman 2004).

Structure of dissertation

The following three chapters consists of individual essays, the first of which is co-authored with Kristina Vaarst Andersen, the second with Kristina Vaarst Andersen and Marie Louise Mors, and the final paper is single-authored by me. The three chapters draws on the same empirical data although utilizing different techniques and subsets in order to answer the proposed hypotheses. All three also share a similar theoretical setup, broadly, however each contributes individually to different subsets of theory. Further, each paper focus on different outputs of knowledge networks as stated in, i.e. knowledge creation, knowledge transfer and finally knowledge adoption. Knowledge creation refer to the creation of new knowledge in the form of ideas, research papers, products etc. Knowledge transfer refers to the effort to share and acquire information and knowledge, while knowledge adoption refers to the decision to use or implement a discrete element of knowledge. As knowledge is created, specific resources are needed for it to be transformed, communicated and translated for it to be usable in other domains. Thus, the different touchpoint of knowledge networks on different knowledge outcomes as shown in figure 1.

Insert figure 1 about here

In figure 1 I have mapped each chapter in the dissertation to the specific knowledge outcomes identified. I have also added a category around network evolution. This topic revolves around the antecedents of knowledge networks and asks the question, how did the observed structure come to be – an area of research that has received increased interest (Ahuja, Soda et. al 2012). It is however difficult to disentangle as networks inherently are endogenous, and both co-evolve with e.g. performance and other personal characteristics, but also has a structural growth driven by the structure itself. In chapter 2 I investigate how network structures come to be, by applying a stochastic actor oriented model, SIENA, to simulate the dynamics and growth of a knowledge network. This allows me to identify drivers of change, where I identify that network centrality, specifically the Newman's Degree Centrality, influence ego network development differently, depending on the context in which it has been achieved. I further show how this development effects the production of high impact science. As also illustrated, paper two revolves around the influence of knowledge networks on knowledge creation and emphasizes the need to take into account the networking behavior of alters in determining the ego's potential to create high impactful science. In the paper, from an agent characteristic view we further look into the moderating effect of knowledge domain overlap. The last paper revolves around how network and agent characteristics affect new knowledge adoption.

Chapter 2: Local Heroes – Global Stars? How organizational foci and network dynamics impact tie creation and high impact science

In this paper we investigate the micro-mechanisms governing the structural evolution and performance of a scientific collaboration. One of the micro-foundations is that of being central in a knowledge network, which is often positively linked to tie formation and performance. Yet, extant literature has found diverging effects of centrality and the effect on knowledge creation. At the same time the preferential attachment argument, i.e. central individuals tend to become more central over time, to be prevalent. In the paper we combine social exchange theory with Feld's focus theory and posit that the influence of centrality on network dynamics, rely on the context in which the centrality has been obtained. We identify that in low-durable contexts, the influence of centrality, and specifically power centrality, is reversed so that in high durable contexts, a positive influence is observed and in low-durable contexts, a negative is observed.

Examining scientists' collaboration patterns at a Large Scale Research Facility we explore how centrality acquired in different contexts affect network dynamics and identify that the context influences the impact of centrality, and leads to a negative association to tie formation and performance.

Specifically, we find that when centrality is achieved under a temporary organizing setting, the relationship between centrality, tie formation and performance is negative. This result agrees with theory on the cost and performance detrimental consequences of high centrality, however also opens for new avenues of research. We thus contribute to the emergent literature on knowledge network dynamics, network theory and the organization of science-literature.

Chapter 3: Deflected efforts: How co-authors' effort allocation influence scientists' performance

A growing stream of literature analyzes centrality and the related benefits and spillover effects, yet we still know relatively little about how an individual's performance is affected by changes in the efforts of their collaboration partners. There are specifically two ways to increase centrality in a social system of scientific knowledge production. One, you can either increase the sheer number of collaboration partners or selectively go for collaboration with highly central alters. The risk of the first strategy is that of having limited time and effort available. However, collaboration with highly central others also take significant effort. The effort invested in this collaboration with a highly central alter will most likely benefit the centrality climber but provide little to no effect for co-authors on other papers. An example of the discrepancy in effort needed could be that of the tenured professor working with a post-doctoral student on a paper. The post-doc is expected to spend many hours in the laboratory, while the professor far fewer hours on the actual study design, funds raising etc. In this paper, we analyze how individual scientists' performance is affected when their collaboration partners' centrality increases.

We argue that an increased effort of alters in collaborating with other central collaboration partners may divert the partner's effort allocation. This in turn may lead to a negative spillover effect for the individual scientist's performance. We find empirical support for a negative spillover effect of co-authors' centrality increase on individual performance. We also find that the negative performance effect increases with increasing demands on co-authors' effort, and that knowledge domain overlap decreases the effect. In post hoc analyses, we further find that for star scientists the negative effect of co-authors' centrality increase is reduced or even reversed.

The aim of the study is to contribute to the small but growing literature on the effects of effort allocation and social networks. We expand on the usual focus on the focal scientist's centrality change and extend the analysis to include collaboration partners' centrality increase.

Chapter 4: Networks and Generalists: The moderating effect of knowledge diversity on network brokering and tie strength skewness on new knowledge adoption

The final paper investigates the role of network embeddedness and knowledge generalists with regards to new knowledge adoption.

I specifically investigate the effect of social embeddedness, in the form of structural holes, as well as the skewness of the strength of ties, and posit that they will positively influence the adoption of new knowledge. I further hypothesize that high knowledge diversity increases the opportunities to engage with new knowledge, and effectively acts as an indicator of absorptive capacity, positively moderating the effects observed from the network measures. I confirm the positive influence of skewness and the moderating effects but cannot confirm the positive direct effect of structural holes on knowledge adoption. The study is conducted using a unique dataset consisting of full bibliometric data from a Large Scale Research Facility, and employs a novel machine learning technique (LDA) in order to estimate knowledge diversity. The paper adds to the literature on generalists and specialists by adding a social network perspective, absorptive capacity and network literature by synthesizing the three theoretical models and arguing that further exploration ought to be done within the field of the strength of tie distributions, and its effect on knowledge related outcomes, paired with a focus on agent based characteristics that enable benefits and opportunities to be seized from optimal network positions.

In table 1 I show the three essays and what the variables of interest are.

INSERT TABLE 1 HERE

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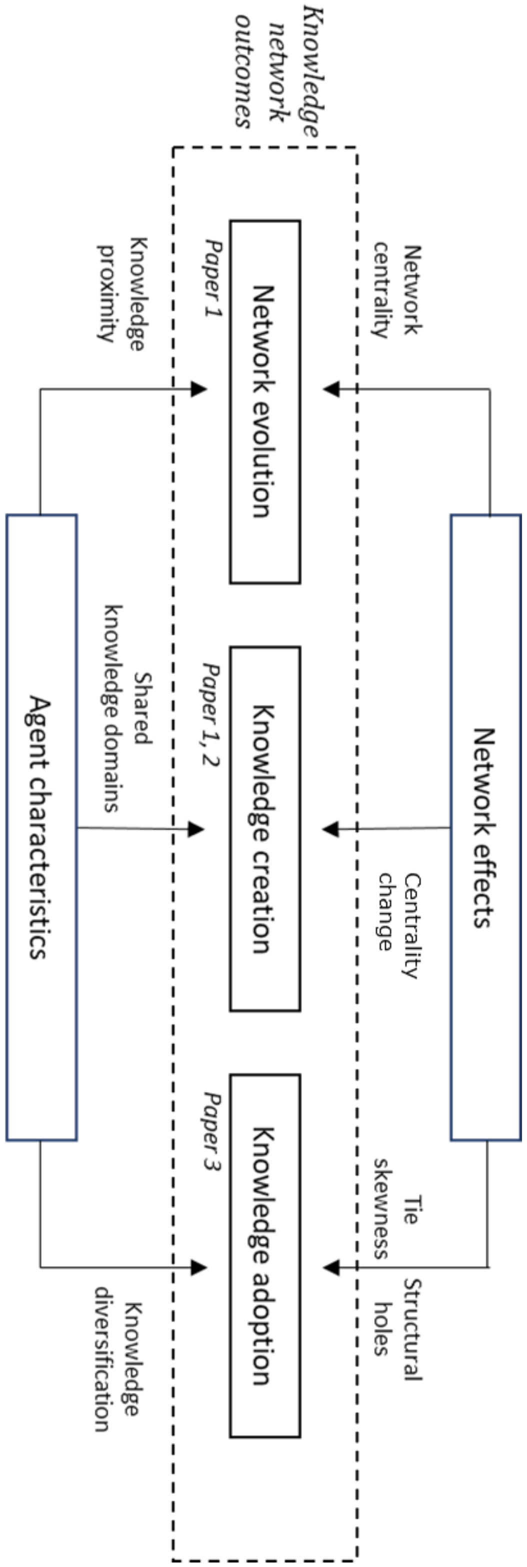
Knowledge network outcomes
Network effects
Network centrality
Centrality change
Tie skewness
Structural holes
Network evolution
Paper 1
Knowledge creation
Paper 1, 2
Knowledge adoption
Paper 3
Agent characteristics
Knowledge proximity
Shared knowledge domains
Knowledge diversification

Figure 1

Table 1

Chapter	Dependent variable	Explanatory variables	Method
2	Tie propability, High impact science	Degree centrality	SIENA
3	Weighted citations	Centrality change of ego and alters, knowledge similarity	Mixed model
4	New knowledge adoption	Tie Skewness, Structural holes, Knowledge diversification	FE Poisson

CHAPTER 2: LOCAL HEROES - GLOBAL STARS? HOW ORGANIZATIONAL FOCI AND NETWORK DYNAMICS IMPACT TIE CREATION AND HIGH IMPACT SCIENCE

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Abstract

In this paper we investigate the micro-mechanisms governing the structural evolution and performance of a scientific collaboration. One of the micro-foundations is that of being central in a knowledge network, which is often positively linked to tie formation and performance. Yet, extant literature has found diverging effects of centrality. Examining scientists' collaboration patterns at a Large Scale Research Facility (LSRF) we explore how centrality acquired in different contexts affect network dynamics and identify that the context influences the impact of centrality, and leads to a negative association to tie formation and performance. Specifically, we find that when centrality is achieved under a temporary organizing setting, the relationship between centrality, tie formation and performance is negative. This result is in alignment with theory on the cost and performance detrimental consequences of high centrality, however also opens for new avenues of research. We thus contribute to the literature on knowledge network theory, as well as the organization of science.

Introduction

Being central in the work environment or social life has been shown to yield substantial benefits to individuals (Newman 2001, Ahuja, Soda et al. 2012, Phelps, Heidl et al. 2012). Central individuals tend to be more positively perceived than their not so central peers (Ibarra and Andrews 1993), they tend to have greater access and control over valuable information flows (Ahuja 2000, Burt 2004), and they tend to convey a positive quality signal (Nerkar and Paruchuri 2005). As there is an increasing need for collaboration to produce high impact science (Wuchty, Jones et al. 2007), not knowing which network strategy to enact, can have significant effects on career trajectories and the novelty of knowledge created (Phelps, Heidl et al. 2012). In this paper we investigate two distinct, but related, networking strategies, that of a dynamic strategy, where specific ties are added within the current context of a scientist or that of a static strategy, where ties from a broader, yet distinct network are relied upon to generate future opportunities.

Our setting, scientific knowledge production, are of interest in that increasing collaboration are needed to create high impact new discoveries. Extant literature has found that collaborative projects have more impact than individual research (Wuchty, Jones et al. 2007), with collaborations spanning organizational boundaries presenting the highest average impact (Jones et.al., 2008). However, in the literature we still know very little of how the evolution of these collaborations in the wider form of a network influence the structure of collaboration and knowledge creation (Ahuja, Soda et al. 2012, Phelps, Heidl et al. 2012). Even though substantial amounts of literature elaborate on the intricate relationship between performance, knowledge production and the network of individuals, results are mixed and inconclusive (see Phelps, 2012 for an overview). One reason for this is the lack of longitudinal network analyses controlling for the inherent endogeneity of collaboration and behavior/performance. Knowledge producers choose their collaboration partners, and this in turn influences and constrains their future performance and selection (Baum et.al., 2010). Thus, network structure provides a powerful endogenous force restricting both performance and future network evolution.

Here, a gap in the literature can be identified, as literature on network evolution and structure is dominated by an intent on reproducing the topological form of real-world networks (e.g. (Erdős and Rényi 1960, Watts and

Strogatz 1998)), and has largely ignored traditions in sociology, psychology and economics regarding the behavior and characteristics of individuals. Thus, where management literature on knowledge networks neglects the endogeneity of network structure, this stream of literature neglects individual agency. As a result, essential questions relating to the production of knowledge and collaboration remains to be addressed.

However, a growing body of literature on this topic has started to emerge – both from within the area of sociology, and from the knowledge network and network dynamics perspective (Snijders 2001, Lomi, Snijders et al. 2011, Bianchi, Kang et al. 2012, Schulte, Cohen et al. 2012, Giuliani 2013, Lu, Jerath et al. 2013, Kuwabara, Hildebrand et al. 2018). In this stream, incorporating time into network theory is essential, opening up for whether network structure represent a stock of capital or more akin to a flow, that must be exploited under the pressure of time before it is lost (Soda, Usai et al. 2004).

In this paper we thus investigate the micro-mechanisms governing the structural evolution and performance of scientists embedded in social networks and aim to answer the question of how the network centrality of individuals influences the probability to become more central, and, in turn, what the impact on the creation of high impact science is. Moreover, we investigate the role of time and context in which ties are obtained, by exploring how ties obtained in one context lingers in a new context, building upon the work of (Soda, Usai et al. 2004).

This focus enables us to contribute in the following way: First, we aim at contributing to network theory by employing a longitudinal perspective to tie formation focusing on the role of centrality in subsequent tie formation and performance, which has received relatively little focus (Ahuja, Soda et al. 2012, Phelps, Heidl et al. 2012). Specifically, we explore the influence of centrality obtained in different contexts, and how past obtained centrality in two distinct contexts influence present opportunities. This expands the work of e.g. (Baum, McEvily et al. 2012, McEvily, Jaffee et al. 2012), on the influence of past network structure on present outcomes. We further seek to complement the findings of (Dahlander and McFarland 2013), by demonstrating the impact of the findings on lasting ties, showing how the structural and individual level impact of their identified tendencies guide tie retention. Our results are aligned with theory on the cost and performance detrimental consequences of high centrality, however also create new opportunities for avenues of research investigating the context in which ties are formed. Specifically, by employing the lens of focused tie formation (Feld 1981), we are able to, theoretically, separate the contextual influence of centrality measures on future outcomes. Second, we aim to contribute to the literature on the organization of science, by investigating the impact of two distinct networking strategies that scientists can employ, that of a static and dynamic strategy. Further, our empirical setting of big science (Weinberg 1967), a mode of centralizing research, has not received much scholarly attention (Lauto and Valentin 2013), even though investment to build these are significant. By analyzing what drives performance and networks alike, we explore how e.g. the variance in scientists receiving access to these facilities influence the capability to develop high impact science.

To study this, we turn to the world of scientists. Specifically scientists' temporary affiliated with a Large Scale Research Facility (LSRF). We selected this empirical setting due to two reasons: (1) in order to have a boundary for the social networks created, as these large pieces of research infrastructure has been documented to stimulate focused and intense collaboration (D'Ippolito and Rüling 2019); (2) the temporal nature of the institutional affiliation, provides a great opportunity to study how the influence of centrality that scientists bring with them, prior to affiliation, compares to the social networks they build while in the temporal delimited setting.

Scientists at a LSRF spend much of their time at the facility collaborating on experiments involving the facility's unique and expensive equipment. These scientists utilize their collaborators to achieve publication in high ranking outlets - often facilitated by successful application for funding - and these objectives are unaltered by the researchers' immediate context, whether it is the LSRF or their home department. Therefore, affiliation with a LSRF represents a significant change in context for researchers. The affiliation focuses their interest and activities on the research field, instruments and interaction with the facility and the facility's staff. We thus study scientists who move between two distinct yet comparable organizational foci: the static and durable context of everyday professional life which is the research anchored at their respective institutions, and the temporary, dynamic context of these scientists affiliated with a LSRF. This change in focus enables us to isolate prior network, performance and centrality effects.

Using the full publication history of scientists affiliated with the LSRF, we estimate how centrality prior to affiliation with the LSRF and attained while at the facility, influences their probability of becoming central – i.e. creating new ties - in the network of scientists evolving around the facility, and their probability of creating high impact science.

We specifically employ a longitudinal network analysis framework, i.e. a Stochastic Actor Oriented Model (SIENA), to control for network endogenous mechanisms, and estimate effects of centrality prior to entry as well as on site centrality for subsequent network centrality and performance. We find that centrality obtained in the temporary context on-site and off-site operates in very different ways. Centrality obtained in the durable context outside the facility network increases the probability of on-site tie formation, while centrality obtained in the temporary context of the facility exhibit a negative effect on tie formation at the facility. Likewise, centrality obtained in the durable context of the general academic environment increases the probability of high performance, while centrality obtained in the temporary context of the facility exhibits a negative effect on performance – however we only find weak significance for the latter effect.

Based on these findings, we conclude that even when centrality and performance criteria are held constant, variation in context durability and organizational focus influences the value of and pursuit for centrality as well as its impact on knowledge discovery.

THEORY AND HYPOTHESES

Network Centrality

Network centrality is likely one of the most studied concepts in the network literature (Borgatti 2005). In its most basic definition, network centrality captures the proximity of a node to alters in a network through ties. From a knowledge network perspective, these ties can be viewed as pipes through which information and knowledge flows, and therefore direct ties will enable a greater communication frequency and higher degree of sharing more relevant information, compared to indirect ties (Owen-Smith and Powell 2004). Thus higher centrality provides agents in the network with timelier access to richer and more diverse information (Phelps, Heidl et al. 2012). Greater centrality are often also associated with higher status (Bianchi, Kang et al. 2012, Piazza and Castellucci 2014), whereby, it provides a large variety of advantages, such as being considered as a better performer (Lynn, Podolny et al. 2009), and access to future resources (Lin 1999).

From a network dynamics perspective centrality also plays a key role, where current centrality often can be explained by prior centrality through the mechanism of preferential attachment (Newman 2001). In their seminal paper, Barabási and Albert use the notion of preferential attachment in their mathematical modeling of graph evolution, finding a large correlation with real world networks, and thus explaining the scale-free networks usually found in both collaboration and information, e.g. co-authorship and citation networks (Barabási and Albert 1999). Preferential attachment is a mechanism where social agents in a favorable central network position can utilize said position to reap further future gains. In science, this concept was originally explained and termed by Robert Merton in 1968 as a means to explain variation in the advancement of scientists (Merton 1968). 'Nicknamed' the Matthew Effect, this mechanism has been shown to have general applicability for explaining the emergence and increase of inequality across many temporal processes (DiPrete and Eirich 2006). Taken together preferential attachment thus refers to the effect of highly visible agents to become increasingly centralized in a network of agents, and therefore refers to an endogenous tendency for each node to have higher probability to – i.e. to prefer –form linkages – i.e. attachment – with prominent alters (Borgatti 2005). On the nodal level, preferential attachment has been identified as a governing mechanism for collaborative choice, both for individuals and firms. It has been argued to guide many aspects of human behavior, from location choices of human capital (Lorenzen and Andersen 2009), to performance in virtual R&D groups (Ahuja, Galletta et al. 2003), to internet browsing (Barabási and Albert 1999), and choice of collaboration partners (Newman 2004).

In conclusion, we regard centrality as a measure of influence—the ability to affect others and control or receive information, either directly or in future time periods (Borgatti 2005).

Centrality and Context

Despite the rich body of research on centrality, we know very little about the effect of the context of centrality generation. Especially when empirical work has shown that centrality tends to build performance and opportunity and vice versa individuals are left with a chicken-and-egg situation offering little insight on how to optimally apply resources, that can only be investigated further by analyzing how agents in a network selects with whom to connect (Ahuja, Soda et al. 2012).

To analyze this further, we first investigate theoretically how individuals choose with whom they connect. Fundamentally, people can be seen as rational and self-interested seeking to maximize potential outcomes and minimize constraints (Blau 1964),. Following, a fundamental strategy for the individual is to increase their own importance by creating ties with those whom they perceive of higher social rank, as resources these poses are perceived of higher quality (Thye 2000). Employing this theory, from an individual perspective, centrality is an intangible asset, allowing agents that increase their centrality to increase individual importance, enabling control over how knowledge and power flows. Therefore, acquiring a central network position can create social opportunities and, typically, decrease social constraints for individuals, organizations, and groups alike.

At the same time, a social network is, by nature, a social construct, and thus tied to the context in which it acts. We here use the term context to describe an organizational affiliation. One context is the focus of everyday activities in one work environment, which will be entirely different if the individual is moved to another department, or another company, sent on mobility assignments etc. Organizational context thus create boundaries for the individual around which a unique shared belief system can unfold, and where new social markers that are often only relevant for a particular context are created (Bianchi, Kang et al. 2012). As a result, it is uncertain whether any spillover effects from one context is directly transferred across other organizational contexts and when individuals change between different context types, network effects become less obvious.

As the positive signaling effect of being central is difficult to change in the short term (Piazza and Castellucci 2014), we expect that high centrality, obtained prior to becoming part of a temporary context, i.e. obtained in the more durable context of the scientific world, where scientists are rooted in their home organization, exhibit a positive influence on individual tie creation even in the temporary context. This resembles a form of static networking strategy, where one can rely on already existing outside network centrality to also positively influence another organizational setting – in our case a temporary one. Thus, we posit:

Hypothesis 1: The network centrality obtained in a durable context is positively related to tie creation in that same temporary context.

In knowledge intensive organizations, rational coordination is expected to steer communication patterns, in such a way that information exchange is not restricted to formal authority, but also involves lateral and cross-level sharing (Stevenson 1990). These emerging communication networks are in fact crucial for the knowledge based organization to survive (Krackhardt 2014), and are described as consisting of dense, lateral, diffuse and reciprocal relations (Krackhardt and Stern 1988, Lazega, Jourda et al. 2007).

From Feld's work on the focused organization of social ties, we know that change of "focus" affects network patterns through changing the probability of interacting with potential collaborators within the same focus area (Feld 1981). Focus is in his work defined as a social, psychological, legal or physical entity around which joint activities are organized. Focus produce patterns of social ties in a non-deterministic way because a joint focus increases probability of tie formation, but do not rule out chance interaction. When the context of centrality, in which a tie is sought is only temporary, or focused, the relationships between centrality obtained outside that context and creating new connections (i.e. tie formation) remains a black box. While some temporary contexts are venues for gaining connections for e.g. furthering future careers (Bendersky and Shah 2012), other temporary, contexts, e.g. project groups, alliances, university classes, doesn't necessarily show positive gains external to the specific context. This can be expected to be the case for participation in one-off projects, temporary postings of employees in subunits within a firm, and other situations involving temporary associations. We therefore pose the question whether a change of organizational focus affects the otherwise established collaboration patterns and incentives for tie creation for each individual scientist. To explain this mechanism, we utilize findings from the advice network literature. Herein, empirical findings seem to contradict the ideal-type image of flat communication structures stemming from individuals dedicated to knowledge sharing norms as mentioned earlier (Agneessens and Wittek 2012). Instead considerations to social rank play a prominent role (Blau 1963, Flynn 2003), sometimes even at the expense of knowledge sharing (Lazega, Mounier et al. 2012). In the literature on group processes, empirical evidence has been found that relations will tend to reflect the formal hierarchical structure, i.e. employees in lower hierarchical positions ask advice to those in higher formal positions rather than vice versa (Agneessens and Wittek 2012). E.g. in a study of R&D project teams (Brennecke and Rank 2016) show that *"employees sharing project memberships create advice ties to each other but do not exchange advice reciprocally"*. They also further find *"a negative relationship between having a high number of project memberships and informally seeking or providing advice"* (Ibid.). As a result, ties in knowledge intensive teams will tend to be asymmetric rather than reciprocal (Agneessens and Wittek 2012). In the context of temporary affiliation within a highly project-based organisation, opposed to centrality obtained within a durable focus, centrality obtained within this context, can turn out to signal a form of lack of available effort, or even ineptness, whereby centrality seeking behavior has a negative effect on later tie creation. Consequently, we should expect centrality obtained in temporary contexts, e.g. under a specific organizational focus, to have a negative effect on subsequent tie creation even in that same temporary context, thereby when this more dynamic networking strategy is enacted, we posit:

Hypothesis 2: Centrality obtained in a temporary focus exhibits a negative impact on tie creation, such that scientists with high centrality are related to subsequent less tie creation within the same temporary focus.

Centrality, context and performance

Becoming central in a network produces an increase in influx of opportunities to connect and receive ideas and resources from alters (Borgatti 2004). Regardless of whether the increase in influx is justified in real improved abilities or rests on irrational perceptions, the consequences remain to be that well-connected agents experience improved opportunities to excel - an ex post effect translating centrality to improved performance. The same reasoning can be found in Merton's (1968) original work, where it not only influences the perception of quality, but scientists that are central are more likely to attract both tangible and intangible resources, which in turn can result in scientific outputs of higher quality. Thus, the premise of this is not only that highly central agents accumulate increasing returns to their centrality, but also their ability to innovate by integrating distant components, and open up whole new lines of inquiry (Uzzi, Mukherjee et al. 2013). Following, the most interesting aspect of the centrality/performance relationship is found at the very top of the performance distribution. However, findings from the knowledge network literature has are inconclusive with regards to the impact of centrality on knowledge creation (Phelps, Heidl et.al., 2012). Here some studies find a positive and linear effect, while others find an inverse u-shaped relationship exhibiting decreasing marginal returns (McFadyen and Cannella, 2004). The argument for the impact of decreasing marginal returns is centered around the fact that building and maintaining ties takes effort and resources. Thus, at a certain point the benefits of having many ties does not outweigh the costs. However, in our context, as we distinguish between a more static latent network effect, and a dynamic one, we expect the centrality accumulated in the durable context to exhibit the same linear effect as in earlier studies. We thus propose hypothesis 3 as a baseline before we turn to hypothesize on the network centrality effects in temporary contexts with organizational focus:

Hypothesis 3: Centrality obtained in a durable organizational focus is positively related to the ability to produce high impact science in the temporary organizational focus.

Social networks tend to be relatively stable, partially due to increased returns on investment for highly central individuals (Benjamin and Podolny 1999). Due to this, increasing centrality is costly, and hence investments in becoming more central may compromise performance. A highly central individual has more social capital to act upon, but the time-demand of managing these social relations is high. This goes two-ways, as alters perceive this tension of wanting to access intangible resources through collaborating with the highly central agent, but also the danger of simply not getting their attention. This is especially prevalent in collaborations that involve substantial face-to-face contact, regular meetings or the transferring of tacit knowledge (Dahlander and McFarland 2013). The stability of such hierarchies and the thereof following expenses inhibit the centrality self-enhancing strategy such as it put too much strain on individuals' resources when time is a pressure (Bendersky and Shah 2012).

Empirical evidence on the effects of time pressure for performance point to an inverse U-shaped relation between time pressure and performance (Baer and Oldham 2006, Rosso 2014). While moderate time pressure will facilitate performance, too much time pressure will produce side effects of discouragement for exploration (Rosso 2014), lack of attention to complex issues and general overload. Thus, coordination costs will increase with each established tie, and more so if this tie is to a highly central alter, and will, at some point, decrease the advantage gained from adding more ties. This cost-benefit relationship between centrality benefits and the costs of maintaining ties shifts in favor of costs for temporary contexts simply because there is less time to recoup the benefits of the investment in tie formation. Many of those who chose to follow the dynamic centrality investment strategy will stretch their limited resources too thin and end up as the plate spinners we know from circus, restlessly spinning multiple plates atop long sticks, adding more and more plates – however in this example the plates will all come crumbling down at a peak moment. In the life of a scientist, the effect will more likely be a decrease in quality or increase in abandoned projects. Knowledge producers investing too much in centrality seeking may consequently find themselves stretching too thin and unable to reap returns to their investment (McFadyen and Cannella 2004). In hypothesis 4 we therefore propose an inverse u-shaped relation between centrality gained in a temporary context and scientific performance:

Hypothesis 4: *Centrality within a temporary focus exhibits an inverse u-shaped relationship with the creation of high impact science.*

Summarizing, compared to hypothesis 2, we propose an inverse u-shaped relationship for hypothesis 4 as we, aligned with prior literature, still expect to see the positive performance effect of collaborating with peers, however as direct ties are associated with a high maintenance costs, and that, given many collaborators, attention will be spread to many different knowledge products, that effect will exhibit decreasing marginal returns.

Taking a network dynamic perspective, we therefore propose that centrality obtained in contexts of varying durability has different effects for centrality and performance. We further posit that individuals' social networks and their performance mutually impinge upon one-another, and coevolve over time, especially due to context specific network dynamics.

EMPIRICAL SETTING

To study how the relationship between status, tie creation and high impact science depend on organizational foci we now turn to the world of Big Science. Here scientists experience tie organizing effects from both the durable context of their research field in general and the temporary focus of affiliation to a Large Scale Research Facility native to Big Science.

Big Science and Large Scale Research Facilities

Big Science requires big budgets, big planning and big collaborative effort. The trade-off for these large investments is the potential for breakthrough discoveries, both in the scientific world and as spillovers in the form of inventions with radical potential. The setting of a Large Scale Research Facility (LSRF), provides us with a geographical localized multi-institutional context, with distinct roles assigned to scientists, according to e.g. the instruments they are operating or whether they are residents or visiting scientists. At the same time a facility like this serves as an extreme case of the paradigm change and professionalization connected with the rise of big science, that has been described as an example of the new model for collaboration in science (Cetina 2009). However, these facilities are not only providing access to expense instrumentation, they also resemble typical modern non-scientific organizations, with a strategic apex deciding the directions of the facility's ongoing foci, an operating core of scientists administrating the highly complex instruments, a techno-structure evaluating project proposals and optimizing the overall layouts of e.g. beams and beam time, a support staff that e.g. communicates the results and a middle line of scientists both managing instruments and aligning this with ongoing research projects. In our context we directly observe a change in collaborative patterns when affiliated with the LSRF compared to before being affiliated. We observe that the density of ties amongst scientists increases manifold when they become affiliated with the LSRF (by approx. a factor 3).

Figure 1: This figure shows, on the left-hand side, the whole network of scientists prior to the first year of observation at the LSRF, while the right-handed side shows the total accumulated network established at the LSRF. The density increases dramatically from 1.61‰ to 4.41‰. This is also evident if we look at the number of components in the network:

Insert table 1 approx. here.

Here we observe that prior to their first observation on the facility 45% are not part of the largest component, while after our last period of observation at the facility, the number of isolates and scientists not part of the largest component, has dropped to 7%.

The LSRF has a resident staff of employees, mostly managing the instruments, and most scientists temporarily visit the facility while employed elsewhere or collaborate on projects focused at the facility. In the case of scientists joining a LSRF, the change in organizational foci are represented by an increasing focus on the work surrounding the LSRF combined with weakened engagement in other foci of which the home affiliation of the scientist would typically be the dominant one. This is evident when we pool all publications by scientists published the year we observe articles affiliated with the specific LSRF together. Following we find that the *on site–off site* publication ratio is approx. 46%. This strong facility focus during the time of affiliation is supported by our interviews and e-mail exchanges with scientists familiar to the inner workings of LSRFs.

Unit of Analysis

As our empirical setting we choose the Spallation Neutron Source (SNS) and the High Flux Isotope Reactor (HFIR) located at Oak Ridge National Laboratories (ORNL), Tennessee. ORNL was established in 1943, the overall facility is a multidisciplinary center financed solely by the U.S. Department of Energy, and perhaps most widely known for hosting the Manhattan Project. The facility conducts both basic and applied science in specific the areas of neutron science, biological systems, energy and high energy physics, advanced materials, supercomputing and national security. Approximately 4,600 scientists are employed at ORNL, and the facility had a budget of USD 1.65 billion in 2011. Since 2006, the research program in neutron science is managed by the Neutron Sciences Directorate. ORNL/NSD employs approximately 600 scientists, technicians, and administrative staff and operates two of the world’s most advanced neutron scattering facilities: a Spallation

Neutron Source (SNS), which became operative in 2006, and a High Flux Isotope Reactor (HFIR), completed in 1965 and renovated in 2007. In our study we focus on the knowledge production surrounding these two facilities. The upstart/restart of the facilities in 2006 and 2007 allows us to observe the network of research collaboration from the start of its formation.

Data and Method

One simple, but powerful, indicator of collaboration in science is the co-authoring of an article. Collaboration on articles creates a social network of collaboration patterns, the study of which allows us to understand some of the characteristics of a specific discipline or research site enabling identification of invisible colleges (Wagner 2009) and social groups that exist in scientific fields. Though interaction often also occurs along fewer formal lines such as friendship, colocation and mentorship, collaboration on a paper is a conservative measure of tie formation creating a lower bound for significant social interaction and creation of informal hierarchies.

Studies have shown the potential of using social network analysis in opening up an interesting line of investigation in this respect (Barabási and Albert 1999, Newman 2001). Yet, the research specifically on structural integration, social homophily and how ability affects this, has been hampered by a lack of longitudinal analysis, with analysis up till now mainly consisting of static network snapshots. Not having a longitudinal perspective greatly reduces the ability to distinct selection from influence (Borgatti and Halgin 2011), and indeed separating these mechanisms is central to addressing the issue of endogenous tie formation in networks (Steglich, Snijders et al. 2010). But to the best of our knowledge, no studies have combined a longitudinal network framework studying the evolution of scientific collaborations, incorporating both structural and performance effects, even though the endogenous network effects of e.g. transitivity and preferential attachment will skew the results when not properly controlled for. The approach utilized in this paper thereby contributes to an active research domain, which seeks to disentangle social selection from influence, and draws upon recent statistical advances in the network literature to model relationships between, tie creation and performance with greater confidence (Snijders 2001, Snijders, Steglich et al. 2007, Snijders, Van de Bunt et al. 2010, Lomi, Snijders et al. 2011, Lospinoso, Schweinberger et al. 2011).

Data

Since 2006, all peer-reviewed publications based on research utilizing SNS & HFIR data and resources or conducted by staff affiliated with SNS & HFIR are publicly listed on the directorate's website. We refer to these publications as facility affiliated or on-site research and publications. We retrieved full bibliographic records from SCOPUS of the publications produced at the facility in the period from 2006 to 2011. The cut-off of 2011 is due to a need to gather at least four years of citation data for each publication record. We also utilized the SCOPUS unique identifier to retrieve the full bibliographic record of unique scientists joining the facility. We collected publications from the year 2000-2015, in order to allow citations for at least 4 years to be observed. A total of 3402 distinct scientists stemming from 1282 publications where collected for scientific research done on-site. The off-site publication counts a total of 97,361 publications. Specific for High Energy Physics (HEP), and work done at LSRF, we find publications with massive amounts of co-authors. For example, the series of papers responsible for conveying the discovery of the Higgs boson at CERN's Large Hadron Collider has an average number of authors beyond 2000. As the premise of this study is to study the effects of collaboration, we remove publications from the dataset not in with an abnormal number of authors (mean +2SD)[1] – this follows prior literature (Wang 2016). As some of our measurements are calculated in 5 year rolling windows, we also remove the scientists where no papers are available in this window prior to their first entrance to the LSRF. Our total population sample is thus consisting of 2906 scientists and approx. 87,000 publications. When modelling the network evolution, we only utilize the publications published with an SNS-based research affiliation.

MEASURES

Dependent variables

Network Tie formation. To assess whether a network tie exists between two scientists, we utilized the co-authoring of an article. By first constructing affiliation matrixes for each focal year, and next multiplying this

[1] The maximum number of co-authors on a paper within the SNS & HFIR corpus are 89, and the maximum in the entire author corpus is 3096. In the entire corpus we drop 3037 publications due to the author size cap and for SNS specifically we drop 4. The citations on the 4 dropped are not significantly larger than the means for the rest of the corpus.

with its transpose, we gain the adjacency matrix with information on whether scientist A has collaborated with scientist B. The adjacency matrix is then dichotomized as this is a prerequisite for SIENA to be able to run.

Performance. For evaluating the probability than an actor is involved in the creation of high impact science, we identify the top 10% most cited publications in that year. As achieving citations typically shows a birth-death process, where initially few additional citations are observed then accumulates and finally dying, we gather the citations in a five-year interval after each publication has been published. An even bigger citation window would be optimal (around 10 years), but we are solely looking within the natural sciences, where the citation cycle is a lot shorter than other scientific categories (Baumgartner and Leydesdorff 2014). Following, every author having a paper in this sample, are coded with a one if they have been part of the top 10% for a focal year, and a 0 otherwise.

Independent Variables

Centrality

To operationalize centrality in this context, there are several options identified within extant literature, specifically *degree*, *closeness*, *power* and *betweenness* centrality (Borgatti 2005). If we see centrality as a measure of global influence, we could look at prior literature on status related network measures, and operationalize centrality based on Bonacich's (1987) measure of power-centrality (Bonacich 1987, Bothner, Kim et al. 2010, Piazza and Castellucci 2014). However, power-centrality is a measure of global centrality that consider the focal actor's own centrality as well as that of its connected actors, their connected actors etc., while we are investigating a more local influence of being central, i.e. directly observable behavior/effort in improving connections. We therefore utilize Freeman's degree centrality, i.e. the absolute unique count of collaborators, as our key measure of centrality (Freeman, Roeder et al. 1979).

Centrality off site (Durable Context).

As mentioned, we utilize degree centrality as our measure of centrality in our context. To construct this measure, we only use unique ties made within 5 years before first observation at the facility. As degree centrality can be measured at the ego network level, we do not need to know the entire network of alters, compared to if we used e.g. power, closeness or betweenness centrality (Borgatti 2005), thus utilizing degree centrality is also more robust to e.g. unobserved co-authors not having been at SNS or HFIR at any given point in time.

Centrality on site (Temporary Context). As with above this is measured in a similar way as the prior measure, with the difference that this is calculated for each year of observation on site.[2]

To compare the magnitudes of the two variables, both are centered.

Controls

Research has continuously found that a prime social mechanism is the inclusion of the "third other", or more commonly known as triadic closure. Therefore, we control for the propensity for triads to close in the network. To control for individual ability, we include the total number of off-site citations in five year rolling windows. As further control of scientist ability we include in the estimation of performance, the influence of the avg. off-site citations of collaborating alters. Another often found effect influencing the selection of collaborative partners is that of gender (Bozeman and Corley 2004). We include both controls for scientists' gender and gender similarity (females/males preferring other females/males as collaborators). In the final model these are excluded due to non-significance, following the proposed estimation strategy found in (Schulte, Cohen et al. 2012). To control for the fact that highly experienced scientists are more prone to both become more central and produce higher impact science, we calculate total experience as the year of first observed publication in SCOPUS minus the first year of entrance into the LSRF. We also control for possible network enhancing effects of being employed at the facility, as instrument scientists working at SNS, will be highly sought after as co-authors[3].

Another reason for scientists to collaborate, could be a prior joint publication. This could be in the form of joining the facility together and as being included on the analysis of output data while the project goes along, or after it's finished. By aggregating all publications prior to facility entrance, we can calculate the prior

[2] As a robustness check, we have utilized Bonacich's power centrality with similar results.
[3] This was especially evident in interviews with former researchers at the facility, where a "rule-of-thumb" was that if it took the instrument scientist more than 3 days of work to set up experiments, he/she would be included as co-authors

collaboration matrix as an adjacency matrix of the bipartite incidence matrix. We employ a range of other network controls such as degree assortativity, but they are not reported in the regression results due to size constraints.

ESTIMATION

We are interested in modeling both the evolution of network ties as well as the performance of individuals, and therefore must address three factors. First, as prior work has established that endogeneity in especially social capital research stems from the possibility of reverse causality, e.g. structural features affecting performance and performance affecting structural features, we are thus in need of a longitudinal approach where we can separate both. Second, when conducting quantitative network analysis, one must be aware of the possibility of (structural) autocorrelation (Krackhardt and Stern 1988), which can bias the standard errors of i.e. OLS regression and generate unreliable significance test results (Wooldridge 2002). In network terminology this is also called network dependency and can be exemplified with e.g. the creation of Simelian ties (the friend of my friend tends to become my friend). Third, extant literature has mostly been concerned with estimating effects for discrete observation periods, i.e. network snapshots, whereas the true effect could lie in the interactions having taken place in between observation periods. We thus need a framework operating in continuous time, as well. To address these issues, we utilize the SIENA (Simulation Investigation for Empirical Network Analysis)-framework, that further lends from a series of Stochastic Actor Oriented Models (SAOM). This was developed by (Snijders 2001) in order to investigate both behavior and network formation as joint dependent variables. This model combines random utility models, Markov processes and simulation to estimate network parameters between observations and concurrently estimate parameters for the underlying network dynamics. SIENA can be categorized as a combination of simulation models and traditional econometric models. The model differentiates from traditional simulation models by enabling the estimation of test parameters from empirical data, and it differs from traditional regression analysis by considering network changes as an endogenous evolutionary process.

The stochastic actor-oriented approach employed in this paper differs by other approaches by explicitly addressing both network dependencies and behavior, co-evolving in continuous time. This approach models the evolution of social networks, in terms of tie-establishment and termination between the different actors, as driven by exogenous as well as endogenous forces. The network formation and behavioral change processes are further broken down into a series of micro-steps, where at each stochastic determined moment in between the observed time periods, an agent can choose to either form, dissolute or maintain a given tie. The probabilities of tie changes are thus modeled as a function of individual actor characteristics as well as their network position. It enables us to capture endogenous effects of high importance when explaining the evolution of social networks. The SIENA approach has previously been used, amongst others, to analyze network formation among Chilean wine makers (Giuliani 2013, Giuliani, Balland et al. 2018) and coevolution of network ties and perceptions in work teams (Schulte, Cohen et al. 2012). Basically, SIENA estimation consists of some objective function, containing the parameters, independent variables, explaining either the behavior or the network metrics of individual actors. In our case the objective functions are (without controls):

$$f_i^{per}(x,z) = \sum_k \beta 1 * centrality_{onsite}^{beh} + \beta 2 * centrality_{offsite}^{beh} + \varepsilon\,(x,z)$$

$$f_i^{net}(x,z) = \sum_k \beta 1 * centrality_{onsite}^{net} + \beta 2 * centrality_{offsite}^{net} + \varepsilon(x,z)$$

These are modeled in a series of micro-steps, where in each micro-step an actor can choose to change ties (form tie, dissolve tie, maintain current setup) controlled by a stochastic determined rate function, where the random draw is taken from the Gumbel-distribution. As we are interested in modeling whether an actor takes part in the creation of a high impact paper, we only consider upward changes in the behavioral variable, and thus we utilize the behavioral creation function, where effects only are included in instances where the actor considers increasing his performance score by one unit. Parameter estimates are finally modeled according to the following equations:

Behavioral Change (prob. of creating a publication in the 90th percentile (0/1).

$$Pr(z(0 \uparrow 1|x,z) = \frac{f_i^{beh}(x,z)}{\sum_{\varphi=0}^{1} f_i^{beh}(x,z(i \updownarrow \varphi)}$$

Network change (prob. of *i* to form a tie with *j* compared to all other possible connections (0/1):

$$Pr(x(i \rightarrow j|x,z) = \frac{f_l^{net}(x,z)}{\sum_{l=1}^{N} f_{il}^{net}(x,z)}$$

We model the entire network as a growing network (only tie formation allowed[4]), were scientists not at the facility at year t and t +1 are denominated with structural zeros and are not part of the estimations until entrance. This created a series of iterations wherein in year 2006, the network of 667 authors are used as baseline, where 589 authors then enter for the simulation of tie formation/performance from 2006 to 200. The 589 authors are coded with a 0 in the adjacency matrix for 2006 and in the adjacency matrix for 2007 are coded 1 if they form a tie with actor j. The adding of authors then continues until the last year of observation (2011). All parameter estimations are based on 3,000 simulation runs. Due to the size of the network, convergence of the approximation algorithm was not excellent for all the variables of the different models, especially for some of the similarity measures. Following prior literature (Snijders 2001, Schulte, Cohen et al. 2012) in the final models we kept only those that were individually significant in order to prevent convergence problems and inflated standard errors. For the final model, convergence was excellent (all around t-values < 0.1). The convergence indicates whether the deviation of the simulated structures compared to the observed structures is acceptable (t-values < 0.1) and can be used as an approximate goodness of fit of the different parameters. For goodness of fit estimations for the entire model, the Monte Carlo Mahalanobis distance test (i.e. estimated probability of greater distance than observation) was conducted on the degree distribution following (Lospinoso 2011). The test didn't find support for the null-hypothesis, indicating that the distance of simulated degree distribution to observed are non-significant. We also used Wald tests for individual estimations, testing estimators against the null-hypotheses.

Time heterogeneity

For issues regarding time heterogeneity, i.e. whether parameters are constant across time periods, we use the method proposed in Lospinoso et al. (2011). This works by including time dummies for parameters that fails

[4] We also tested our models with a tie decay function of 3 years and found no significant differences.

the score-type test, where a rejection of the null hypothesis of the CHI-2 value, means existence of time heterogeneity.

By running the tests, we could see that there is time heterogeneity between some of the parameters going from wave 1 to wave 2, and from wave 3 to wave 4. Empirically this makes sense as part of the facility only became operational in 2006 and was closed for reconstruction during a period in 2008, thus restricting access and utilization. Following, we included time dummies for the parameters of degree off-site and triadic closure for those periods and ran the test again.

Goodness of fit

The overall goodness of fit for SAOM-models is tested utilizing the approach proposed by (Lospinoso, Schweinberger et al. 2011), and makes use of auxiliary statistics of networks, e.g. degree distributions, geodesic distance and triadic closure. In general, it works by computing the Monte Carlo Mahalanobis Distance between observed network statistics and those networks generated through the simulation process. A model is satisfactory if the average values of the statistics over the simulation runs are close to the values observed in the data. This condition corresponds to verifying the null hypothesis of a Monte Carlo Mahalanobis Distance Test. The test produces as output the frequentist p-values, which are used to assess the overall fit. The figures show the p-values and a graphic representation of the goodness of fit test. We found that in the tests for the networks containing only controls and network endogenous mechanisms, the overall fit is not good (It fails to verify the null). But as we add both controls, network endogenous mechanisms and key independent variables, we can see that the overall fit converges quite nicely, and the null-hypothesis is statistically significant.

DESCRIPTIVE STATISTICS

Insert Table 2 about here

Table 2 shows the summary statistics for the dataset employed in this study. The average publication at the facility has a total number of co-authors of 6.86 with a standard deviation of 5.35. After deleting publications with having more than the mean +2SD of co-authors, this drops to 6.43 – a very minor change. The mean number of publications pr. author in our data is 5.45 and the standard deviation is 9.21. The maximum number of publications pr. year by a scientist is 66. This indicates the typical skewed distribution of scientific productivity, meaning the existence of potentially "star scientists" with a high productivity rate, and a long tail of scientists with much lower productivity.

Insert table 3 about here

Insert table 4 about here

Table 3 and 4 show the descriptive as well as the overall evolutionary network statistics. We observe that the average degree of each scientist starts of at 3.78 and ends at 13.16, indicating a highly collaborative environment, much in line with prior anecdotal evidence from the high energy physics-community. The change in network ties is especially low in periods 2008→2009 and 2009→2010, which can be due to a series of temporary breakdowns in the years 2008 and 2009. This is also indicated by the large number of formed ties in the period 2010→2011. We further observe that the Jaccard coefficient - indicating the degree of change between network observations - are higher than 0.2 and lower than 0.9 giving preliminary evidence that change in the network are present, but not that the network changes to much to render estimation by SIENA unfruitful (Snijders 2001, Lomi, Snijders et al. 2011).

RESULTS

Table 5 shows the results of the stochastic actor-based analysis for network ties and performance respectively.

Insert Table 5 about here

The parameter estimates can be interpreted as non-standardized coefficients obtained from logistic regression analysis (Steglich, Snijders et al. 2010). Therefore, the parameter estimates that are reported can be read as log-odds ratios, i.e. how the log-odds of tie formation change with a one unit change in the corresponding independent variable. Every variable has been centered to the mean, prior to estimation. Odds ratios can be computed as the exponentiated form of the coefficients of each predictor. In table 6 these transformed coefficients are presented for our hypothesized variables:

Insert Table 6 about here

Regarding hypothesis 1, we posited that centrality obtained in a durable context, has a positive influence on the creation of network ties. We confirm this hypothesis by finding the estimate positive and significant at the 5% level, and find that the probability of forming a tie increases by exp(0.56)=1.75. Looking at hypothesis 2 we posited that status obtained in a temporary context has a negative influence on the probability of creating a tie. We also confirm this hypothesis and find that when choosing with whom to collaborate, having a high degree decreases the probability of creating a tie by 1-exp(-0.43)=0.35. Hypothesis 3 are also confirmed as we find a positive and significant coefficient exp(1.51)=4.53, meaning for raising the degree centrality by only 1, increases the probability of producing high impact science by 4.53 compared to one with a degree centrality 1 lower. We only find weak support for hypothesis 4, as it is only significant at the 5% level in a one-sided test, and non-significant for the curvilinear effect.

It can be seen from the results of the network ties that two of the most prominent effects predicting tie formation are those of prior collaboration, transitivity and prior distance 2. As an example given the choice of collaboration, the probability of collaborating with a scientist you have previously collaborated with is exp(3.90)=49 times higher than if you had not. We also find that increasing citations increases likelihood of tie-formation with about and that scientists with high experience exhibit a significant small increase in the likelihood of establishing ties, even though the magnitude of the coefficient is negligible. When looking at the performance model we find, aligned with prior literature, that the citations of the scientist has a positive and significant effect as well as the experience.

Robustness checks

We did several robustness checks of our results. First and foremost, the results could be driven by the choice of cutoff-point of team size and we hence experimented with different cut off points, besides the one driven by numerical analysis. Specifically, we tested the cap by excl. publications with >10, >20, >50 and >100 authors with similar results. Second, our results could diverge with different schemes for scientific performance. Thus, we also tested the model with a performance dependent variable divided into quartiles in discrete intervals [0;5]), with similar results, although we saw an increase in the magnitude of the experience variable. We also tested our models with different measures of ability on the independent variable side based on outside prior citations – i.e. changing the citation window of observation, only counting the maximum cited publication and weighting according to journal impact – with similar results. Fourth, we tested the model with a tie decay function of 3 years on site, and as well for ties formed outside the facility, also with similar results, although both convergence and goodness of fit of the model was significantly worse in the instances with a smaller tie window, due to fewer ties being formed. Lastly, one concern could be that for hypothesis 2, we observe the impact we do on centrality obtained outside the facility, because agents already are so well connected that they do not need to form new ties to accomplish their job. Here we addressed this methodologically by applying a unique SIENA control possibility, allowing to control for other network structures. We thus included controls for the both the prior direct internal network of scientists before (i.e. whether a prior collaboration could be observed), as well as prior degree 2 (i.e. whether nodes where connected at a distance 2). Both controls are significant and has a large effect on the probability of tie formation.

All models are available from the authors upon request.

DISCUSSION AND CONCLUSION

In this paper we started out positing that the organizational context matters for the effect of both an individuals' network trajectory and knowledge related performance. Specifically, we hypothesized that the effect of being central on both future network position and performance are affected by whether the centrality was achieved in a durable vis a vis temporal context. We find a difference in how individual centrality affects both the probability to become central (tie creation), as well as its influence on the creation of high impact science. We confirmed hypothesis 1 that degree centrality obtained in a durable context exhibits spillover effects to the temporal. Further, we confirmed hypothesis 2, stating that centrality obtained in the temporal context, had a negative spillover effect on subsequent tie formation.

This indicates, that centrality could be separated into two components according to whether it is obtained within a temporary context of a specific organizational focus or in a more durable context. This further opens for the possibility that for the individual agents to become central in a network, and create innovative findings, i.e. centrality achieved in the durable context, it is important to not just form ties by trying to participate in all potential collaborations, but instead seek out few ties to high performing collaboration partners. This opens for future studies to explore the effect of time on tie creation, and specifically in contexts of temporal group or organizational association. Our findings thus add to the litterateur on network theory, specifically in the area of longitudinal network dynamics, where e.g. (Ahuja, Soda et al. 2012), identify a gap in the network literature with regards to whether a tie or a central position will have the same effect on knowledge related outcomes in time *t* vis as vis time *t+1*. Our findings thus add to this by identifying that ties created in time *t* within a temporal context, will have negative spillover effects at time t+1 in the same context. Our confirmation of hypothesis 3 also further expands the findings of (Baum, McEvily et al. 2012, McEvily, Jaffee et al. 2012) where the relationship between e.g. structural holes and weak ties are explored in a longitudinal lens, where e.g. performance benefits of closure ties increases with age, and the influence of bridging ties decreases with age. They find the network impact changes with the age of the network position. We add to this the importance of both employing a time perspective, and the contextual information and bring the unit of analysis to the individual level. This begs the question whether the contextual influence of in-focus ties vis a vis out-of-focus bridging and closure ties on both future network creation and performance will are the same.

Our findings also seek to extend those of Bendersky and Shah (2012) by illuminating the limits of our current understanding of centrality. As Bendersky and Shah we study a temporary context, but unlike their context of MBA study teams, we study a temporary context with low spillover effects and find that the combination of a temporary context and weak spillover effects dramatically change the impact of centrality. We further employ a different metric, degree centrality, which, compared to the measure used in Bendersky and Shah (2012), further extends their results indicating a not only global status based effect – they utilize Bonachich's Power Centrality - but also a more direct and local based on degree centrality.

By confirming hypothesis 2 and 4, we add to the findings of Dahlander and McFarland (2012), as we suggest that our local stars, i.e. high centrality in temporal context, face the unhappy situation that their many collaboration partners are drawn from a stock deprived of prime collaboration partners. Dahlander and McFarland (2012) demonstrated that high performance increases the probability of repeat interaction among collaboration partners. These lasting ties decrease the opportunities for newcomers to engage with high performing colleagues', as their repeat interaction brings them near their collaboration capacity. Those individuals, the local stars, who engage in many high centrality collaborations experience a negative impact on performance because they engage in highly distributed efforts of the limited resource of their time. Here our findings complement those of Dahlander and McFarland (2012) by demonstrating the structural and individual level impact of the dyadic tendencies they find to guide tie retention. Despite the difficulty of finding new high-quality collaboration partners, we do see a positive performance effect of collaborating with higher ability peers. Stars may be born in the enclosed world of LSRF, and the path of rising stars seems to be formed by limiting activities and collaborating with few high ability partners. Scientists with low degree centrality may rise through a strategy of investing in few projects involving high quality alters, and then use the performance of these projects to leverage status in the wider academic context.

From wider organizational literature perspective, few contexts are completely temporal defined and isolated from spillovers, but many are starting to lean in that direction, where temporal projects can be seen as temporary organizations (Hobday 2000, Winch 2014). Our findings indicate that individuals may experience a one-way spillover effect of centrality effects similar to scientists affiliating with LSRF. Another example of our findings is that of the difference between centrality in a local context, e.g. a department, versus centrality in a more global context, e.g. the academic field of management research, for the probability of tie creation and performance. Depending on context importance and spillover effects of centrality across contexts, local or temporary network centrality may hold little value in a more global context. We can extend these findings to the literature on status, where scholars have started investigating how the social position of actors co-evolve with their performance – especially the notion of 'centrality' in the guise of, in many studies, 'status' has been receiving increasingly scholarly interest (Piazza and Castellucci 2014).

However, this notion of status as centrality, in a social network perspective, has remained fixed upon either static measures of status (Piazza and Castellucci 2014), or focused on sudden status bursting events (Azoulay, Stuart et al. 2014), ignoring both the dynamics of the changing status hierarchy and the specific context in which it is generated. As networks more than often are described as the "pipes and prisms of the market" (Podolny 2001, Owen-Smith and Powell 2004), the flow of centrality, and the manner in which social networks co-evolve with performance are an important issue. Our theoretical framework and findings incorporate a dynamic evolutionary network model, showing that centrality exhibits an important impact on this evolution, according to the durability of the context in which is obtained.

Summarizing, our findings support that the centrality of actors influence the probability of coming central in different ways, depending on the durability of the context within the status position was obtained. centrality from a durable context has a positive impact on tie creation and performance, while status from a temporary context has a negative impact for tie creation and performance in that same temporary context. This has implications for especially our understanding of network dynamics, underlying the importance of understanding the specific context from where network centrality is formed. Following, for the individual actors, to become central and create innovative findings and become a global star, it is important to not enact a dynamic networking strategy, and not just form ties by jumping into all potential collaborations, but to seek out ties to high performing collaboration partners in contexts that are temporal.

Thus, our study marks a boundary condition for centrality effects identified in research so far. When time constraints increase, and spillover effects are weak, centrality changes from a resource to also presenting constraints for future actions. Even in similar networks with same performance criteria, same tie strength and content, and same resources exchanged, centrality effects vary with context durability. In temporary contexts, time constraint will pressure actors to fulfill their collaborative obligations within a short timeframe. This creates a more imminent pressure which reduces the potential effort allocated to each project and change the effect of centrality from a resource to a constraint. Those individuals who engage in many collaborations experience a negative impact on performance because they engage in highly distributed efforts of the limited resource of their time. They will find it difficult to allocate enough attention to make each of their many projects successful.

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APPENDICES

Table 1. Size of network components before and at the LSRF

Before LSRF												
Size	1	2	3	4	5	6	8	14	15	19	53	1648
Actors	932	56	29	8	4	5	3	1	1	1	1	1
At the LSRF												
Size	2	3	4	5	6	7	8	9	12	15	26	2769
Actors	6	6	6	5	4	3	2	1	1	2	1	1

Table 2. Data Descriptors

	Variable	Mean	SD	Min	Max
1	Pubs pr. author pr. year	5.45	9.21	1	66.67
2	Authors pr. pub not SNS	16.39	102.56	1	3096
3	Authors pr. pub not SNS (corrected)	5.74	3.01	1	
4	Authors pr. pub SNS	6.86	5.35	1	97
5	Authors pr. pub SNS (corrected)	6.43	3.32	1	17
6	Pubs SNS not SNS ratio[5]	0.43	0.35	0	1

[5] Measured as total number of SNS affiliated publications divided by total number of publications published by each author in years also publishing SNS-affiliated papers.

Table 3| Descriptive statistics

	Variable	Mean	SD	Min	Max	1	2	3	4	5	6	7	8	9	10
1	High Impact Science	0.26	0.43	0	1	-									
2	Centrality – on site	6.36	9.24	1	27	0.09	-								
4	Indirect ties	0.10	0.44	0	1	0.03	-0.02	0.32	-						
5	Prior collaboration	0.00	0.04	0	1	-0.03	0.21	0.06	0.03	-					
6	Prior indirect ties	0.00	0.09	0	1	0.04	-0.18	0.06	-0.16	0.26	-				
7	Gender (1=male, 0=female)	0.86	0.35	0	1	0.02	0	0.01	0.00	0.05	0.03	-			
8	Experience	14.43	11.74	0	56	0.03	-0.24	0.02	0.00	0.00	0.05	0.05	-		
9	Instrument employee	0.12	0.33	0	1	0.02	0	0	0.12	0.00	-0.06	0.06	0.00	-	
10	Citations	98.77	159.74	0	1616	0.33	0.06	-0.05	-0.04	0.26	0.00	-0.04	0.25	-0.04	-
11	Centrality – off site	13.16	15.11	1	222	-0.18	0.36	-0.01	-0.06	0.03	0.02	-0.1	0.06	-0.05	-0.03

Table 4. Changes between subsequent observation periods

Period	Tie formation	Tie retention	Jaccard Index	Avg. Degree
2006-2007	3534	2109	0.374	3.78
2007-2008	3645	5643	0.608	6.22
2008-2009	2473	9288	0.790	7.89
2009-2010	2783	11761	0.809	9.74
2010-2011	5105	14544	0.740	13.12
Total	**17540**	**43345**	**-**	**-**

Table 5. SIENA Estimation Results: Coevolution of co-authorship ties and Performance

Submodel	**Parameter**	**MC Estimate**	**SE**	***p***
(A) DV: Co-authorship ties	**Centrality**			
Hypothesis 1	*Off site*	0.56	.12	<.001
Hypothesis 2	*On site*	- 0.43	.04	<.001
	Controls: Network			
	Triadic closure	1.02	.03	<.001
	Prior collaboration	3.90	.03	<.001
	Prior degree 2 collaboration	0.75	.05	<.001
	Controls: Characteristics			
	Experience	0.00	.00	<.001
	Gender	-0.01	.00	<.001
	Citations	0.21	.03	<.001
	Instrument employee	0.45	.04	<.001
	Rate function			
	Rate period 06-07	3.35	.05	<.001
	Rate period 07-08	3.01	.04	<.001
	Rate period 08-09	1.82	.03	<.001
	Rate period 09-10	1.90	.03	<.001
	Rate period 10-11	3.16	.05	<.001
(B) DV: High Impact Science	**Centrality**			
Hypothesis 3	*Off site*	1.51	.48	.037
Hypothesis 4	*On site*	-0.80	.41	.070
	On site sq.	0.28	.14	.121
	Controls : Characteristics			
	Experience	0.02	.00	<.001
	Gender	-0.13	.15	.374
	Citations	0.45	.06	<.001
	Citations average alter	0.81	.14	<.001
	Rate function			

Rate period 06-07	0.79	.09	<.001
Rate period 07-08	0.71	.06	<.001
Rate period 08-09	0.41	.03	<.001
Rate period 09-10	0.39	.03	<.001
Rate period 10-11	0.30	.02	<.001
Time Dummies	Yes		

N=2906

Table 6. Odds ratios of coefficients

	Co-authorship ties	Performance
Centrality		
Off Site	1.46***	2.58***
On Site	0.38***	0.50
On site squared		-0.28

CHAPTER 3: DEFLECTED EFFORTS: HOW CO-AUTHORS' EFFORT ALLOCATION INFLUENCE SCIENTISTS' PERFORMANCE

(Submitted to Research Policy)

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Deflected efforts: How co-authors' effort allocation influence scientists' performance

ABSTRACT

Despite the abundance of studies on collaboration in scientific communities and the related benefits, we still know relatively little about how scientists' performance is affected by their collaboration partners' activities outside of the joint project. Collaboration is an essential part of the production of science, and collaboration partners are important for individual scientists' performance. In this paper, we analyze how an individual scientist's performance is affected when her collaboration partners become more central in the scientific community. We argue that when collaboration partners become involved in many or big projects, it is likely to take a toll on these partners' effort allocation to each project, which in turn may lead to a negative spillover effect for the focal scientist in terms of lower performance. These arguments are tested using unique data on 12,023 observation consisting of 1,553 scientists collaborating on 4,433 papers within the scientific community associated with a large-scale research institute. We find empirical support for a negative spillover effect from collaboration partners' increased centrality in the scientific community. We also find that the negative spillover effect increases with increasing demands on the collaboration partners' efforts. In contrast, we observe that the extent of knowledge domain overlap in the focal project decreases the negative effect.

Key words: collaboration, effort allocation, knowledge domain, scientist, centrality, individual performance

INTRODUCTION

How are individual scientists' performance affected by their collaboration partners' activities outside of the collaboration? Scientific work is increasingly a collaborative effort due to the growing depth and complexity of scientific knowledge and the associated benefits of bringing together individuals with complementary skills (Wuchty et al., 2007; Uzzi et al., 2013). The increase in scientific collaboration raises the question of how an individual scientist's performance is affected by the co-authors in her team. Recent studies focus on the effect on individual scientist's performance of team size (Wuchty et al., 2007), star co-authors (Oettl, 2012), and team composition across a range of dimensions (Jones et al., 2008; Wagner et al., 2019; Bercovitch & Feldmann, 2011; Uzzi et al., 2013). We complement and extend these insights by exploring how individual scientists are affected when their collaborators become more or less central in the scientific community.

As science increasingly relies on teams to produce new insights (Wuchty et al., 2007), each individual scientist and her collaborators are likely to become more tightly knit in research communities bound together through networks of collaboration. Authors engaged in many projects or with many and well-connected co-authors are central in these collaboration networks (Bonacich, 1987). Prior work has indeed shown that network centrality and performance is closely related in science. Although the relationship is complex and endogenous, researchers have managed to identify an inverse u-shaped relationship between centrality in scientific networks and performance. It has further been established, that for the majority of scientists, network centrality leads more publications as well as more citations (Rotolo & Petruzzelli, 2013; Badar et al., 2016; Badar et al., 2015). The direct link between centrality and performance of individual scientists is therefore well established, but what happens when scientists' *collaboration partners* increase or decrease their centrality? Do focal scientists benefit when their collaboration partners increase their centrality, or does their performance remain unchanged? We might even expect that as collaborators become more central in the scientific community, they face more demands on their research efforts. Recent work has argued that engaging in too many different projects and tasks can lead to cognitive overload and difficulty in deciding where to allocate attention (Hansen and Haas, 2001; Haas et al., 2015). Work on multiple team membership also suggest that it may lead to issues with allocating attention and effort (O'Leary et al., 2011; Schultz et al., 2013). Hence, we might expect collaborators to expend less effort on each project (O'Leary et al., 2011; Schultz et al., 2013), which in turn will lead to negative spillovers for the focal scientist.

Multiple team membership is generally considered to provide individuals and firms with an advantage in terms of productivity and learning (O'Leary et al., 2011), and centrality in collaboration networks is associated with status and access to resources (Cattani & Ferriani, 2008). Yet, we know little about the spillover effects when scientists' co-authors change their position in the collaboration network. In this paper, we propose and show that individual scientists' performance suffers when their co-authors' centrality in the collaboration network increases. We argue and test that this result stems primarily from co-authors' spread in effort allocation and that the negative effect is reduced, when the co-author team shares a knowledge domain. Our contribution therefore lies in getting a better understanding of how individual scientists are affected by co-authors' centrality in the scientific community when scientists are members of multiple co- author teams. We build on and extend work on both multiple team memberships, as well as the relationship between centrality and performance. Until now these two streams of literature have been considered in isolation. We connect these two streams of literature and propose that individual scientists may suffer negative spillovers if their co-authors are engaged in multiple projects.

We test our theory on 12,023 observations of 1,553 scientists collaborating on 4,433 papers in a scientific community connected to the Oak Ridge National Laboratory in the US. In this research community, collaboration among scientists on joint papers is the standard way of working, and the supersized papers associated with other large-scale research facilities such as CERN in Switzerland are rare (D'Ippolito & Rüling, 2019). To deepen our understanding of the mechanisms at play, we interviewed scientists affiliated with the research community.

SPILLOVER EFFECTS FROM CO-AUTHORS' CENTRALITY CHANGE

The dramatic growth in knowledge production (Fortunato et al., 2018) has led to increased specialization where scientists congregate in research communities focused on specific disciplines and topics (Shwed &

Bearman, 2010), and also pursue a high degree of individual specialization within these research communities (Fortunato et al., 2018). With increasing specialization, scientists are forced, or motivated, to collaborate, leading to an increase in the number and size of teams (Wuchty et al., 2007). Each scientist in a collaboration has certain skills which can be deployed to undertake a range of tasks. Skills and tasks can, for example, be related to framing the paper, conducting experiments, making theoretical calculations, empirical analysis and writing of the paper. These are all time-consuming tasks associated with non-interchangeable skillsets. Each scientist is likely to be member of several such co-author teams at any given time and must therefore balance effort allocation across these papers.

Multiple team memberships and effort allocation

Scientists seldomly work on only one project at a time. As scientists collaborate, they rely on each other and a focal scientist may sometimes be unable to work on any particular project while she waits for others to complete parts of the project or while the project undergoes scientific peer review. The ebb and flows, bottlenecks and uneven time-pattern to the work on any project, mean that if scientists worked on only one project, they would be "directly inefficient", instead, multiple team memberships increase utilization maximization (O'Leary et al., 2011). But this is not without drawbacks, working on multiple projects with multiple teams imposes a whole new set of challenges pertaining to coordination and effort allocation. Whether scientists work on projects sequentially (one project at a time, not commencing the next project before the first one is finished) or in parallel (contributing to more than one project on any one day/week/month); they will have to allocate their effort across projects. Although individuals at times can extend their work hours, it is fair to assume that any one person's work time is finite in the sense that even the most dedicated scientist cannot exceed her workday indefinitely (O'Leary et al., 2011; Schultz et al., 2013). Whether the allocation is a matter of how to divide the hours of a workday between two projects, or a matter of when to submit one project and move on to a new project, a scientist must decide how to allocate the finite work time. Hence, if a scientist increases the number or size of their collaborative projects, they will on average have less effort to expend on each project. This may be a good strategy for the individual scientist and increase her impact in the scientific community, but our interest here is in the spillover effects of co-authors' collaborations. From this perspective, it is not necessarily in a scientist's best interest that her collaborators increase their centrality in the collaboration network; if this leads to an increase in the number or size of projects that the collaborators work on and the associated cost is a greater workload.

Effort allocation across teams

Prior research on status shows that social dynamics work in intricate ways, that affect collaboration patterns (Dahlander & McFarland, 2013), assessment of the quality of a scientist's work (Merton, 1968, 1973; Azoulay et al., 2013), and spillovers across "neighbors" working in the same field (Reschke et al., 2017). However, we do not know if scientists are similarly affected by ripple effects caused by changes in collaboration partners' centrality. Scientists and their co-authors can increase centrality in the collaboration network by increasing the number or size of their collaboration projects, or they can engage with collaboration partners with higher centrality in the community (Bonacich, 1987). If a scientist's co-author increases the number of collaboration projects in their portfolio, or alternatively increases the size of the projects they work on, this will increase the pressure on their effort allocation (O'Leary et al., 2011). As a result, the co-authors will on average have less effort to allocate to the joint project with the focal scientist. Co-authors can also increase their centrality through collaboration with scientists that are central to the research community. Even if co-authors work on as many and as big projects as usual, but start to work with co-authors that are more central in the network this will also require substantial effort. Very central collaboration partners are typically very busy, but likely have excellent access to resources (Cattani & Ferriani, 2008). While this means that they will contribute with contacts and resources in a collaboration, they will in turn also expect their collaboration partners to exert themselves and put a lot of effort into the project (Castellucci & Ertug, 2010). For our focal scientists the consequence is the same: collaboration partners are likely to have less effort to allocate to the joint project regardless of whether they increase their centrality through an increase in project number, project size or increase the centrality of their co-authors.

Based on the premise that the amount of effort to allocate across papers is finite, an increase in activity level is likely to stretch any scientist's efforts thin. This may not bear any negative consequences for the effort stretching scientist who simultaneously increases her pipeline of papers, but what about the scientists working with her? An example is a scientist (our focal individual in this example) collaborating with two co- authors on a paper. If these co-authors increase the number or magnitude of papers that they work on; they will have less effort to allocate to the joint paper. The focal scientist must either deliver on her co-author's obligations or must accept that the paper is delayed or diminished in terms of quality, and it is likely that the impact of the paper and thereby her performance will suffer from the co-author's deflected efforts. This is a negative spillover effect for the focal scientist who gains nothing from these extra projects her co-author works on, but instead suffers from the decrease in effort spent by her co-author on the joint project. This logic can also be reversed: when the centrality of co-authors decreases, the available effort to deploy across their remaining projects increases. Everything else equal, when co-authors invest more effort on the joint project; this is likely to benefit the focal scientist.

Consequently, a scientist's co-authors' allocation of effort across papers may conflict with the interests of the focal scientist. Within the field of science production, we can expect this trade-off to appear as a choice of effort allocation between papers. Co-authors' increase in network centrality will therefore lead to a negative spillover on the focal individual's performance. Hence, we hypothesize accordingly:

Hypothesis1. *An increase(decrease) in co-authors' centrality in the collaboration network has a negative(positive) effect on the focal scientist's performance.*

Collaboration and Effort Allocation

If the negative spillover effect from co-authors' increased centrality is indeed caused by an increase in pressure on co-authors' effort allocation, we should expect the effect to increase with co-authors' increasing workload. One factor that significantly increases pressure on collaborators' effort allocation is if they simultaneously work on more/bigger and at the same time more impactful projects (Bendersky & Shah, 2012). In our setting, co-authors' effort allocation is therefore challenged the most when they simultaneously increase their centrality and are involved in papers aimed for high impact. Such ambitious papers require much more effort than mundane publications. In the particular field of science in our setting, the time invested in complex, ambitious papers is ten times that invested in less complex papers. When co-authors increase both centrality and impact it will intensify their effort allocation trade-off across papers and thereby reinforce the negative relationship between co-authors' changing centrality and the focal scientist's performance. In sum:

Hypothesis 2. *The negative effect on the focal scientist's performance of co-authors' increase in centrality is reinforced when co-authors' also increase in scientific impact.*

Knowledge domain overlap

The field of science has seen an increase in international collaboration (Wagner et al., 2019; Glänzel & Schubert, 2001) and increasing focus on interdisciplinary collaborations (Uzzi et al., 2013). This presents an interesting dilemma: Collaboration across national, organizational, institutional and knowledge domain boundaries have proven particularly useful and at times even necessary to address grand challenges and also tends to increase scientific impact (Jones et al., 2008). At the same time, it has also proven difficult and collaboration that spans boundaries has proven to be particularly demanding (Bercovitch & Feldman, 2011). Particularly, successful collaboration across knowledge domains requires participants to exert extra effort in order to pay attention to new information and integrate knowledge across boundaries (Uzzi et al., 2013).

The increasing tendency towards specialization means that even within research communities, scientists focus on different knowledge domains and specializations. Scientists affiliated with a large scale research institute may, for example, come from the knowledge domain of chemistry (creating materials such as crystals and liquids), experimental physics (conducting experiments), theoretical physics (modelling), or even biology and medicine (D'Ippolito & Rüling, 2019). Typically, co-author teams encompass scientists from different knowledge domains with different skills, specialized in undertaking the various tasks necessary to craft a scientific contribution. Each co-author team consequently experiences some degree of cognitive spread (Nooteboom et al., 2007). This can even manifest as cognitive overload (Bawden & Robinson, 2009) in the sense that each co-author must exert substantial effort to communicate across knowledge boundaries and facilitate collaboration.

We propose that the cognitive spread of a co-author team is likely to influence effort allocation in two ways: First, being part of a team with a high degree of cognitive spread challenges co-authors' effort allocation. Because co-authors from different knowledge domains face high communication and coordination costs (Bercovitz & Feldman, 2011; Vural et al., 2013; Taylor & Greve, 2006; Leahey, Beckman & Stanko, 2017). Team diversity also presents a challenge to integration of knowledge (Dahlin, Weingart & Hinds, 2005). When effort allocation is already under pressure, this may present a problem. Co-authors suffering from challenges pertaining to effort allocation issues will lack the time to invest in communication, collaboration and knowledge integration across the boundaries of specialized knowledge domains, and at the same time, the variation in skills inhibits other co-authors from picking up the slack. Consequently, scientists involved in projects that span multiple knowledge domains are more likely to experience a negative influence on their performance if co-authors have an increase in their workload.

Second, a high degree of knowledge domain overlap amongst collaborating scientists can potentially moderate the negative effect of co-authors' effort allocation. Scientists with greater knowledge domain overlap share scientific perspectives and language, which in turn facilitates effective collaboration (Reagans & Zuckerman, 2001; Wuyts et al., 2005; Nooteboom et al., 2007). Furthermore, in co-author teams with high knowledge domain overlap, each scientist will likely tap into the very core of her skillset and reproduce already known knowledge. Such efficiency-oriented collaborations are much more robust towards the effort allocation pulls of multiple team memberships than more explorative activities (O'Leary et al., 2011).

Hence, we propose that overlap in co-author teams' knowledge domains is likely to positively moderate the negative relationship between co-authors' increased pressure on effort allocation and the focal scientist's performance. We do not claim that teams with a shared knowledge domain are superior to diverse teams, rather, we propose that when team members have overlap in the primary knowledge domain, collaboration is less challenged, and they can in effect substitute for each other and as a result continue to work on the project even if a co-author is expending efforts on other project. As a result, the focal scientist's performance will be less affected by the co-authors' increase in network centrality. In formal terms:

Hypothesis 3. *The negative effect on the focal scientist's performance of co-authors' increase in centrality is positively moderated by the degree of knowledge domain overlap in the co-author team.*

EMPIRICAL CONTEXT

We test our hypotheses about the association between co-authors' increase in centrality and the focal scientist's performance using a sample of 12,023 observations based on 4,433 papers by 1,553 scientists in the scientific community affiliated with the large-scale research institute Oak Ridge National Laboratory in the period 2007 to 2011. Delimiting our sample by using scientists' affiliation with a large-scale research institute such as Oak Ridge National Laboratory ensures that the scientists and papers are relatively compatible, that their typical mode of collaboration are in line with our theory and that the sample of papers and scientists is from a comparatively cohesive scientific community. Contrary to work by, for example, Wuchty and colleagues (2007) or Fortunato and colleagues (2018); we are not only interested in team composition and collaboration outcomes, but also interested in collaboration spillover effects. We therefore need to focus on one scientific field and one research community to ensure that norms and forms of collaboration are comparable across teams.

We measure collaboration as co-authorship. Co-authoring papers is a powerful indicator of scientific collaboration, and co-authorship networks are also useful for understanding the characteristics of a discipline or research site (Katz & Martin, 1997; D'Ippolito & Rüling, 2019). One concern is that performance and centrality are closely related. To mitigate this issue, we utilize the longitudinal structure of the data to separate selection and influence (Borgatti & Halgin, 2011): We observe changes rather than absolute levels in both centrality and performance (while we control for absolute levels), add a time lag, and control for the level of all key variables in order to reduce endogeneity issues (Echambadi et al., 2006).

The Oak Ridge National Laboratory

The Oak Ridge National Laboratory was established in 1943 and is the largest research laboratory under the US Department of Energy. Both basic and applied science activities are conducted in the areas of neutron science, biological systems, energy and high-energy physics, material science, supercomputing, and national security. The Neutron Sciences Directorate has managed the research program in neutron science since 2006. Our analysis focuses on scientists affiliated with the Spallation Neutron Source (SNS), which came into operation in 2006, and the High Flux Isotope Reactor (HFIR), which underwent a major renovation and reopened in 2007. Affiliation with SNS and HFIR are available to scientists of all nationalities based on evaluation of research proposals by an independent council of scientists.

Co-author teams affiliated with Oak Ridge predominantly consists of small groups[6] where all authors contribute directly to the paper. Solo publications are rare within the research field and hence the setting is ideal for observing spillover effects across collaborators. Second, allocation of beam time at this kind of facility is competitive and the visiting scientists are at the top of their field (D'Ippolito & Rüling, 2019). Finally, publishing within this field of natural science is fast. Simple experimental results can be published in a matter of months while it typically takes a year or two to develop ambitious papers based on more than one experiment. Scientists in this field typically have higher publication rates than within e.g., social sciences.

[6] We want to avoid co-author teams that are too big so that we ensure direct interaction among all involved scientists in the teams that we observe.

All of these characteristics make a large scale research institute such as Oak Ridge an optimal setting in which to observe the performance effects of collaboration partners' change in centrality.

In order to get a better understanding of the setting, we conducted six interviews with scientists that have been affiliated with Oak Ridge National Laboratory. Table 1 provides a full overview of the interviews. The scientists were identified by looking at publications in our data set. Our initial contacts then referred us to other colleagues affiliated with Oak Ridge.

---- TABLE 1 ABOUT HERE ----

The interviewees corroborate extant studies of large scale research institutes (D'Ippolito & Rüling, 2019) and science in general (Dahlander & McFarland, 2013) and unanimously described their field as driven by a need for collaboration. Single authored papers are rare and typically limited in scope and impact. They also describe a clear division of labor, where each co-author on the team has relatively well defined and non-overlapping tasks at the outset. If one or more co-authors fail to deliver, the rest of the team must either deliver on those tasks, publish a less impactful paper with fewer experiments, without theoretical calculations or with an inferior analysis, or in the worst-case scenario abandon the project. Either outcome would negatively affect the potential publication outlets and impact of a paper. The structure of the research field is reflected in the author order. The first author(s) listed on the paper conduct the main experiment, the last person listed is the senior scientist overseeing the work, and all authors listed in the middle of the author list contribute either with small, additional experiments, graphs, calculations, advice or analyses, or by securing funding for the paper. The first author(s) typically delivers approximately 50% of the work on the paper, while all "non-first" authors each typically deliver an effort roughly equivalent to 10-20% of the work on the paper. The 10-20% amounts to several months of work for each junior scientist. It is uncommon to list authors who have not actively participated in the work on a paper, but it is not uncommon that the first author(s) has written most of the paper based on input from the entire co-author team. This is usually the case if the junior scientist on the team writes well. If not, the write-up task falls on one of the other junior scientists or the last author, i.e., the senior scientist overseeing the experiment.

Collection of Empirical Data and Data Description

We collected a list of all peer-reviewed publications affiliated with the SNS and HFIR instruments at Oak Ridge from the Neutron Sciences Directorate website from the period from initiation and restart after renovation of the facilities in 2006/2007 until 2011. We retrieved information on each paper from SCOPUS, identified all the affiliated scientists and utilized SCOPUS's unique author identifier to retrieve a full bibliographic record of each scientist including their 196,302 publications not affiliated with Oak Ridge. Since our objective is to study the effects of change in co-authors' centrality, we excluded publications with only one author or an abnormal number of authors from our main analyses (Mean+2SD). We exclude one-off authors, i.e., authors only appearing on publications affiliated with the large-scale research institute in one year, we also exclude 1,462 observations due to lack of information[7]. Our final sample which we base our analyses on consists of 12,023 observations of 1,553 scientists collaborating on 4,433 papers.

Dependent variable. We are interested in how co-authors' change in network centrality affects a focal scientist's performance. In science, academic impact is a good measure of performance and follow prior studies and use quality-adjusted citations as an indicator of performance in guise of scientific impact (see Dahlander & McFarland, 2015; Azoulay et al., 2014; and Reschke et al., 2017 for similar measures of academic performance). Specifically, to ensure that citations are weighted according to quality of the journal and citation practice of the specific journal, we multiply the count of citations received by each publication by the publication outlet's snip value (Source Normalized Impact per Paper, see Cross, 2010). The main benefits of using snip rather than impact factor is that the snip measure was designed to account for differences in publication patterns across scientific fields and that journals have a snip value even when they

[7] For approximately 10% of the sample we lack information on the year of first publication, year of entry at the facility, and scientists' primary knowledge domain.

have not been assigned an impact factor, hence, the snip value is tailored to the journal field and available for most potential outlets (Cross, 2010). We are therefore able to calculate performance change based on even publications in low ranked outlets. To capture the effect of change in co-authors' centrality for a scientist's performance, we construct a variable that takes into account both the focal scientist's average performance level and the influence of the specific team of co-authors. We calculate the distance between the scientist's average performance in $year^{t}$ and the performance of each paper a scientist publishes in $year^{t+1}$. This calculation produces a unique value for each scientist-paper combination that accounts for how the co- authors allocate their effort on each paper and the resulting influence on the focal scientist's performance. This is our unit of observation and reflects how the composition of co-authors affects the performance of the focal scientist on each publication.

Key independent variables. Co-authors' centrality change is measured as Bonacich centrality because this measure encompasses both the number of ties held by the focal scientist and the centrality of those to which he or she is connected (Bonacich, 1987). For each scientist-publication combination, we measure the average change in co-authors' centrality from $year^{t-1}$ to $year^{t}$. Co-authors' centrality change is measured for the period prior to the period used to measure the focal scientists' performance change. Without in-depth insight into the process behind the creation of each paper, this time lag should capture as much as possible of the delay from collaboration on a paper to publication of the results. Figure 1 shows the logic behind this lag between independent and dependent variable.

--- INSERT FIGURE 1 ABOUT HERE ---

To control for whether the hypothesized negative effect of change in co-authors' centrality is due to their allocation of effort on other papers, we include a variable measuring co-authors' change in performance from $year^{t}$ to $year^{t+1}$ (i.e., co-authors' performance change)[8]. This measure captures whether co-authors are involved in papers that aim for high impact in the same period where they work on the focal paper. We are aware, that not all high aiming papers will be published in top outlets and receive high citation counts. However, in this research field, an ambitious design that involves many experiments and complex analyses, is often a precondition for high scientific impact. Our measure therefore captures only part of the papers designed for high impact, namely the successful ones. It is thus a conservative measure and if anything; this will reduce the likelihood of finding a significant moderating effect.

Regardless of whether co-authors work on competing papers in the same period as the focal publication or sequentially; high impact publications are likely to pull co-authors away from the focal paper. If co- authors undertake other papers simultaneously as the focal publication it divides their attention. If other papers are undertaken sequentially it shortens the time-period co-authors allocate to the focal publication.

To measure co-author knowledge domain overlap, we use each scientist's publications to identify their primary knowledge domain. Based on this, we construct a Herfindahl-Hirschman Index (HHI) of concentration of co-authors' primary knowledge domain for each publication. The index varies between 0 (no overlap in co-authors' knowledge domain) and 1 (complete overlap in co-authors' primary knowledge domain).

Control variables. We control for the focal scientist's centrality level in $year^{t}$ measured as Bonacich centrality (Bonacich, 1987), the focal scientist's centrality change from $year^{t-1}$ to $year^{t}$, and to comply with standard practice for multilevel models we also control for the focal scientist's centrality change from $year^{t-1}$ to $year^{t}$ centered around the co-author team average. To control for the focal scientist's performance we include; the focal scientist's performance level in $year^{t}$ (3-year window); the focal scientist's performance level in $year^{t}$ centered around the co-author team average; the number of papers published by the focal scientist in $year^{t+1}$. We also control for whether the focal scientist is the team star in terms of quality adjusted

8 We also control for the number of publications co-authors publish that year.

citation performance (3-year window), as the highest performing scientist in a team of co-authors likely will "pull up" the remaining co-authors. Finally, the analyses include a control for whether the focal scientist is in the top 5% of the quality adjusted citation distribution, measured in a three-year window. A range of demographic variables are also included: the focal scientist's tenure in science measured as the number of years since first publication; gender; the year of affiliation with the large scale research institute; and whether the scientist is employed by a university, a private or public research organization or directly at Oak Ridge National Laboratory. To control for status by affiliation we also include a control for whether the scientist is employed at a university in the global top-50 (according to the Times Higher Education Ranking, 2017). A control for whether the focal paper is published in a top journal (top 5% journal snip value) is also included. We also control for co-authors' number of other publications in the same year as the focal publication (year^{t+1}). At the team-level, we control for the number of authors on the focal publication to capture citation inflation caused by co-authors referring to or promoting the paper. Table 2 shows the descriptive statistics and pairwise correlations.

---- TABLE 2 ABOUT HERE ----

MODEL CHOICE

In our data, scientists are nested in co-author teams. These teams are not randomly assigned, and it is therefore highly likely that selection into co-author teams reflects scientists' ability and affects performance outcomes. Hence, any analysis aimed at addressing the effects of co-authors on the performance of the focal scientist must address this selection. Regular regression techniques will ignore variation across co-author teams– i.e., that some teams have higher ability than others (Albright & Marinova, 2010). Standard errors will be artificially small and could lead to incorrect inferences[9]. Instead we estimate a multi-level model, which produces both adjusted standard errors and estimates between-group variance (Szmaragd & Leckie, 2010). The benefit of a multilevel model is the use of random variables to model between-group variation (Szmaragd & Leckie, 2010). This helps us account for selection of collaboration partners, and allows us to separate the effects of selection into co-author teams from the influence of our key variables. A multi-level model fits separate regression lines with random intercepts for each team, to account for the different ability levels of co-author teams. In our population, a vast part of the variation is explained by selection into groups, and in this paper, we focus on explaining the remaining part, i.e., the spillover effects within co-author teams. We have no theoretical reason to believe that regression slopes should vary across co-author teams, and the average team size is small, hence we specify a mixed model with random intercepts, but not with random slopes, for each team (as recommended in Szmaragd & Leckie, 2010). The fixed part of the model estimates the effect of change in collaboration partners' centrality for the performance change of the focal scientist. The parameters of the fixed part of the model are estimated with a standard OLS specification.

FINDINGS

We follow a hierarchical estimation strategy suitable for multi-level models (see Schyns, 2002 for an example of this approach to multilevel estimation), the results are displayed in table 3. First, the empty model is estimated, controls are added in model 2, key independent variables in model 3, and interaction effects are added in models 4, 5 and 6. Model 1 shows only that selection into teams accounts for 80% of variation found in the data. Our analysis focuses on explaining the remaining 20%. Hypothesis 1 is tested in model 3 and in models 4, 5 and 6. In model 3, the relationship between co-authors' centrality change and the scientist's

[9] One option is to use co-author team dummies to capture the effect of selection, but because we cannot expect many co-author teams to produce more than one paper with an identical composition of co-authors, a fixed effect model is not a viable solution. Such a model would also include estimation of a large number of additional parameters in the model and the effects of group-level predictors will not be estimated together with group residuals. To fit a single-level model with group level predictors is also not a viable option, because even though it would correct standard errors (adjusted for clustering), the degree of between-group variation would not be assessed.

performance is significant and negative: A one unit increase in co-authors' centrality results in a performance decrease of 131 quality adjusted citations for the focal scientist. The mean performance change is a 28.99 increase in quality adjusted citations from the previous year's average, and co-authors' centrality change therefore have a substantial effect on the focal scientist's performance. This finding supports hypothesis 1. Hypothesis 2 is tested in models 4 and 6 with the inclusion of the interaction between co- authors' change in centrality and co-authors' performance change. In both models the estimated coefficient is negative. Based on model 6, a one unit increase in co-authors' performance change corresponds to a 0.002 decrease in quality adjusted citations for the focal scientist, which does not seem as much. However, mean co-author performance change is the quality adjusted citations of all co-authors, which may increase dramatically, when one or more co-authors publish a high-impact paper, and consequently, the impact on the focal scientist is not negligible. This supports the hypothesized relationship that co-authors' effort allocation to other, high performing papers increases the negative relationship between co-authors' centrality increase and the focal scientist's performance change. Hypothesis 3 is tested in models 5 and 6. Neither model shows a direct effect of the concentration of co-author teams' primary subject field, which is in line with extant findings that some papers benefit from diversity in knowledge domains while others don't (see Bercovitz & Feldman, 2011 for a review). As hypothesized, we find a positive interaction effect between the concentration of the co-author teams' primary subject field and co-authors' centrality increase. In model 6, the marginal effect of the interaction between co-authors centrality increase and team concentration of knowledge domains corresponds to an increase in 308 quality adjusted citations for the focal scientist. We test this effect against the negative main effect and find that the moderating effect reverses the negative relationship. This means that when the focal scientists work on papers with a high degree of knowledge domain overlap, co-authors' increase in centrality results in a net benefit in terms of more quality adjusted citations.

---- TABLE 3 ABOUT HERE ----

The control variables show that tenure in science, the scientist's gender (male), the number of papers published, the number of co-authors on the publication and the number of papers published by co-authors on the focal publication in the same period all have a positive relationship with the focal scientist's performance. The focal scientists' performance level, the performance level centered around the co-author team mean, if the focal scientist is the star performer on the co-author team, and the focal scientist's centrality change all have a negative relationship with the focal scientist's performance. The other control variables have no significant effects.

ROBUSTNESS CHECKS

We conduct several robustness checks. First, we test if our results are affected by certain control variables or omitted variables. Our main analyses include many controls, and several controls are constructed from other measures included in the analysis. To ensure our results are not driven by any of the control variables in the main model, we estimate models with limited sets of controls. We further add interactions between co-authors' increased centrality and publication in a top journal and the focal scientist's own centrality: both are insignificant. Finally, we conduct robustness tests with cut-off points for top performance at 1% and 10% and also test for interaction effects. In all these tests, the results remain unchanged.

Second, we investigate whether our sampling decisions influence the results in the main models. We limit our sample to scientists working in co-author teams of three people or more and four people or more, the results remain unchanged. We include scientists working in very large teams (17 co-authors or more) and the results remain, though with slight changes in significance levels. To be sure, we do not theorize about spillover dynamics in these very large teams of co-authors. Collaboration dynamics vary substantially across papers with e.g., 5 and 55 co-authors and we do not interpret this robustness check as an opportunity to generalize our findings to large teams. We also test the robustness of our findings by excluding all observations where the centrality change of co-authors is negative. This reduces our population substantially, but only affects the findings in terms of reduced significance levels. We also run the models excluding the three variables with missing values on three variables (tenure in science, year of entry at the facility, and primary knowledge domain) and thereby increase our sample. Again, the results that we can test with this reduced sample remain consistent.

To ensure the results are not affected by multicollinearity, we calculate variance inflation factors for all models. The maximum VIF value for any variable is 7.3 and the maximum for the average VIF is 2.1. This is well within the limit of concern for multicollinearity. Finally, we construct a model in SIENA (Steglich etal., 2010; Snijders et al., 2010) that resembles model 3 as much as the SIENA framework permits. The SIENA model addresses network endogeneity resulting from the structural properties and history of the network. The results of this model are similar to our main findings.

DISCUSSION

In this paper, we set out to get a more nuanced understanding of the relationship between co-authors' centrality change and scientists' performance in scientific collaborations. In particular, we examine how scientists' performance is affected when their co-authors become more central in the scientific community. Our findings show that a scientist's performance suffers, when co-authors increase their centrality, and further indicate, that the negative spillover effect is likely caused by spread in effort allocation. Specifically, we find that the negative effect on the focal scientist's performance increases, when co-authors simultaneously increase their centrality and performance. We further find that when working within the same knowledge domain, the negative spillover effect of co-authors' increased centrality is not merely moderated, but even reversed, resulting in a net positive effect on performance for the focal scientist. In this section, we build on the insights from prior literature on centrality and performance as well as our interview insights, to elaborate on the contribution of our findings.

The ripple effect of co-authors' effort allocation

That effort allocation creates spillover effects among co-authors resonates with the insights from our interviews. The interviewees emphasized the negative spillover that affects the progress and quality of a paper, when one or more co-authors are unable or unwilling to allocate sufficient attention to that paper. One effort allocation issue pertains to the situation where one of the ordinary co-authors (in the middle of the author order) fails to deliver results in a satisfying or timely manner (e.g., on a sub-experiment or theoretical calculations). In this case, it may be possible to find another (second best) scientist to contribute, but this will delay the publication process. Alternatively, the other authors may decide to go ahead without the missing piece, which will reduce the potential impact of the paper in terms of where it can be published and the number of citations. One scientist describes this situation: *"If one set of scientists – for example the theoretical physicists – loose interest in the paper, then we have to do it ourselves….or you just have to publish the data and then hope someone else will calculate the models. But then we are not looking at Science (top journal outlet). Then we just go a step down…it is a trade-off between finishing and the level of ambition."*

Another issue may be that the senior scientist on a paper (last co-author in the author order) becomes a bottleneck and thereby slows down the progress of the publication process. For example, one successful senior scientist we spoke to said: *"The most important thing I have to do, primarily because I have so many people working for me – about 12 in all – is to ensure that I don't become a bottleneck on the papers."* There are two likely outcomes of such a situation, if the senior scientist does become a bottleneck; either the paper is delayed until the senior scientist can allocate time to complete the task, or one or more of the junior scientists take on the tasks and do their best to fill the role (i.e., write up the analysis). Sometimes the junior scientists grow with the responsibility and the papers is published timely though perhaps in a suboptimal form, in other cases they do not. In either case co-authors will experience a negative spillover effect of their co-authors' effort being allocated elsewhere.

Often, successful senior scientists are crucial to produce high impact research. The scientists we spoke to explained how input from a star co-author had elevated their papers *"Sometimes it is great to have one of the big shots on the paper, for example (name of senior co-author). He just came in and said if we do like this and this then there is really something about this (paper)."* They also illustrated how the absence of senior attention had made it difficult to complete papers or even led them to abandon papers: *"If the professor is not paying attention, then you don't get very far. At least not as a Ph.D. student. Perhaps as a post-doc you are more independent."*

Performance effects of co-authors increasing both centrality and performance

In the analyses, model 6 demonstrated, that the negative effect on the focal scientist's performance increases, when co-authors both increase in centrality and performance. This result suggests that the mechanism driving the negative spillover effect relates to co-authors' effort allocation: Co-authors that becomes more central to the research community will have more opportunities available (Gould, 2002; Sterling, 2014); opportunities that will make demands on their time. If they are simultaneously involved in the time-consuming endeavor of publishing high impact papers (other than the focal paper), these co-authors will find it difficult to honor all their obligations. Figure 2.a. shows the marginal effect of this interaction effect. If the focal paper is published in a top journal, the intercept shifts upwards and the marginal effect remains positive for the whole distribution. Our interviews offer insights into the behaviors creating these distributions.

Reflecting on *their own allocation of effort*, the scientists we interviewed all emphasized that when choosing where to allocate their effort, they prioritized the most promising papers in terms of impact, and the papers that they believed would make the most progress; in other words, the papers prioritized by senior co-authors and first authors. Reflecting on the *effort allocation of their co-authors*, several scientists emphasized that the papers with the potential to become high impact papers were a major drain on their co-authors time. One scientist thought of this as a priority conflict: *"You can usually feel when (co-authors) are busy. It can be* *difficult to meet expectations. And of course, you understand if they are working on the Nature (top journal outlet) article then that is just how it is."*

-- FIGURE 2 ABOUT HERE --

This is in line with another insight from the quantitative analyses; namely that the co-author team is the most important determinant for performance. This may be because scientists cannot reverse investments into a paper once they have been made. This is a classic issue in team production, i.e., that team members' investments are sunk costs, and that their performance therefore depends on team composition and effort allocation (Bercovitz & Feldman, 2011; Groysberg & Lee, 2008; Bercovitz et al., 2017). This is a likely explanatory factor for why prior research has observed strong preferences for repeat collaboration in project based settings (Sorenson & Waguespack, 2006), and why scientists hold strong preferences for repeat collaboration with co-authors that they have had successful outcomes with in the past (Dahlander & McFarland, 2013).

Positive spillovers in co-author teams with shared knowledge domains

All our interviewees explained, that the papers that involve many knowledge domains are the most complex and hence take longer to complete. One successful senior scientist highlighted the challenges associated with cross disciplinary papers: *"You have to get used to the fact that you only understand about half of what is going on, but at the same time you cannot just relax, but instead have to try and understand how you can help each other. That is difficult and it is hard for the younger researchers to learn. It is difficult to work across disciplines."* Another successful senior scientist said: *"...communicating across the disciplines becomes more difficult…there may also be some miscommunication. It is more high risk, but also high gain."* Figure 2b shows the marginal plot for the interaction between change in co-authors' centrality and the co-author team's knowledge domain overlap (0=no overlap, 1=complete overlap). The plot shows that when all variables are at mean values; when the collaboration is characterized by high knowledge domain overlap then co-authors' centrality change is associated with higher performance for the focal scientist. Hence in line with the interviews; knowledge domain overlap positively moderates the otherwise negative effect of change in co-authors' centrality.

The complex papers usually address the most interesting questions in the field, but working in this way requires that co-author teams bridge different knowledge domains and venture into unknown territory. Obviously, this is a challenge (Bercovitz & Feldman, 2011), and therefore these papers are described as high risk, high gain. On a positive development path, these are the papers that intrinsically motivate scientists, yet they are also complex papers and can therefore easily be delayed or derailed. In the interdisciplinary collaborations, pooling resources is not straight forward, and with the pace at which research is moving, together with the changing knowledge landscape and its inhabitants, it may become all but impossible to extract value from these kind of collaborations (Aral & Van Alstyne, 2011).

In contrast, when co-authors primarily work within a shared knowledge domain, their joint papers are likely to be within that knowledge domain. Working within a shared knowledge domain has consequences beyond cognitive proximity and ease of collaboration (Bercovitz & Feldman, 2011). One junior scientist explained the benefits of collaboration within a shared research domain: *"We are very good at collaborating in our group. Even when we do data analysis…we share scripts and so on."* She also described the personal benefits of collaboration within her knowledge domain: *"I read less….and then I ask some of the others that I know also read many papers. We are good at helping each other. If you want to do it all yourself, then you will maybe have time for (writing) one paper, while we have time for ten."*

Limitations

One limitation of this study is that performance is measured in terms of citations and the dependent variable therefore focuses on the product and its reception, rather than on the process and collaborative dynamics within scientific collaborations. Future work may examine the collaboration process more closely to reveal further nuances in the interaction between change in centrality and collaboration dynamics.

In the interviews, scientists also pointed to differences in experiences, which may derive from their access to resources and position in the research community. We encourage future work to examine whether scientists' power in collaborative teams or differences in the hierarchy and control over collaboration partners effort allocation moderates how performance is affected by co-authors' changing centrality.

CONCLUSION

While prior work has examined the direct effects of scientists' network centrality on their performance; the spillover effects of collaboration partners' centrality – i.e., the indirect effects – have been largely ignored. Our findings indicate that such spillover effects do indeed exist and that the effect is generally negative: A focal scientist's performance suffers when her collaboration partners' centrality increase. We further find evidence in support for the notion that this negative spillover effect is due to collaboration partners' effort allocation away from the focal paper; the negative effect increases when collaboration partners simultaneously increase centrality and performance. Interestingly, our findings also reveal that a shared knowledge domain acts as a positive moderating condition, which is potentially strong enough to transform the disadvantage of collaboration partners' effort allocation to a benefit. The insights from our analysis suggest that although collaboration with highly central partners is often an advantage; collaborating while centrality is in the making is not. This adds to our understanding of the effects of centrality dynamics in social systems. And, specifically, how collaboration partners' increased centrality affects focal individuals under various conditions. Prior research has not explored such distinctions in the effects of centrality for performance and future work may indeed reveal further nuances in the related dynamics.

By viewing centrality as not only tied to the individual, but as embedded in a larger social system in which one individual's centrality change spreads like ripples and affects collaboration partners, we contribute to recent work that has extended the understanding of spillover effects in social systems (e.g., Liu, Mihm & Sosa, 2018). While prior work has shown that there is a general positive relationship between centrality and performance, more recent work points to a reverse u-shaped relation. We build on and extend this stream of work on the relationship between centrality and performance. In line with prior work, we find that collaborating with high-centrality collaboration partners increases performance for a focal scientist. Yet, surprisingly, working with co-authors that are in the process of increasing their centrality does not increase performance.

Our findings indicate that centrality changes create ripple effects, and in science, this evidently has important implications for individual scientists, co-authors, research teams, as well as departments and institutions.

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APPENDICES

Figure 1

Time lag between independent and dependent variables

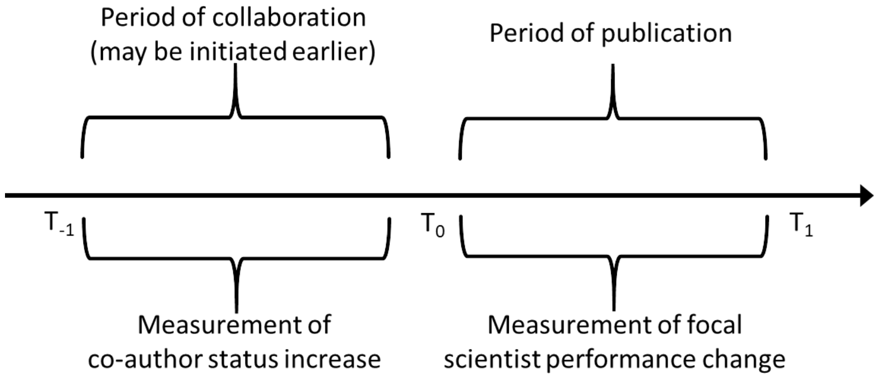
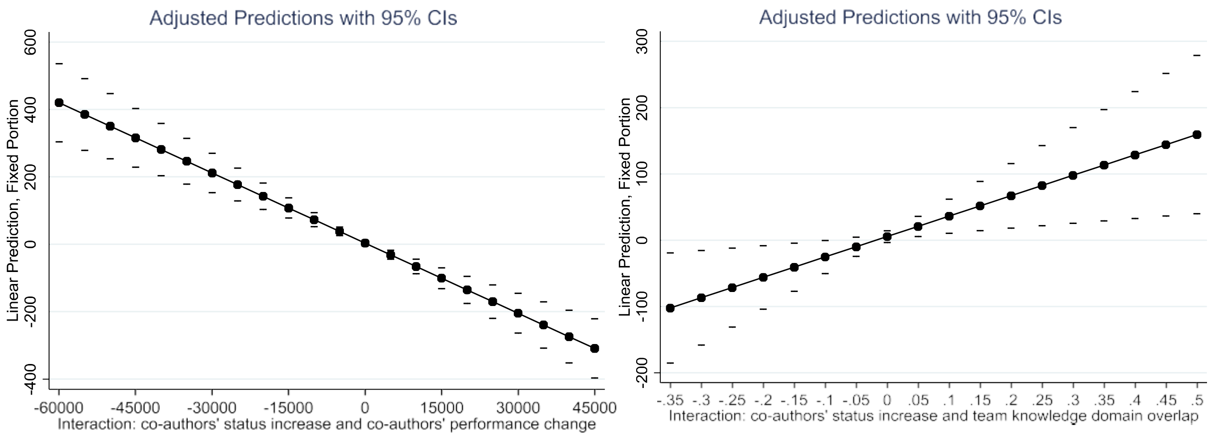


Figure 2

Marginal effects of interactions with co-authors' centrality change

a: Interaction between co-authors centrality change and performance change. All other variables at mean or most common values.

b: Interaction between co-authors s centrality change and team knowledge domain overlap. All other variables at mean or most common values.



Calculated based on model 6

Table

Table 1

Interview Data

Scientist	1	2	3	4	5	6
Gender	Female	Male	Male	Male	Female	Male
Position	Professor Leader of laboratory with 12 post docs and PhD’s	Professor Emeritus	Professor, former Head of Department, currently Manager of a LSRF	Associate Professor	Postdoc (late stage)	Professor
Duration of interview	1h 8min	38min	42min	39min	1h 5min	59min

Table 2: Descriptive statistics and pairwise correlation coefficients

	Variable	Mean	Std. Dev.	Min	Max	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	*Performance change*	28.99	374.08	-1587.5	11132	1															
2	*Co-authors' centrality change*	-0.007	0.104	-0.58	0.62	-0.12*															
3	*Co-authors' perf.change*	6829.97	18825.37	-0.0002	142968.9	0.22*	-0.08*	1													
4	*Knowledge overlap*	0.313	0.156	0.0644	1	-0.05*	0.07*	-0.23*	1												
5	*Top 5% journal*	0.049	0.218	0	1	0.34	-0.2	0.76	-0.19	1											
6	*Performance star*	0.007	0.083	0	1	0.00	0.02*	-0.02*	0.05*	0.00	1										
7	*Performance (centered)*	-227	3823	-36750	54946.8	-0.03*	0.01	-0.38*	0.00	0.00	0.47*	1									
8	*Project star*	0.276	0.447	0	1	-0.03*	0.04*	-0.16*	0.29*	0.00	0.12*	0.40*	1								
9	*Cent. Change*	0.073	0.464	-4.5	3.84	-0.08*	0.43*	-0.02*	-0.02*	0.00	-0.01	0.00	0.01	1							
10	*Cent. change (centered)* *Centrality*	-0.0003	0.059	-0.657	0.511	-0.01	-0.21*	0.00	-0.00	0.00	-0.01	-0.07*	-0.04*	0.53*	1						
11	*Centrality*	0.074	0.094	0	.71	0.03*	0.19*	0.13*	-0.20*	0.02	-0.04*	0.13*	0.05*	0.27*	0.02*	1					
12	*Performance*	2762.19	4973.04	0	73726.36	0.08*	-0.03*	0.12*	-0.01	0.09	0.59*	0.65*	0.28*	0.01	-0.07*	0.17*	1				
13	*Tenure*	19.84	11.73	0	64	-0.00	-0.02	-0.02*	0.00	-0.3	0.00	0.03*	0.02*	-0.00	-0.00	-0.02*	0.02	1			
14	*Gender*	0.856	0.352	0	1	-0.01	0.03*	-0.01	0.01	-0.01	0.00	-0.04*	-0.06*	-0.01	0.00	-0.06*	-0.05*	0.10*	1		
15	*No. of papers in the period*	60.48	55.42	1	307	0.01	-0.01	0.00	0.06*	0.01	0.10*	0.34*	0.38*	0.02*	-0.04*	0.16*	0.48*	-0.11*	-0.08*	1	1
16	*Top 50 University*	0.096	0.294	0	1	-0.01	-0.05*	-0.01	0.04*	-0.02	0.17*	0.04*	0.02*	-0.05*	-0.01	-0.11*	0.08*	0.08*	-0.03*	-0.00	-0.00
17	*No. of authors*	8.4	3.57	1	17	0.06*	0.02*	0.19*	-0.39*	0.01	-0.02	0.01	-0.13*	0.04*	0.00	0.09*	0.07*	0.00	0.02*	0.02	-0.04*

Table 3

Mixed effects regression models of performance change

	Model 1 (empty model)	Model 2 (controls)	Model 3 (Main effect)	Model 4 (Int. I)	Model 5 (Int. II)	Model 6 (Int. I & II)
Co-authors' centrality change			-56.311**	-47.699**	-272.194***	-180.337***
			[23.266]	[23.294]	[56.440]	[57.998]
Co-authors' centrality change * Co-authors' performance change				-0.008***		-0.007***
				[0.001]		[0.001]
Co-authors' centrality change * Knowledge overlap					502.975***	307.835**
					[117.622]	[121.062]
Co-authors' performance change			-0.002***	-0.002***	-0.002***	-0.002***
			[0.000]	[0.000]	[0.000]	[0.000]
Knowledge overlap			-29.490	-28.979	-31.694	-30.401
			[28.329]	[27.982]	[28.275]	[27.962]
Top 5% journal		469.678***	447.746***	446.278***	447.414***	446.191***
		[19.031]	[19.148]	[18.851]	[19.103]	[18.850]
Top 5% scientist		7.028	11.751	0.801	11.502	1.534
		[11.991]	[11.957]	[12.084]	[11.958]	[12.082]
Performance (centered)		-0.011***	-0.012***	-0.012***	-0.012***	-0.012***
		[0.001]	[0.001]	[0.001]	[0.001]	[0.001]
Project star		-10.768***	-10.083***	-10.491***	-10.301***	-10.591***
		[1.524]	[1.520]	[1.528]	[1.521]	[1.528]
Centrality change		-14.213***	-13.134***	-13.237***	-13.693***	-13.557***
		[3.516]	[3.529]	[3.543]	[3.532]	[3.544]
Centrality change (centered)		15.397	-4.567	-34.271*	-20.663	-41.737**
		[17.077]	[19.931]	[20.357]	[20.282]	[20.562]
Centrality		3.284	2.445	7.925	3.312	7.999
		[10.848]	[10.786]	[10.855]	[10.789]	[10.851]
Performance		-0.005***	0.005***	0.006***	0.005***	0.006***
		[0.001]	[0.001]	[0.001]	[0.001]	[0.001]
Tenure		0.202***	0.200***	0.207***	0.198***	0.205***
		[0.056]	[0.056]	[0.056]	[0.056]	[0.056]
Gender		4.338**	4.154**	4.117**	4.094**	4.084**
		[1.828]	[1.815]	[1.824]	[1.816]	[1.824]
No. of papers in the period		0.281***	0.279***	0.270***	0.280***	0.272***
		[0.018]	[0.018]	[0.018]	[0.018]	[0.018]
Top 50 university		-3.878	-3.945	-4.030	-3.959	-4.032
		[2.955]	[2.933]	[2.946]	[2.933]	[2.945]
No. of coauthors		3.602***	4.118***	4.102***	4.099***	4.092***
		[1.208]	[1.197]	[1.178]	[1.194]	[1.178]
Collaborators no. of papers		1.541***	1.496***	1.557***	1.503***	1.556***
		[0.441]	[0.438]	[0.440]	[0.438]	[0.440]
Constant	19.820***	-45.272***	-51.971***	-52.733***	-51.616***	-52.442***
	[4.265]	[10.960]	[16.544]	[16.300]	[16.507]	[16.300]
Between-subject variance	5.638***	5.636***	5.583***	5.567***	5.581***	5.567***
	[0.011]	[0.011]	[0.011]	[0.011]	[0.011]	[0.011]
Within-subject variance	4.077***	3.995***	3.988***	3.993***	3.988***	3.993***
	[0.008]	[0.008]	[0.008]	[0.008]	[0.008]	[0.008]
Pseudo LL	-7.49E+04	-7.42E+04	-7.39E+04	-7.39E+04	-7.39E+04	-7.39E+04
No of Obs	12023	12023	12023	12023	12023	12023
Wald-Chi2	.	1375.813***	1987.331***	2050.596***	2007.549***	2058.227***

Note. Year dummies and dummies for type of employing organization not displayed

*p<0.1 **p<0.05 ***=p<0.01

CHAPTER 4. NETWORKS AND GENERALISTS: THE EFFECT OF KNOWLEDGE DIVERSITY, NETWORK BROKERING AND TIE STRENGTH SKEWNESS ON NEW KNOWLEDGE ADOPTION

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ABSTRACT

This paper investigates the role of the generalist with regards to new knowledge adoption from a knowledge diversity and social network perspective. I posit that social embeddedness, in the form of structural holes, as well as the skewness of the strength of ties positively influence the adoption of new knowledge. I further posit that high knowledge diversity increases the opportunities to engage with new knowledge, and effectively acts as an indicator of absorptive capacity, positively moderating the effects observed from the network measures. I confirm the positive influence of skewness and the moderating effects but cannot confirm the positive direct effect of structural holes on knowledge adoption. The study is conducted using a unique dataset consisting of full bibliometric data from a Large Scale Research Facility (LSRF), and employs a novel machine learning technique (LDA) in order to estimate knowledge diversity. The paper adds to the literature on generalists and specialists, absorptive capacity and network literature by synthesizing the three theoretical models.

INTRODUCTION

The role between knowledge production, innovation and economic and firm growth has long been of scholarly interest (Schumpeter and Redvers 1934, Nelson and Winter 1977). At the foundation of this lies the ability to find and integrate knowledge, where most benefit is reaped when the knowledge integrated are distant and diverse (Tushman and Anderson 1986, Fleming and Sorenson 2001, Uzzi, Mukherjee et al. 2013).

This ability to find and integrate diverse knowledge has been explained by what (Cohen and Levinthal 1990) termed "absorptive capacity", and has frequently been shown to be a critical capability for firms to invest in (Lane, Koka et al. 2006). Even though the majority of the literature within this area has been dedicated to firm level analysis, it is widely accepted that absorptive capacity is a multi-level construct appearing at both firm level, business unit and individual level (Volberda, Foss et al. 2010). Understanding the variance in individual level knowledge producers' cognitive processes, that enables adoption of new knowledge, can thus help explain firm-level heterogeneity in building necessary organizational capabilities for competitive advantage (Yao and Chang 2017, Distel 2019).

However, the individual level construct has not received the same scholarly attention as the firm level construct (Volberda, Foss et al. 2010). Turning to the original paper by (Cohen and Levinthal 1990), for inspiration, knowledge diversification is posited to play an important role in individual level absorptive capacity: *"(...) diverse knowledge structures coexisting in the same mind elicit the sort of learning and problem solving that yields innovation".* They further posit that organizations' absorptive capacity does not solely reside within individuals' internal knowledge structure. Instead, it is depending on the (…) *transfer of knowledge across and within sub-units* (Ibid.). As a result, to investigate mechanisms leading to new knowledge adoption further, it is necessary to not only focus on the role of individual level diversity of knowledge, but also the role that is played by said individual within a knowledge network (Tortoriello 2015). Recent literature addresses aforementioned gap, and explain the emergence of individual level absorptive capacity by employing both types of measures separately; e.g. social network based measures e.g. (Ebers and Maurer 2014, Tortoriello 2015) and knowledge based measures, e.g. (Yao and Chang 2017, Schweisfurth and Raasch 2018). Common for these studies are the identified influence of variance in individual knowledge composition and network position on the ability of individuals to find and integrate new knowledge. Thus, I, in this paper, propose that an individual's ability to absorb new knowledge into their existing knowledge portfolio hinges on both their relational and structural networks and existing knowledge diversification.

As context for this study, the most obvious knowledge creation process at the individual level is found in science. However, empirical evidence indicates that the knowledge processes in science are changing. The sheer size of the stock of knowledge and the speed at which it continues to grow has resulted in an increasing distance to the knowledge frontier. This effect has, in the literature, been termed the "knowledge burden" (Jones 2008, Jones 2009, Jones 2011). Here, knowledge producers face an increase in educational effort needed to advance to the frontier of knowledge, whereby more and more time are needed for successive cohorts to invest in training or further education before arriving at an expertise level sufficient to make significant contributions.

For knowledge producers, two main strategies are treated in the literature that enable them to address above difficulty. First, they can choose to learn more. The effect of this strategy can be directly observed since the age at which individual researchers discover key breakthrough as well as the doctoral age of Nobel price winners are increasing (Jones 2010). From an innovation perspective the potential cost to society is that it leaves less time to produce impactful knowledge. If knowledge producers choose to enact the second strategy, they compensate for the increasing distance to the knowledge frontier by specializing in narrower subject fields. The cost of this strategy is that it may lead to a decrease in individual capabilities to integrate disparate knowledge sets, effectively facilitating a trade-off between knowledge depth and breadth. This trade-off necessitates an increased need to collaborate to compensate. This can be quite clearly observed as extant literature document the increased specialization and the increase in team collaboration in science, measured as both increases in share of co-authored papers and average team sizes (Wuchty, Jones et al. 2007, Jones 2008, Jones, Wuchty et al. 2008, Jones 2009, Jones 2011, Wang 2016). Even though the result of scientific collaboration more often results in increased scientific production and impact (Wuchty, Jones et al. 2007, Jones, Wuchty et al. 2008, Abbasi, Altmann et al. 2011), the increase in average team size, suggests that coordination costs across knowledge areas grows as specialization increases (Nagle and Teodoridis 2017).

At the same time, we know from the innovation literature that new knowledge is a recombination of existing knowledge (Henderson and Cockburn 1994, Cockburn and Henderson 1998), and that the degree of novelty increases if distant knowledge sets are mixed with convention (Uzzi, Mukherjee et al. 2013). The underlying hypothesis is that if scientists access knowledge outside their main domain, the possible sources of new ideas effectively increase, resulting in an increased probability of creating novel ideas. This results in the apparent paradox that specialization is necessary to get to the knowledge frontier, but diversity in knowledge base is important to push the knowledge frontier forward, as solely specialization within narrow fields will, at some point, exhaust recombination possibilities.

To decrease the costs associated with increased distance to current knowledge base, as well as the increased need for coordination across knowledge boundaries in research teams, a demand for researchers who have enough exposure to a broad set of knowledge to recognize opportunities for creation of new knowledge and lower the coordination costs between a team of specialists is created (Jones 2008, Teodoridis, Vakili et al. 2017). The need for scientists with generalist knowledge breadth would then become more important as research specialization become increasingly narrower, thus creating a third strategy for researchers to pursue. As a result, an emergent stream of literature emphasizes the impact of generalist research profiles, where they play significant roles in spotting new knowledge opportunities (Jones 2009, Jones 2010, Teodoridis, Vakili et al. 2017, Teodoridis 2018).

Considering above, the motivation of this paper is to answer the following questions: First, what is the impact of knowledge diversification and social networks on the adoption of new knowledge? Second, how is the individual's level of knowledge diversification moderating the impact of their network structure and relational properties on new knowledge adoption?

The motivation of the paper is further to add to the increasing literature on the trajectory of science, given the knowledge burden hypothesis and increasing dominance of teams, investigating two distinct strategies new researchers often are confronted with early in their careers – that of pursuing increased specialization or emphasizing a more generalist cross-topic strategy (Jones 2010, Teodoridis, Vakili et al. 2017, Furman and Teodoridis 2018, Teodoridis, Bikard et al. 2018).

With this paper I aim to make the following contributions: First, by combining network theory with that of knowledge diversity, I add to the absorptive capacity literature, by showing that the positive influence of ego's social network, both has a structural and relational impact on new knowledge adoption and that this impact is further enhanced by their existing absorptive capacity, in the form of knowledge diversity. Specifically, I find that ego's distribution of ties impact knowledge adoption, and, further, I find that generalists tend to be able to reap the benefits of these positions better than scientists with a narrower knowledge breadth. Second, I aim to add to the literature on the organization of science, by combining the emergent topic on the importance of generalists in the identification of new knowledge, with a network-based view. Third, I explore the effect of tie configuration within knowledge networks contributing to the further development of network relational theory going beyond just strong and weak ties, emphasizing the need for a more holistic view on ego's entire tie distribution, expanding the findings of (Wang 2016).

The rest of the paper will be structured as follows: Section 2 will contain the theory and hypothesis generation. Section contains a description of my empirical strategy. Section 4 describes the measures I employ and Section 5 my econometrical approach. Finally, section 6 and 7 showcases the results, analysis, discussion and conclusion.

THEORY AND HYPOTHESES DEVELOPMENT

Absorptive capacity, Generalists and Specialists

At the root of absorptive capacity is the ability to identify and adopt knowledge and effectively combine these pieces to create novel and impactful new ideas. Extant research has utilized the concept to explain many different organizational phenomena, e.g. knowledge transfer, knowledge acquisition and R&D innovation, at many different levels of analysis, e.g. individual, team and organizational, and measured in many different ways, e.g. as investment in R&D activities, presence of knowledge, experience and previous training (e.g. (Cohen and Levinthal 1990, Cockburn and Henderson 1998, Lane, Salk et al. 2001, Zahra and George 2002, Matusik and Heeley 2005, Fabrizio 2009, Lewin, Massini et al. 2011, Bouguerra and Glaister 2016, Schweisfurth and Raasch 2018). Taken together, there is agreement that absorptive capacity is a major determinant of the knowledge transfer process (Lane, Koka et al. 2006) and that the greater the absorptive capacity, the greater the degree of knowledge transfer is expected (Gupta and Govindarajan 2000). At the individual level, these cognitive processes and resulting creative behavior are an important micro-foundation of absorptive capacity (Volberda, Foss et al. 2010, Yao and Chang 2017, Distel 2019).

From this perspective (Cohen and Levinthal 1990) mention specifically that the knowledge diversity of the individual are a key mechanism: *"(...) knowledge diversity (...) facilitates the innovative process by enabling the individual to make novel associations and linkages".* Thus, if an individual has a diverse knowledge pool, this allows for easier absorption and recombination of extant knowledge, where the breadth of categories into which prior knowledge is organized, the differentiation of those categories, and the linkages across them permit individuals to make sense of and in turn acquire new knowledge.

Acknowledging this relationship between knowledge transfer, absorptive capacity and knowledge diversity, an increasing body of literature investigates the relationship between individual level knowledge diversification and knowledge related outcomes (Jones 2009, Agrawal, Goldfarb et al. 2016, Nagle and Teodoridis 2017, Teodoridis, Vakili et al. 2017, Furman and Teodoridis 2018, Teodoridis 2018, Teodoridis, Bikard et al. 2018).

The common approach, comparing the two seemingly ends of a spectrum of knowledge diversity, is to describe having high knowledge breadth as a *generalist*, that have had broad exposure to knowledge due to involvement in a wide variety of topics. This can be compared to the specialists that have a depth of knowledge required to push knowledge further and deeper within few knowledge domains.

Generalists will choose to have exposure to knowledge that stem from multiple disparate knowledge sets, or knowledge circles as (Jones 2009) posit, whereas the specialist will choose to increase knowledge within a particular set of knowledge. This effectively creates a "paradox": Impactful discoveries are the result of the recombination of distant knowledge sets (Katila and Ahuja 2002, Uzzi, Mukherjee et al. 2013), however, due to the rapid expansion of the distance to the knowledge frontier, achieving diversification is increasingly difficult (Jones 2009). To accommodate this, researchers are increasingly engaging in collaboration (Wuchty, Jones et al. 2007), which in turn increases the coordination costs associated with collaboration (Bikard, Murray et al. 2015).

Generalists will, in this model, act as coordinators across subject fields (Ibid.). This will reduce the cost of collaboration and facilitate more broad collaboration between specialists across the knowledge frontier (Cummings and Kiesler 2005, Teodoridis 2018, Teodoridis, Bikard et al. 2018). However, that strategy is not without limitations as communication and coordination costs within teams can be high due to the differences in scientific language – this is especially true when team sizes increase and include more specialists from diverse fields (Cummings and Kiesler 2007). Emergent literature gives indication of another strategy, where individuals with a diverse portfolio of knowledge not only acts as coordinators, but also acts as conduits to diverse knowledge (Jones 2010, Teodoridis, Vakili et al. 2017). Specifically, while at the firm level knowledge diversification has been shown to be an important characteristic for successfully integrating new knowledge (e.g. (Van Wijk, Van den Bosch et al. 2001, Van Wijk, Van Den Bosch et al. 2001, Shipilov 2006), this diversification is generally obtained across individuals by hiring specialists in different areas and using the firm and managers to act as a supervisor to integrate their knowledge (Arora and Gambardella 1994, Garicano 2000). Furthermore, it precludes benefits from diversification within one individual researcher relative to the propensity to recognize the value of new information. In other words, comparing specialized researchers with their generalist counterparts, diversified individuals are better at recognizing and integrating novel knowledge in a manner consistent with absorptive capacity. In conclusion, I consider the following hypothesis:

> *Hypothesis 1: The higher the knowledge diversification of an individual, the higher the likelihood of adopting new knowledge.*

Social networks, science and new knowledge adoption

An extensive literature on the social factors influencing success for collaborating in teams can be found, focusing on drivers for performance (Katz 1994, Katz and Martin 1997, Newman 2001, Singh and Fleming 2010, Bercovitz and Feldman 2011). In a research setting, previous studies have extensively investigated the role of knowledge networks, e.g. (McFadyen and Cannella Jr 2004, Abbasi, Altmann et al. 2011, Gonzalez-Brambila, Veloso et al. 2013), covering topics such as patterns and evolution of collaboration networks and their effect on research performance (Newman 2001, Newman 2004, Lee, Walsh et al. 2015). These studies confirm that even though knowledge is created by individuals, it is, in essence, also a social and collaborative process. It is therefore imperative to understand how individual researchers adopt, transfer and create knowledge, as scientists with a high level of intellectual or social capital can significantly contribute, and especially so for "star"-researchers, to all collaborative teams (Azoulay, Graff Zivin et al. 2010). A rich body of literature has shown that there are certain characteristics of individuals exhibit within these networks of collaboration that influence the efficiency and efficacy of which knowledge producers, at multiple levels, can create knowledge. This is done as the network they are embedded in, influences the ability to access, transfer, absorb and apply knowledge.

Generally, two areas of research are most prevalent in investigating what influences knowledge related outcomes: 1) The network structure and 2) a network's relational properties. Network structure involves the network position, e.g. degree centrality and ego network structure, e.g. triadic closure, and relational properties involves e.g. tie strength and nodal proximity/similarity (Phelps, Heidl et al. 2012).

Both strategies influence knowledge adoption at the interpersonal level, where centrality provide individuals with easier, more timely access to a potentially more diverse knowledge pool and relational properties can facilitate either trust, distrust, ease of transfer of tacit knowledge or provide individuals with opportunities due to disconnected others. Thus the two social network strategies matter for individual knowledge adoption, and even though the concepts are correlated they are conceptually distinct, and needs to be investigated simultaneously to disentangle their effects (Reagans and McEvily 2003). Therefore, in the following paragraphs I will develop the hypotheses centered around the influence of structural holes as well as relational properties, in the form of tie strength configuration on knowledge adoption.

Structural holes and new knowledge adoption

The central tenet of structural holes is that for people that are near "holes", i.e. low density of alters, in a social structure are more exposed to novel ideas, and thus have a higher probability to develop novel ideas themselves (Burt 1992). Underlying this is the assumption that knowledge and information tend to be more homogeneous within rather than across groups, and networks that span multiple groups have access to a diverse pool of knowledge. Extant literature within this area has shown that individuals that span network boundaries tend to have greater capacity for knowledge sharing (Reagans and McEvily 2003), tend to be more creative (Perry-Smith 2006) and are perceived as being a rich and efficient source of information (Nerkar and Paruchuri 2005). This is significantly different when embedded in a social network with closed ties *"favors the development of idiosyncratic languages and shared mental models (…) familiarity with diverse and distant contacts helps individuals understand and adopt different approaches"* (Tortoriello 2015). Thus, individuals with access to non-redundant networks, has an increased likelihood to acquire new and distant knowledge.

These arguments suggest that individuals within a network that is rich in structural holes, have more opportunities to be exposed to new knowledge by accessing disparate collaborators. This has the implication that this increased exposure will lead to an increased probability of new knowledge to be adopted in an individual's existing knowledge portfolio. In the context of science, prior literature has shown that the creation of novel knowledge relies on the recombination of atypical and distant knowledge sets (Uzzi, Mukherjee et al. 2013), thus, in the setting of science and new knowledge adoption I posit:

> *Hypothesis 2a: Structural holes in the internal network spanned by a researcher, has a positive effect on their ability to subsequently adopt new knowledge.*

Being in a structural hole position will confront the individual with ideas from diverse knowledge domains and prompts the need to explore unexplored mental representations, thereby exposing potentially useful relations between previously unrelated ideas. However, as mentioned previously, in order to reap the benefits to the fullest it is necessary to be able to absorb the potential new ideas. Here, knowledge diversification act as a proxy for the absorptive capacity of an individual, effectively increasing the efficacy of occupying a network position with many structural holes:

> *H2b: Knowledge diversification positively moderates the effect of structural holes on the likelihood of adopting new knowledge*

The influence of tie configuration on new knowledge adoption

The direct ties that connect agents in a social network play a central role in knowledge related work, and allows the studying of the effect of collaborative actions (McFadyen and Cannella Jr 2004). Research centered around relational properties of a network, shows consistently that strong direct interpersonal ties, defined by e.g. communication frequency, duration or similar, are more effective than weaker ties, in enhancing knowledge transfer or learning (Granovetter 1977, Rost 2011, Tortoriello, Reagans et al. 2012). The reason behind is that strong consistent ties facilitates trust and reciprocity between individuals.
With the increased trust comes an increased expectation of more altruistic collaboration, resulting in greater awareness and access to collaborators' knowledge base (Uzzi and Lancaster 2003, Levin and Cross 2004).

In contrast, weak ties increases the likelihood of providing non-redundant information, and tends to bridge structural holes between communities, therefore providing access to resources unavailable to one's own immediate network (Granovetter 1977, Burt 1992, Uzzi 1996, Perry-Smith 2006). Weak-tie-collaborations are therefore more likely to generate novel ideas by increasing exposure to diverse knowledge portfolios, by pooling collaborators of different expertise and perspectives. This effect has been explored in extant literature with focus on knowledge creation, where e.g. (Perry-Smith 2006) found that a person's weak ties had a positive influence on creativity beyond that of structural holes, (Zhou, Shin et al. 2009) showed that the count of weak ties has an inverted U-shape effect on creativity. Thus, from a knowledge transfer and absorption perspective, the literature seems to indicate that stronger ties facilitate easier transfer and absorption, however juxtaposed to the knowledge creation literature, the effect seems more ambiguous, where weak ties facilitate increased access to diverse knowledge, thereby increasing the probability to create (subsequently adopt) new knowledge, however, the positive effect might diminish with the absolute number of weak ties. This can also be seen in the papers studying the effect of average tie strength, where some studies indicate a linear effect of weak ties on knowledge creation (Ebadi and Utterback 1984, Moran 2005) and others an inverted U-shape, (Perry-Smith 2006) finds that weak ties are generally beneficial for creativity and stronger ties have neutral effects. In contrast, (Rost 2011) finds that high avg. tie strength positively impacts the novelty of patentors ideas. Summarizing, the theory behind the strength of weak ties states that it is they they provide opportunities for individuals to search broadly for diverse and complementary knowledge, and strong ties enable to quickly absorb and share knowledge more closely to existing knowledge portfolio (Nagle and Teodoridis 2017), even though empirical support might be a conclusive yet. Therefore, the question is not whether strong vis a vis weak ties influence knowledge adoption – they can both positively foster the adoption of new knowledge – it is more a question whether the individual knowledge creator that rely more on weak ties vis a vis strong ties, gain increased opportunities to engage with more disparate knowledge.

From a knowledge perspective, as described earlier, having strong ties eases the cost of collaboration and transfer of knowledge, however maintaining these strong relations are costly, whereby having too many is inefficient (McFadyen and Cannella Jr 2004). Further, strong ties are more likely to be connections to people of similar characteristics to oneself (McPherson and Smith-Lovin 2001), therefore decreasing the likelihood of transferred knowledge to be distant. While strong ties may indicate deep narrow search, weak ties may reflect a scientists' broad search for diverse and complementary knowledge and enhance absorptive capacity (Reagans and McEvily 2003, Wang 2016).

Therefore, the relationship between tie strength and knowledge adoption is not straightforward. In science, it is not uncommon for researchers to have both a small group of colleagues with whom they have frequent collaboration with and several other loose contacts with less frequent contact. The tie strength distribution will therefore tend to be non-normal, whereby the underlying empirical assumption, when using average tie strength, as homogenous, as well as the mere dichotomous count of strong vs weak ties might be problematic (Wang, Berzins et al. 2012, Wang 2016).

In conclusion, a more skewed network might perform better with regards to new knowledge adoption, as it allows for broader exposure to alters that are more likely to have a significantly different knowledge base. Based on above I posit that:

> *H3a: The more skewed an ego's network of alters is towards relying on weak ties, the higher the adoption of new knowledge to ego's existing knowledge portfolio can be observed.*

Extant literature has investigated the effects of tie strength on types of knowledge transfer, where it has been shown that increasing tie strength ease the transferring of complex, tacit knowledge and improve explorative learning.Thus, increasing tie strength improves the efficacy of transferring complex tacit knowledge (Reagans and McEvily 2003) and individuals with strong ties to others with dissimilar competencies or to others separated by structural holes have been shown to be more innovative. This suggests that strong ties enhance an individual's ability to create knowledge by partnering with partners possessing disparate yet not distant knowledge (Ebadi and Utterback 1984, McFadyen, Semadeni et al. 2009). However, since egocentric collaboration networks usually exhibit a long tail distribution with a right sided long tail and the bulk of the values to the left of the mean, the highly skewed tie distribution might reflect a specific scientist's broad search opportunities, where the most distant knowledge can be found through weak tie collaborators.

Further, individuals' access to direct weak ties act as an increase in opportunity to receive new knowledge, having a highly diversified individual knowledge portfolio must also increases the likelihood of these opportunities to be caught and absorbed into the scientists' existing knowledge portfolio. Thereby if the knowledge producer is not sufficiently able to identify the potential recombination of distant knowledge provided by weak ties, any positive opportunity will not be reaped. As shown earlier, having high knowledge diversity is an indication of an individual's ability to absorb new knowledge, thereby under such circumstances where a scientist has had broad previous experience in a multitude of scientific fields, the likelihood of integration knowledge increases. Thus, I posit:

> *H3b: Knowledge diversification positively moderates the effect of tie skewness on the likelihood of adopting new knowledge*

Figure 1 shows my theoretical model.

INSERT FIGURE 1 ABOUT HERE

DATA AND EMPIRICAL STRATEGY

To examine the effect of individuals' social networks on propensity to adopt new knowledge, I draw on a population of publications and scientists associated with the Spallation Neutron Source (SNS) at Oak Ridge National Laboratory (ORNL) in Tennessee. Since 2006 all publications associated with researchers at the facility has been published on the ORNL webpage. I scraped these papers and identify their unique identifier in SCOPUS. From there I can utilize the unique author SCOPUS ID to identify individuals on the publications. Life-time publications of the authors were subsequently gathered. Even though the author SCOPUS ID is used to identify unique authors, I still cleaned the data for potential homonymous authors using the method used in (Wang, Berzins et al. 2012). In physics it can often be observed that some papers requiring complex instrumentation has hundreds, if not thousands of authors. Therefore, papers with more than 15 authors were not used for constructing variables, following the approach seen in (Wang 2012). This leaves a total of 2,906 authors publishing a total of 145,007 publications in the period of 2001-2015.

Measuring new knowledge adoption

The unique feature of ideas space, compared to a physical space, is that delineating factors, separating two 'spaces' between each other, are only available ex ante of their actual realization. Many analyses typically rely on observable indicators such as keywords, taxonomies or citation maps to estimate the changes to idea space. However, the scientific fields do not necessarily subject itself very well to a pre-defined and stable set of keywords or topics. Even though a high prevalence of material science within this setting, specifically within crystallography, can be observed, the applicability is widespread in many different topic areas. Thus, many new domains and keywords based on recombination has emerged within the last years alone. In this paper I utilize two distinct types of approaches to measure diversification and new knowledge adoption in ideas space. First, I leverage advances within machine learning to develop measures along the lines observed in (Wang, Berzins et al. 2012, Furman and Teodoridis 2020). I therefore employ a Latent Dirichlet Allocation (LDA) (Blei, Ng et al. 2003) technique, which is a type of algorithm that falls within the category of unassisted machine learning topic modeling. It is a probabilistic model that employs a hierarchical Bayesian analysis of text, in which the data are assumed to be characterized by a set of observable variables, i.e. words in a corpus, that subsequently develop from a set of hidden variables. As a result, words are bundled into a set of categories, i.e. topics, as they are found to appear together across texts with a certain probability. I conduct the LDA utilizing the abstracts of the academic publications made by the authors that has conducted research at the Spallation Neutron Source in the period of 2006-2011.

Secondly, I employ a more traditional method to measure knowledge diversification, as I use the Scopus "All Science Journal Classification Codes" (ASJC). This consists of 334 unique categories that are all associated with the journal or conference proceeding that a journal is published within. A journal/conference proceeding can be associated with multiple classification codes. I here follow the approach outlined in extant literature on knowledge diversification and calculate the reversed Euclidean distance in the space of the 276 categories that are used by my population and falls within the field of Health Science, Life Science and Physical sciences (Nagle and Teodoridis 2017, Teodoridis, Vakili et al. 2017, Teodoridis 2018, Teodoridis, Bikard et al. 2018, Furman and Teodoridis 2020). I utilize a 4-year moving average, with the last observed being one year prior to the year of analysis (t-1) (Agrawal, Goldfarb et al. 2016). One could argue that the outcome of the analysis would depend on the length of the selected time-period of the moving annual total, however I experimented with several different periods, and achieved similar results (all regression can be made available upon request).

Identifying topics using Latent Dirichlet Process

To identify topics within scientific publications, I utilise a machine learning technique within the area of topic modelling. Herein the goal is to identify hidden semantic structures of text in a collection of documents. There are several techniques within this area of machine learning, however for this purpose I select a class of unsupervised machine learning technique called Latent Dirichlet Allocation (LDA), that employ a hierarchical Bayesian analysis of text. It is a generative probabilistic model of a corpus, where the basic idea is that documents are represented as random mixtures over latent topics, where each topic is characterized by a distribution over words. The goal is to identify short descriptions of a corpus of texts that enable an efficient analysis of large collections of text, while at the same time preserve essential statistical relationships useful for e.g. classification, summarization and similarity. One drawback of utilising LDA is that the number of topics needs to be specified ex ante of the analysis, and no standard and accepted way of identifying this can be found in the literature. However, I utilise the approach found in (Griffiths and Steyvers 2004, Arun, Suresh et al. 2010) and compute the posterior probability of a given set of topics given the observed data. In this case, the data are the words in the corpus, and the model is specified by the number of topics. This can then be approximated by taking the harmonic mean of the set of values using a Gibbs sampling algorithm. The output with regards to optimal number of topics for a specific year can be found in figure 2, where the estimate is 24 distinct topics. However, as no standard way of handling the optimal number of topics, I also ran sensitivity tests with 20, 60, 100 and 200 topics with similar results.

INSERT FIGURE 2 ABOUT HERE

After identifying the optimal number of topics, the result is that input text is assigned to topics with a certain probability. I conduct the analysis using the abstracts of all publications in my dataset. Following the approach by (Furman and Teodoridis 2020), I run the algorithm each year. Each word or bigram (collection of two or more words that tend to cluster together – e.g. "Angular flux" or "Diffraction peaks") are then assigned to a specific topic with a specific reliability called probabilistic coherence (Röder, Both et al. 2015). An example of the word to topic identification can be seen in table 1 below.

INSERT TABLE 1 ABOUT HERE

Utilising the identification of words associated with certain topics, the next step is to identify how each publication can be assigned to the identified topics. Here I utilise a Bayesian approach with Gibbs sampling[10], where the result is that for each publication id, a probability of belonging to a specific topic is assigned. Following (Furman and Teodoridis 2020) I ignore scores below 1%.

MEASURES

Explanatory Variable: Knowledge adoption

Investigating the adoption and utilization of new knowledge has a long history in empirical research. At the organizational level, a large research stream has investigated how knowledge transfers between organizations – here one study utilizes the licensing in of technology and subsequent patenting as indicators for the speed of which an organization absorbed knowledge (Moreira, Markus et al. 2018). In the absorptive capacity literature

[10] Each run of the LDA is computational very intensive and takes between 5-7 days on a laptop with 7 processor cores and 64Gb of ram.

a ratio of R&D over sales (Cohen and Levinthal 1990) or the utilization of strategic alliances (Vasudeva and Anand 2011) has been shown to correlate with the adoption of new topics within patenting (Cohen and Levinthal 1990, Rost 2011). In this paper I adopt a quite simple approach, following (Nagle and Teodoridis 2017), I compare the 4-year moving annual list of subjects an individual is associated with at time t-1, with their knowledge portfolio at time t. Each new subject field addition count as an increase in knowledge adoption. I thus see knowledge adoption as pertaining the individuals' current knowledge portfolio, and not whether the knowledge is new to the population. As mentioned previously I utilize an approach where subject fields are defined ex ante of the publication and then assigned, utilizing the AJSC.

Network based measures

To construct the networks utilized for in this paper I use the total publication history of all researchers visiting the SNS in the period between 2006 and 2011. From the resulting publication I'm able to derive the incident author-publication matrix, and from that the calculate the author-author affiliation matrix. I use all publications not only the ones observed affiliated with the SNS, in order to minimize the influence of unobserved collaboration within the network.

Tie strength is operationalized as the frequency of collaborations in a five-year time window, including current and preceding years. More specifically, the strength was measured as the number of co-authored papers between ego and alter in year *t-4* to *t*.

The skewness of the tie distribution are thus measured following the methodology from (Wang 2016):

$$Skewness = \frac{n}{(n-1)(n-2)} * \frac{\sum_1^n (x_i - \bar{x})^3}{(\left(\frac{1}{n} - 1\right) * \sum_1^n (x_i - \bar{x})^2)^{3/2}}$$

Where n is the number of ties in an ego-network, x_i is the tie strength for the i-th tie in the egocentric network. This effectively means than an increase in skewness means a heavier reliance on more weaker ties vis a vis strong (repeated) ties.

To measure the extent of structural holes in the network, I follow the methodology of (Burt 2004, Tortoriello 2015):

$$SH_i = 1 - \sum_j c_{ij}$$

Structural holes can thus be understood as a decreasing function to the extent relationships are embedded in a dense system of common third-parties. C_{ij} measures dyadic constraint and is described by Burt by the following relationship:

$$c_{ij} = \left(p_{ij} + \sum_{q \neq i \neq j} p_{iq} p_{qj} \right)^2$$

Two components are important in above: p_{ij} reflects the proportion of which i's interaction is devoted to j. The other term $p_{iq}p_{qj}$ explains the indirect dyadic constraint by accounting for the strength of third-parties around the dyad *i*. The measure thus indicates the degree to which ego's network is concentrated and ranges from 0-1. A large SH_i thus indicates a network rich in structural holes.

Diversification measure

I measure the diversification of research utilizing the common approach found in the knowledge diversification literature, see e.g. (Agrawal, Goldfarb et al. 2013, Nagle and Teodoridis 2017, Teodoridis, Vakili et al. 2017, Furman and Teodoridis 2018, Teodoridis 2018, Teodoridis, Bikard et al. 2018), as the Euclidean distance in the space of defined SCOPUS categories:

$$DiversificationIndex_i = 1 - \sqrt{\sum_{k=1}^{n} CategoryPct_{ik}^2}$$

I use two separate methods for deriving the subject fields for individual scientists. I use the approach AJSC topic fields that provides a stable comparison over the course of the years, as well as utilizing Latent Dirichlet Allocation technique to identify topics based on the actual abstracts of the scientist.

To calculate the diversification utilizing the LDA measure, I follow the approach of (Furman and Teodoridis 2020) and calculate it as a measure of yearly weighted spread across topics identified by the algorithm.

Specifically, the number of distinct topics a researcher has been assigned to are counted and then multiplied by the sum of probabilities of assignment to said categories.

Controls

To control for time-variant individual characteristics I employ a series of controls. It is important to control for productivity to avoid concerns of mechanical correlation between that and the measure of diversification. Thereby I control for the number of papers published each year. I also control for the avg. team size, as the mere presence of more people might result in increased new knowledge adoption and diversification, even though the knowledge is not per se adopted by the individual researcher. Ego's prior performance might influence the likelihood that people will engage and add him or her as collaborator on a paper, just to receive expected spillover effects – disregarding whether or not an actual knowledge adoption took place – whereby I control for prior total citations. As I'm specifically interested in the skewness of the tie strength distribution, I'm controlling for the avg. tie strength and the avg. tie strength squared (McFadyen and Cannella Jr 2004, Wang 2016). As prior research has shown that the career trajectory of the focal scientists may influence both their propensity to seek new knowledge and their impact, I subtract the current year with when I first observed the focal researcher publishing in SCOPUS – e.g. proxying their total tenure in the form of age of their careers. I further include this as squared terms, as tenure has been shown to have a decreasing marginal return on productivity. It also allows controlling for a potential "young scholar" behavior, where early in their career, scientists are very actively seeking distant knowledge domains to specialize in later (Levin and Stephan 1991). Network centrality and it's squared version has been shown to influence knowledge productivity as well as influx of ideas which could lead to artificially inflating the impact of my hypothesized network variables, if not controlled for (McFadyen and Cannella Jr 2004). As the empirical setting is a large research facility, resident researchers that are experts in specialized equipment, might be needed to complete a specific study. Thus, even though they might be experts in a certain field, these researchers might receive unusual high amount of network connections. I identified resident researchers as those only having SNS as their primary institution at a given period.

ECONOMETRICAL APPROACH

Several issues need to be addressed when utilizing publication data. First, as citation patterns varies according to the age of the publication, where papers can take long time to establish themselves as highly cited, while others receive early citation boosts, a sufficient time window needs to be used. Following (Wang 2016) I utilize a five-year window. Second, citations are difficult to compare across fields, as citation patterns and publication rates differ widely. Third, I address the so-called halo-effect in citations, where highly prestigious scientists, tends to be evaluated more highly (Reschke, Azoulay et al. 2018), by utilizing ego fixed effects and thereby estimate within-ego effects. Lastly, some studies have found that up towards 36% of all citations represent author-self citations, thus over-representing own scientific impact. This has been shown to be increasingly true when the number of co-authors increase. To address this, I utilize the functionality within SCOPUS to remove self-citations.

As the outcome variable is a non-negative count of adopted subject fields or key words, and thus lends itself for analysis using a non-linear count model such as the Poisson or Negative binomial model. To select which one to use, the assumption of overdispersion needs to be tested. I do that using the regression test developed by (Cameron and Trivedi 1990), and find support for overdispersion, which would beg for implementing a negative binomial model. However, even though (Hausman, Hall et al. 1984) developed a conditional maximum likelihood strategy for negative binomial models, the method allows for the introduction of individual specific regressors. This (Allison and Waterman 2002, Guimaraes 2008) notes, and subsequently state that it is not a true fixed effects model. I thus move ahead with implementing the FE Poisson model with robust standard errors – also following prior literature with regards to this choice (Wang 2016). Another specification could be to manually include all dummy variables for the individual, however this can be very computationally demanding – especially with datasets that are large. I could also adopt a hybrid method in where I estimate a negative binomial random effects model where all time-varying covariates are included as deviations from the individual specific means (Allison 2014). I also conducted robustness checks utilizing a negative binomial model, with similar results. The final estimated model is an individual level FE Poisson model, that accounts for unobserved and time-invariant heterogeneity, as well as adding year-fixed effects to account for any potentially unobserved changes in the scientific community in a specific year.

RESULTS AND ANALYSIS

Descriptive statistics

INSERT TABLE 2 ABOUT HERE

Descriptive statistics and correlations are reported in Table 2. On average the number of citations is 10.07, the amount of publications 7.62. From the network variables, the average tie strength is 3, and ranges from 0 to 103. This means that some in the population has no collaborations with alters in the network, i.e. only published single-authored papers, and further that some have a very significant working partner. The average network size is 9.19 and again, varies from 0 to 128. The numbers do not cause for any concern, as the speed and collaboration of which these academic subject fields, material science, physics, chemistry etc. are working are well known for high publishing rates. Tie skewness has a mean of 0.83 and varies from -2.47 to 5.74 – indicating some scientist with significantly skewed tie distributions. It is significantly correlated to publications, citations and the size of co-author teams, but maybe more worrying is the very high correlation with network centrality (0.71). The same goes for structural holes (-0.58). However, I conducted a variance inflation factor (VIF) analyses, and none of the factors indicated issues with multicollinearity (see table 3 for an overview). Knowledge diversity (ASCJ) has a mean of 0.72 and a max of 0.94. It is significantly correlated with several other variables – similar to the knowledge diversity variable calculated using the Latent Dirichlet Allocation-technique.

Regression results

Insert table 3 about here

Insert table 4 about here

Table 3 and table 4 presents regression results from a FE Poisson model. For each column, variables of interest are added sequentially, to appropriately check the interaction effect.

I report my main results both with interaction terms and variables of interest introduced sequentially. I interpret the magnitude of effects in the samples and remain aware of the less than perfect approach of comparing estimated coefficients across samples. I do so since interpreting the magnitude of interaction coefficients in Poisson models is problematic. (Ai and Norton 2003) show that the sign and magnitude of the marginal effect of interaction terms in non-linear models are not necessarily the same as the sign and the magnitude of the interaction-coefficients. As a robustness check I conducted the analysis using a linear probability model, with similar results. Following, I also present plots of the estimated effect of the interaction term with estimated confidence intervals, to clearly understand the impact.

In hypothesis 1 I stated that an increase in knowledge diversification effectively increases an individuals' ability to absorb new knowledge, and I thus expected a positive and linear relationship with knowledge adoption. The positive, linear and significant sign of both regression models enables me to confirm this, indicating that a true generalist is key for adopting new knowledge.

Hypothesis 2a stated that increasing structural holes in an ego's surrounding network is positively correlated with increased opportunities for influx of new knowledge, and I expected to see a positive and significant result in the regression. Surprisingly I observe a negative and significant coefficient, thus I am unable to confirm hypothesis 2a. This indicates that in the network scientists are embedded in in this context, acting as the bridge, connecting disconnected others does not positively impact knowledge adoption. Hypothesis 3a stated that a tie strength distribution favoring weak ties, will have a positive impact on new knowledge adoption. In the main regression I find a positive and significant result.

For the hypotheses containing moderators, H2b and H3b, it is necessary to look at the plots of the interaction effects between knowledge diversity and structural holes (h2b) and knowledge diversity and skewness (h3b). The plots can be found as figure 2 and figure 3 in the appendix. They both show that knowledge diversity has a positive effect on the effect of structural holes, where the negative effect is lessened, and the impact of skewness on new knowledge adoption is increased, thus confirming H3a and H3b.

DISCUSSION AND CONCLUSION

In this paper I investigated the relationship between absorptive capacity, social networks and new knowledge adoption. The findings bring about several contributions. First, I contribute to the emergent literature of generalists and specialists, and their different roles in identifying and creating new knowledge. I contribute to this by adding a social network dimension where the embeddedness of the researcher positively influences their ability to gain new knowledge opportunities, and a generalist are subsequently better at absorbing and identifying these new opportunities. The individual network position is therefore an important contingency in understanding the role of the generalist with regards to knowledge related outcomes, as both the network structure and relational properties of the individual, influences individual level knowledge related outcomes. This adds to the body of literature pertaining the organization of science, as well as the emergent literature on scientific knowledge strategies, given the increasing distance to the knowledge frontier (Agrawal, Goldfarb et al. 2013, Nagle and Teodoridis 2017, Teodoridis, Vakili et al. 2017, Teodoridis 2018, Teodoridis, Bikard et al. 2018, Furman and Teodoridis 2020).

I aimed at contributing to the literature on absorptive capacity, by arguing that individual level knowledge diversification is an effective proxy for absorptive capacity, and that this will moderate the network effects shown in prior literature. The rejection of hypothesis 2a and the acceptance of 3a, provides an interesting view into the relationship between network position and knowledge diversity. It seems to indicate that increasing structural holes negatively impacts the adoption of new knowledge, but when knowledge diversity is added this effect becomes positive, indicating that to reap the benefits of structural holes in knowledge adoption, it is necessary to have a certain level of diversity in knowledge, i.e. absorptive capacity, to successfully recombine and adopt the increased influx. The finding adds to the existing literature by emphasizing the contingency of being able to absorb and utilize the opportunities network related positions enable. This can be juxtaposed the literature on network density, where conflicting results on the influence of structural holes on knowledge adoption has been found. Here (Phelps, Heidl et al. 2012) suggests, that it is the actual knowledge objective that defines whether high density or structural holes facilitates new knowledge adoption. The otherwise often found positive effect of structural holes on new knowledge creation may then be explained by the context in which my empirical setting is situated. (D'Ippolito and Rüling 2019) finds that specific to large scale research facilities, a multitude of collaboration types exists simultaneous, and that these in some cases favors similarity and in other dissimilarity between ego and alter. In cases that favors similarity, they identify that peer collaboration would be most prevalent, indicating an established community that partakes in a similar shared theoretical domain. If this is indeed the context in which the LSRF works, then an emphasis on high density facilitates trust and thus increased diffusion of knowledge in the network, explaining the negative impact if they are embedded in a structural hole position – they are not given the opportunity unless a certain level of knowledge within several domains can be exhibited. Their value proposition is simply too low for the densely connected group.

Third, I add to the literature on knowledge networks, expanding on the findings of (Wang 2016), emphasizing the need to not only study a dichotomous relationship between strong and weak ties, but also the configuration. This effect was previously only shown to influence knowledge creation, whereas I show a similar effect for knowledge adoption. However, I also find a negative impact of structural holes, whereas in the literature both a positive effect of structural holes, and of high density on new knowledge adoption has been found. Thus, my finding of knowledge diversity positively moderating this relationship adds to the contingency view proposed in (Phelps, Heidl et al. 2012). This calls for further investigations on how, and whether, generalists utilize their network embeddedness differently than more specialized peers. Finally, as tie skewness has been found to influence several knowledge related outcomes, future studies on network evolution could investigate the mechanisms in which variance in tie distributions influence the evolution social networks.

Several limitations can be identified in the current study. First, the use of bibliometrics to identify knowledge adoption and infer collaboration, while extant literature has shown that there are many alternative modes of collaboration (Katz and Martin 1997). However, the empirical setting employed in the study may reduce the potential impact as the setup of the LSRF, with expensive experiments, a hugely collaborative environment (interviews with former and current employees at such a facility confirms this), whereby incentives for collaborating with an actual outcome as purpose are very much present.

In the study I only measure knowledge adoption as perceived by the individual – meaning I do not measure whether the adoption of knowledge is actually of high-value or new to the community as a whole. I did construct a follow up analysis, utilizing a lagged binary new knowledge adoption/no-adoption variable as the input and then weighted citations as the output, finding a significant and positive effect, however more emphasis could be brought to this relationship.

Second, two alternative views on new knowledge adoption could be explored: 1) the identification of a quasi-experiment where a sudden previously unknown piece of knowledge becomes available (as seen in (Nagle and Teodoridis 2017), would add to the validity of the findings. Further, inclusion of larger networks that goes beyond the SNS, and beyond the quite specifics of scientists that makes the way to a LSRF, would significantly add to the generalizability of the study. However, similar results of the positive correlation to knowledge adoption on a main variable of study, knowledge diversity, can be found in extant literature, with different units of analysis (Carnabuci and Bruggeman 2009, Melero and Palomeras 2015, Mannucci and Yong 2018).

Third, the evolution of science is very difficult to describe ex-ante, due to the complexity of the needed knowledge. Thus, application of machine learning algorithms, in the literature could help in qualifying the diversity argument, by not only accounting for the adoption of knowledge in buckets of overlapping topics, i.e. categories, but also the entire used vocabulary. Here one can employ a similarity metric between the word distributions of time t and t+1 using e.g. TFIDF weighted cosine similarity, or the Kullback-Leibler divergence to indicate the newness between the two time periods.

Fourth, interviews with LSRF scientists and prior, mostly qualitative, studies, both indicate that the sheer co-location of researchers facilitates collaboration, but also that there is a sharp division of labor (D'Ippolito and Rüling 2019), where instrument scientists administering the access to specialist knowledge are much sought after. I therefore ran regressions on a similar model to one presented in this paper controlling for the employees that where employed solely by the SNS and ORNL, but without individual level fixed effects (as these scientists tend to be quite stable in their position) with similar results. All regression can be made available if needed.

Fifth, I do not account for any differences in collaboration partners' status network position, whether they are prestigious or peripheral to the network – all factors that may influence the possibility of new knowledge adoption. As an example (Azoulay, Graff Zivin et al. 2010) finds a significant spillover effect of the death of superstar co-authors on the impact on ego research.

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APPENDICES

Figure 1: Theoretical model

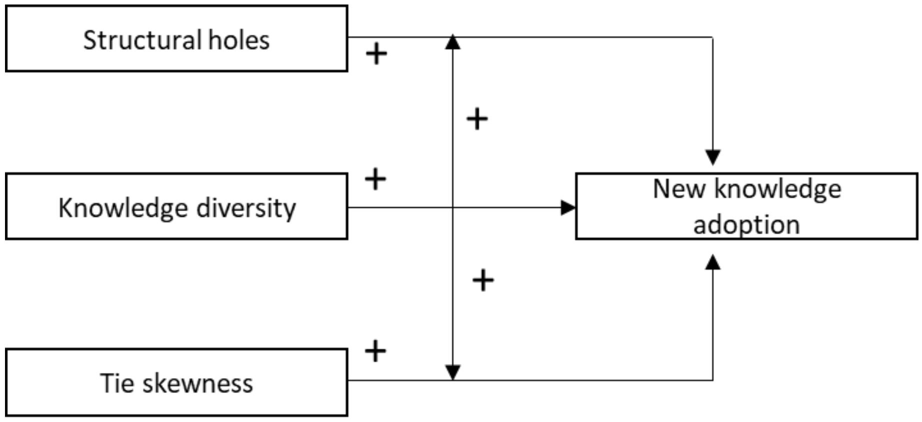

Figure 2a. Simulating optimal number of topics through LDA of abstracts.

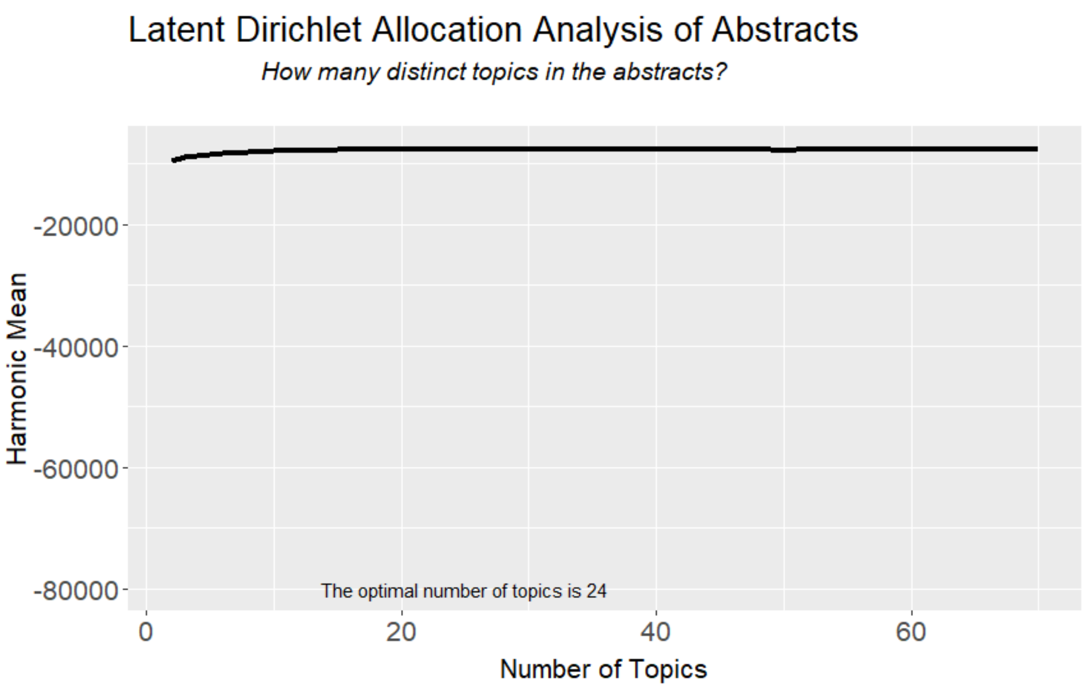

Table 1 | Examples of Predicted topics and terms

Topic #	Predicted label	Coherence	Prevalence	Top terms
t_15	rare_earth	0.214	6.009	magnetic, measured, minus, equals, experiments
t_19	small_angle	0.171	5.414	temperature, scattering, degree, small, neutron
t_11	cr_mo	0.504	5.191	heat, steel, heats, cr, tensile
t_9	angular_flux	0.066	5.11	ray, presented, model, interface, approach
t_23	gallium_citrate	0.072	4.971	pressure, authors, gallium, method, cell
t_16	glucose_phosphate	0.336	4.84	phosphate, ion, glucose, rate, glucose_phosphate
t_7	fibrinogen_uptake	0.241	4.775	fibrinogen, tests, positive, patients, uptake
t_26	functional_imaging	0.242	4.702	functional, time, images, function, scintigraphic
t_14	diffuse_scattering	0.402	4.472	beta, velocity, rewetting, spray, dimensional
t_22	diffraction_peaks	0.048	4.4	energy, scattering, system, high, procedures

Table 2 |Descriptive Statistics

	Variables	Mean	SD	Min	Max	Spearman correlations									
						1	2	3	4	5	6	7	8	9	10
1	Publications	7.62	8.26	1.00	123.00										
2	Citations (lag)	2.31	1.31	-2.71	7.25	**0.17**									
3	Avg. Coauthors	7.21	2.56	2.00	15.00	**-0.05**	-0.01								
4	Avg. Tie strength	3	3.46	0.00	103.00	**0.37**	-0.01	0.02							
5	Centrality	9.19	9.89	0.00	128.00	**0.20**	**0.05**	**0.27**	0.00						
6	Knowledge Diveristy (ASCJ)	0.72	0.18	0.00	0.94	**0.52**	**0.15**	-0.01	**0.46**	**0.25**					
7	Knowledge Diversity (LDA)	0.36	0.09	0.00	0.76	**0.17**	**0.05**	0.00	**0.16**	**0.09**	**0.34**				
8	Skewness	0.83	1.05	-2.47	5.74	**0.21**	**0.11**	**0.16**	**-0.04**	**0.71**	**0.27**	**0.10**			
9	New Knowledge Adoption	4.63	7.46	0.00	123.00	**0.62**	**0.09**	**-0.04**	0.15	**0.05**	**0.15**	**0.12**	**0.06**		
10	Structural Holes	0.46	0.29	0.03	1.84	**-0.13**	**-0.07**	**-0.21**	**0.23**	**-0.88**	**-0.18**	**-0.08**	**-0.64**	-0.01	
11	Career age	14.69	10.64	0.00	59.00	**0.09**	-0.03	0.02	**0.08**	**0.07**	**0.32**	**0.13**	0.07	**-0.17**	-0.09

Number of observations: 12,484

Number of egos: 2,906

Correlations with bold numbers are significant at $p<0.05$

Table 3 | Variance Inflation Factor

Variable	VIF	$\sqrt{VIF}$
Publications	1.47	1.21
Centrality	2.15	1.47
Citations (lag)	1.06	1.03
Career age	1.00	1.00
Knowledge diversity	1.53	1.23
Avg. Tie Strength	1.67	1.29
Structural Hole	2.08	1.44
Skewness	1.94	1.39
Avg. Coauthors	1.10	1.05

Figure 3. Estimated interaction effects

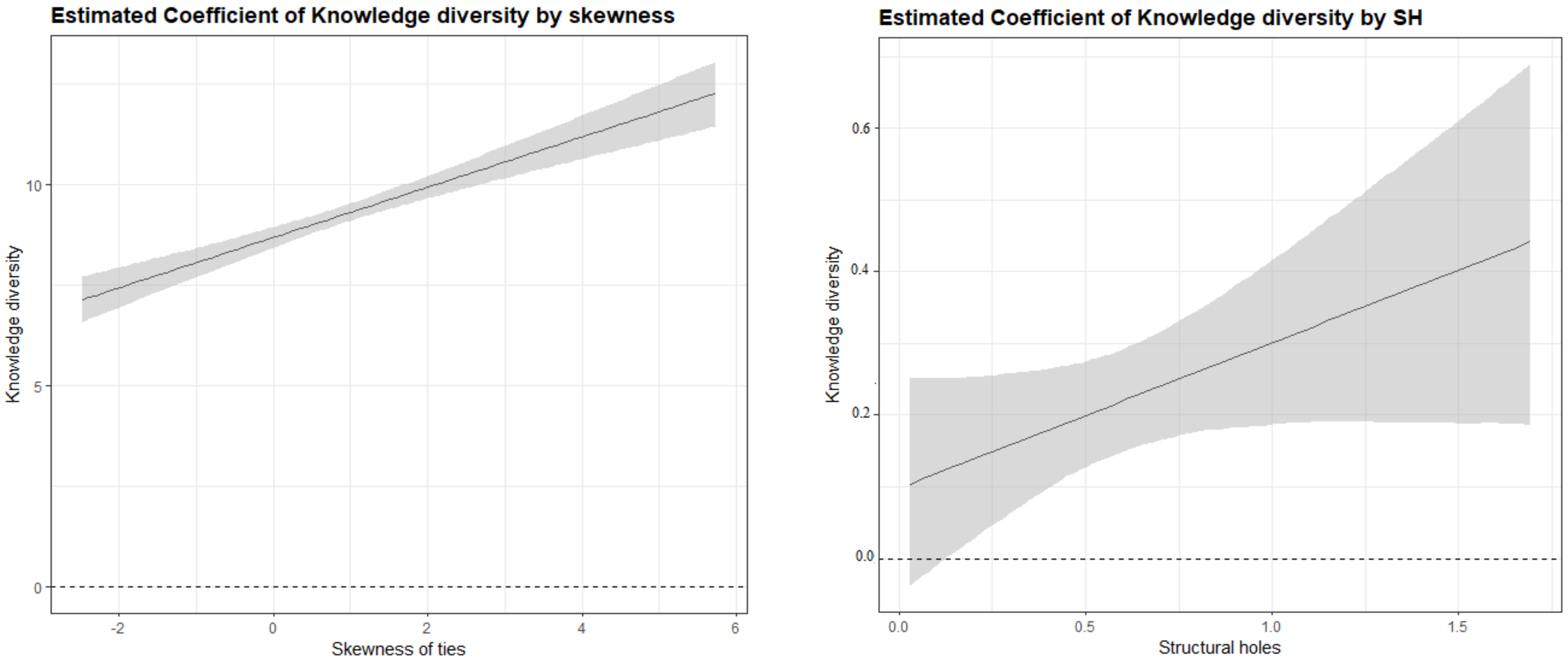

Table 4| Fixed effects Poisson models

	DV: Count of new subject fields						
	Controls only	Knowledge Diversity LDA			Knowledge Diversity ASCJ		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Publications	**0.0692** ***			**0.0691** ***			**0.0683** ***
	0.0006			0.0006			0.0006
Centrality	**0.0341** ***			**0.0312** ***			**0.0429** ***
	0.0021			0.0026			0.0027
Centrality (sq)	**-0.0002** ***			**-0.0002** ***			**-0.0003** ***
	0.0000			0.0000			0.0000
Lagged Citations	**-0.0141**			**-0.0144** ***			**-0.0099** ***
	0.0061			0.0061			0.0061
Career Age	**-1.0792**			**-1.0611**			**-1.2266**
	1.1549			1.1549			1.1549
Career Age (sq)	**0.0016**			**0.0017** ***			**0.0009** ***
	0.0002			0.0002			0.0002
Avg. Tie Strenght	**0.0256** ***			**0.0271** ***			**0.0352** ***
	0.0055			0.0056			0.0057
Avg. Tie Strength (sq)	**-0.0012** ***			**-0.0012** ***			**-0.0015** ***
	0.0002			0.0002			0.0002
Structural Holes		**-0.2719** ***	**0.1323** ***	**-0.3099** ***	**-0.3247** ***	**-0.1580** ***	**-0.3805** ***
		0.0340	0.0282	0.0661	-0.0389	0.0323	0.0374
Skewness		**0.1003** ***	**0.1327** **	**-0.2389** **	**0.1339** ***	**0.1772** ***	**0.2890** **
		0.0022	0.0084	0.0152	0.0085	0.0327	0.0362
Knowledge Diversity		**0.7060** ***	**1.1236** ***	**0.8767** ***	**0.7302** ***	**1.1621** ***	**1.4176** ***
		0.0101	0.2545	0.1986	0.0049	0.1236	0.1308
Skewness*Knowledge Diversity			**0.0408** ***	**0.3002** ***		**0.0504** ***	**0.3726** ***
			0.0075	0.0552		0.0408	0.0460
Structural Holes*Knowledge Diversity			**0.1725** ***	**1.4386** ***		**0.8986** ***	**1.4189** ***
			0.0346	0.2886		0.1725	0.1830
Ego FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Log pseudolikelihood	-20450	-29455	-29513	-20433	-29541	-29513	-20176
Nmb of observations	12484				* p<.10		
Number of egos	2906				** p<.05		
891 observations dropped because of single observations	891				** p<<01		

Robust s.e. beneath coefficient

CHAPTER 5. CONCLUDING REMARKS

Social networks has been shown to have significant effects on knowledge related outcomes – from the creation, to the transfer and adoption of knowledge (Phelps, Heidl et al. 2012). The dissertations' main contribution is to the knowledge network literature. The vast literature on the subject has shown that many structural positions provides opportunities and constraints across the different knowledge outcomes at the individual, team and organizational level (e.g. (Granovetter 1977, Burt 2004, Tortoriello, Reagans et al. 2012, Gonzalez-Brambila, Veloso et al. 2013, Wang 2016, Grigoriou and Rothaermel 2017, Moreira, Markus et al. 2018).

However, three distinct areas within the knowledge network literature still remain somewhat unexplored, in which I aimed to contribute with this dissertation. First, focus in extant literature has been on proving the actual downstream effect of network embeddedness or relational position, and less on the network antecedents (Ahuja, Soda et al. 2012, Phelps, Heidl et al. 2012). A reason for this might be the difficulty in gathering longitudinal data usable for network analyses as well as a lack of access to models controlling for the inherent endogeneity of collaboration and behavior/performance. And as the network structure is an endogenous force providing either opportunities or constraints on both performance and network structure, it can have significant impact if not properly controlled for. I contributed to the area of knowledge network theory by utilizing Feld's focus theory, and found that the context, specifically it's durability influences the impact of commonly used network measures. Here, centrality obtained in focus, i.e. temporal settings, has a negative impact on both the probability of scientists becoming more central, as well as holding a negative impact on the probability of creating high impact papers (only weak significance, though). This is in sharp contrast to the impact of centrality obtained out of focus, where we observe the reverse effects. This calls for further investigation of the context in which network metrics is observed, especially when the ties are created in a setting with limited organizational temporal duration.

Second, most studies on the effects of social networks on knowledge related outcomes has emphasized the structural position of an ego, or the tie configuration that connects ego to his or her alters. However, recent literature has started to emphasize the network effects of alters' network on ego (Shah, Levin et al. 2018).

Further, recent literature has shown effects of effort increases can be negative (Reschke, Azoulay & Stuart, 2017; Bendersky & Shah, 2012). In the second essay, I, alongside my co-authors, build on and extend this stream of work on the relationship between alter centrality and performance. The finding that while highly central collaboration partners increase performance, working with co-authors engaged in centrality increases do not, were surprising. Further, it was not observed how the centrality increasing parties themselves are affected over time. The negative spillover effect could result in focal scientists choosing to work with other co-authors in the future and perhaps the centrality increasing co-authors ability to collaborate might suffer from that. Future work ought to explore this relationship. The essay also contributes to the literature on top performers as the stars of a field seems to play by a different set of rules than other collaborators. From a societal perspective, it might be concerning about the very highest performance levels and how these extremes are reached. Future work should prioritize the relationship between network effects, network dynamics, and top performance, which could further our understanding of the dynamics proposed by Merton (1973) and later Reschke et al. (2014) on how status dynamics affects opportunities and constraints for top performance.

Third, my last essay adds to the literature on knowledge networks emphasizing the need to not only study a dichotomous relationship between strong and weak ties, but also the distribution (Wang 2016). Further, I expand on network theory, where I find a negative effect of structural holes on new knowledge adoption, which is counter the hypothesized relationship. However, in the literature both a positive effect of structural holes, and of high density on new knowledge adoption has been found. Thus, my finding of knowledge diversity positively moderating this relationship adds to the contingency view proposed in (Phelps, Heidl et al. 2012). This calls for further investigations on how, and whether, generalists utilize their network embeddedness differently than more specialized peers.

Besides adding to the literature on knowledge networks I also add to the emergent literature within the organization of science, specifically on generalists and specialists (Agrawal, Goldfarb et al. 2013, Agrawal, Goldfarb et al. 2016, Nagle and Teodoridis 2017, Teodoridis, Vakili et al. 2017, Furman and Teodoridis 2018, Teodoridis 2018, Teodoridis, Bikard et al. 2018). Here, recent findings indicate that the knowledge diversity of individuals are indicators of individual level absorptive capacity (Tortoriello 2015, Nagle and Teodoridis 2017). As (Cohen and Levinthal 1990) originally states, an organization's absorptive capacity depends on the cognitions and behaviors of individuals (Distel 2019). From that, it follows that organizational capabilities are rooted in the interactions and actions of individuals in where they are embedded (Volberda, Foss et al. 2010). This gives indications that the social networks in which agents are embedded has explanatory power for the absorptive capacity at the individual level (Tortoriello, Reagans et al. 2012). By combining these views, the absorptive capacity view and findings with regards to knowledge diversity, I proposed that knowledge diversification acts as a moderator on the influence of network positions on new knowledge adoption. As the individual has more exposure to knowledge from different knowledge domains, it effectively increases their ability to reap the benefits of being in a socially embedded position. Since I only measure whether a new knowledge topic is adopted, this begs the question for future studies whether the distance of the adopted topic play specific roles.

Last, I add to our understanding of how knowledge production evolves at large scale research infrastructures. The findings of (Lauto and Valentin 2013, D'Ippolito and Rüling 2019) indicates that in order to reap the benefits of these facilities, that each constitute major, often cross-nation, funding, it is important to understand the collaborative patterns that is created in lieu of these constructions. The findings of all the essays is based on data from one of these facilities, and thus gives a unique insight into the collaborative nature of these facilities. As an example, understanding the need for not only very specialist instrument scientists, by also make room for scientists with a broader scope of accomplishments, could be beneficial. Further, for the selection of scientists to stay at the facility, I identified two distinct strategies, where selecting scientists to stay at the facility who are highly central in the network of scientists, would increase the probability of creating high impact science. It further begs the question on how to control collaborative strategies, in that I have shown that certain strategies, that of pursuing centrality increases yourself (direct) or also your alters, might impact knowledge production.

This dissertation should also be viewed in the light of its general limitations. First, only one specific facility was used as the empirical setting. This study would undoubtedly have benefitted from data on other LSRF in order to increase generalizability. Further, as with all networks, it is important to gather insights of the full scope of the embeddedness of the agents that is part of it (Schilling and Phelps 2007). However, the sudden co-location of scientists in my setting does enable me to isolate the network mechanisms better than if choosing e.g. a university or firm, as unit of analysis. Third, lacking an experimental, or quasi-experimental setup reduces the effective predictive power of the estimates made in the quantitative analysis. I have controlled for most effects typically seen in the literature when using bibliometrics (Wang 2016) as the core data source, however evidence shown is still only correlational.

Despite these limitations, this dissertation is an initial attempt to open up an avenue for future research on the influence of network alters on individual performance the nature of knowledge diversity as a moderating effect, on network positions, effectively acting as absorptive capacity at the individual level, and finally on the endogenous nature of network evolution.

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