GREAT IDEA, NOW WHAT? THREE ESSAYS EXAMINING THE RELATIONSHIP BETWEEN ORGANIZATION DESIGN AND COMMERCIALIZATION OF KNOWLEDGE

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This Dissertation is dedicated to my late parents Jack and Maria Eklund

Thank you for supporting all the crazy diversions in my life

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"If any particular organization isn't screwed up now, it used to be, or soon will be! That is the reality of organizational life"

Geoffrey M. Bellman (The Consultant's Calling, 2002)

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ABSTRACT

GREAT IDEA, NOW WHAT? THREE ESSAYS EXAMINING THE RELATIONSHIP BETWEEN ORGANIZATION DESIGN AND COMMERCIALIZATION OF KNOWLEDGE

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Innovation is a key driver of a firm's overall performance. Within an organization, innovation involves multiple actors transforming a firm's knowledge into a final market offering. How an organization is designed can shape this transformation by influencing actors' behaviors and interactions. However, despite prior studies, our understanding of the relationship between organization design and innovation is somewhat limited.

In this dissertation, I offer a framework in which I conceptualize innovation as a process consisting of upstream tasks around invention, and downstream tasks around product development and commercialization. This enables me to combine both knowledge- and incentives- based views of the firm to develop a more complete theoretical understanding of the relationship between organization design and innovation. The design attribute I focus upon is the degree of organizational centralization. On the one hand, more centralized designs are associated with enhanced intra-organizational knowledge flows, which can enhance innovation. On the other hand, more decentralized designs are associated with higher observability of effort and facilitate the more effective use of incentives, which can increase innovation efforts.

I empirically examine this trade-off in the context of the pharmaceutical industry. I use a unique dataset of firms' patents, clinical trials, sales and organization structures supplemented by 61 interviews with senior managers from 28 of my sample firms. I find that greater decentralization while yielding higher numbers of inventions is associated with

less original inventions, and fewer inventions progressing through the earlier stages of development. However, greater decentralization is associated with more inventions progressing through the later stages of development and greater sales of new products as a proportion of total sales. Further, I find that firms with decentralized Research & Development units are associated with a higher proportion of externally sourced inventions primarily driven by licensing.

This dissertation contributes to the organization design and innovation literatures by highlighting where (in the organization) and when (in the innovation process) design choices can impact both how firms innovate as well as their innovation outcomes.

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Organization Design and Innovation: Old Hat or Perpetual Problem?

> *"We think we have the right architecture not just in silicon but in our organization to build these kinds of products." Steve Jobs, Former CEO Apple (2011)*
>
> *"You have to combine both things: invention and innovation focus, plus the company that can commercialize things and get them to people," Larry Page, CEO Alphabet (2014)*
>
> *"Structure is super important," Satya Nadella, CEO Microsoft (2018)*
>
> *"It occurred to me that building a company was the best way to align a group of people towards building something great. And it's really... it's a good organizational structure where you can really reward people," Mark Zuckerberg, CEO Facebook (2010)*

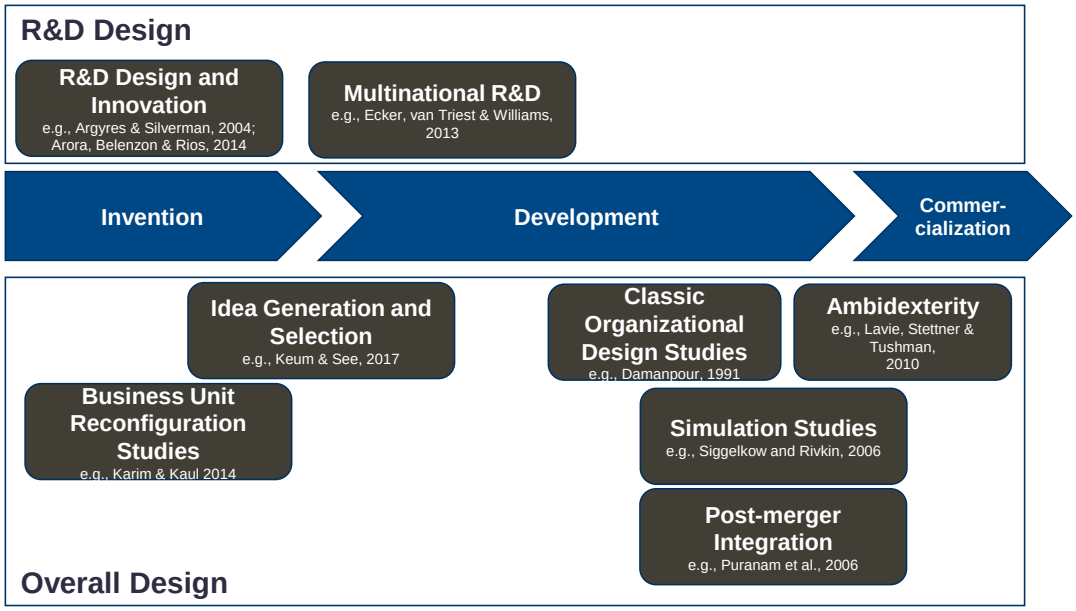
These quotes by the CEOs of some of the most innovative companies of the twenty-first century serve to highlight that senior managers pay a great deal of attention to organization design. This is not surprising because within an organization, innovation involves multiple actors transforming a firm's knowledge into a final market offering. These actors can include scientists within Research and Development (R&D) who create the initial idea, engineers in manufacturing that ensure the idea can be created at scale and marketers who identify the appropriate target markets and define plans to launch the idea into the market. Innovation involves broad swathes of an organization, it is not just an R&D thing! How an organization is designed can thus shape the transformation of knowledge into a final offering by influencing actors' behaviors and interactions.

Yet, despite the clear importance of understanding the relationship between organization design and different facets of organizational performance such as innovation, scholars turned away from the study of organization design in the late 1980s. This was driven by multiple challenges associated with examining the topic such as obtaining accurate data on firms' structures (Greenwood & Miller, 2010). However, recently the study of organization design has gone through a renaissance driven by multiple scholars

(e.g., Arora, Belenzon, & Rios, 2014; Csaszar, 2012; Joseph, Klingebiel, & Wilson, 2016; Puranam, Alexy, & Reitzig, 2014; Zhou, 2013).

Despite this hiatus, the relationship between organization design and innovation has been touched upon in multiple literatures within the strategic management domain. However no clear, coherent picture emerges of the relationship between organization design and innovation.

Figure 1: Brief overview of the variety of literatures examining the relationship between organization design and innovation.



These studies have examined a variety of facets of organization design and innovation as illustrated in Figure 1. As can be seen, these studies have tended to focus on the creation of inventions (e.g., Argyres & Silverman, 2004; Arora et al., 2014), the development of inventions into new products or internal adoption of new innovations (e.g., Damanpour, 1991; Damanpour & Aravind, 2012) and the commercialization of new products (e.g., Tushman, Smith, Wood, Westerman, & O'Reilly, 2010) in isolation. Thus this prior work has examined different stages of the innovation process separately providing a disjointed picture of how design and various facets of innovation are related as

very different innovation outcomes are examined (Garud, Tuertscher, & Van de Ven, 2013). These outcomes range from patent outputs (e.g., Arora et al., 2014) to product launches (e.g., Puranam, Singh, & Zollo, 2006) and overall performance (e.g., Siggelkow & Rivkin, 2006). These studies have also examined design at a corporate or overall organization level (e.g., Damanpour, 1991) and at a functional unit level such as R&D (e.g., Argyres & Silverman, 2004). Further, design has been examined from a horizontal perspective (e.g., Tushman et al., 2010), in which an organization is divided into more units, and a vertical perspective, in which authority is delegated down the organization (e.g., Keum & See, 2017). Thus, despite this existing body of work, a "joined-up" perspective of how different facets of organization design impact both how firms innovate as well as their innovation outcomes across the innovation process is needed.

In organizing to innovate a key design feature is the degree to which firms centralize or decentralize their innovation activities in order to enable ample integration yet facilitate sufficient focus and clarity of roles and responsibilities (e.g., Galbraith, 1977; Lawrence & Lorsch, 1967; Puranam, Alexy, & Reitzig, 2014). Much of the organization design literature suggests that increased decentralization is associated with enhanced innovation outcomes (e.g., Damanpour, 1991; Siggelkow & Rivkin, 2006). In contrast, studies focused primarily on firms' Research and Development (R&D) units suggest that greater decentralization of R&D is associated with reduced inventive productivity and less original and general inventions (e.g., Argyres & Silverman, 2004; Arora et al., 2014; Ecker, van Triest, & Williams, 2013). However, as highlighted above these studies are looking at different stages of the innovation process and different facets of organization design making it difficult to compare outcomes and develop a holistic picture. Thus in this dissertation I aim to unpack the innovation process into its constituent stages and examine how decentralization at both an innovation unit (e.g. R&D) and an overall corporate level are related with a variety of innovation outcomes across the innovation process.

Internal organization design can also impact how firms innovate as well as their innovation outcomes. Specifically, firms' designs could shape their decision to create inventions internally or source them externally prior to developing them internally. However, despite significant attention being paid to the phenomenon of open innovation

(e.g., Chesbrough, 2006; Lichtenthaler, 2011; West, Salter, Vanhaverbeke, & Chesbrough, 2014), our understanding of how internal design choices can shape this "make-buy" choice is limited. Recent studies have started to address this gap by illustrating that decentralized firms are more reliant on external knowledge (e.g., Arora et al., 2014) but this remains a nascent research domain with several unanswered questions. Further, existing research has considered this decision to take place at the firm-level and the logic for decision-making at the transaction-level (e.g., Argyres & Liebeskind, 1999; Bidwell, 2012). However, firms may decentralize such decisions within specific units, and decision-making might operate at the pipeline-level rather than at the individual transaction-level.

This brief overview highlights that internal organization design can vary in its impact on firms' innovation outcomes across the innovation process as well as shape whether firms undertake certain parts of the innovation process with the boundaries of the firm or externally. However, we do not have a coherent picture of how organization design is associated with both how firms innovate (i.e. undertake certain stages of the innovation process internally or externally) as well as their innovation outcomes across the innovation process. Thus the focal research question in my dissertation is:

> *How are different facets of organizational decentralization (e.g. R&D, overall organization) associated with how firms innovate as well as their innovation outcomes across the innovation process spanning invention to ultimate commercialization?*

In answering this research question, I develop a theoretical framework that unpacks the innovation process into its key stages and on-going sets of activities. I conceptualize the innovation process as consisting of invention, development and commercialization stages (e.g., Garud et al., 2013). This enables me to juxtapose a knowledge-based with an incentive-based perspective in building my theoretical arguments. This builds on previous work which has called for scholars to use both theoretical lenses when examining firms' pursuits (e.g., Argyres, Felin, Foss, & Zenger, 2012; Dosi, Levinthal, & Marengo, 2003; Foss, 1996; Kapoor & Lim, 2007).

In the remainder of this introduction chapter I describe the three key components of my dissertation that I use to examine how firms' organization designs and their

innovation outcomes as well as how they innovate are related. First, I describe the innovation process framework that I leverage in this dissertation and that links all three chapters of the dissertation. Second, I describe how I examine organization design in this dissertation. Third, I highlight the two primary theoretical lenses that I utilize to develop my unique theoretical argumentation and set of hypotheses. I then describe the empirical context for this dissertation. I conclude this chapter with an overview of the three dissertation papers and a brief statement about the novel elements of this dissertation.

Examining Innovation as a Process

Rather than viewing innovation as an outcome I view innovation as a process as illustrated in Figure 2. Clearly the framework simplifies and linearizes the conversion of knowledge into ultimate commercial outcomes. The crux of this framework revolves around distinguishing between invention, development and commercialization. In reality, innovation is unlikely to be such a linear process with firms moving back and forth between stages and potentially completely missing stages.

Figure 2: The innovation process framework that I utilize in this dissertation

Innovation Process

	Invention	**Development**	**Commercial-ization**
Tech. knowledge intensity	High	Medium	Low
Knowledge focus	Recombination of technical knowledge	Troubleshooting development issues	Market and customer knowledge
Functions involved	R&D	R&D Commercial Functions	Commercial Functions
Key Innovation Outcomes	Number of Inventions Originality	Progression of Inventions through process	Value capture from innovations

However, this simplified framework provides me a way to systematically unpack the major elements of firms' innovation activities. Further, this framework helps me to compartmentalize specific research questions that will form the focus of each of my three dissertation chapters. I will now describe each of the three stages in this innovation process model.

Stage 1: Invention

The first stage involves the aggregation of a firm's knowledge to develop an invention. Scholars have generally defined invention as the generation of new ideas and knowledge (e.g., Arora, Cohen, & Walsh, 2016; Kapoor & Klueter, 2015; Schumpeter, 1939). However, other scholars indicate that the ideas generated must work and have a degree of usefulness above some threshold value (e.g., Fabrizio, 2009; Roberts, 1999) despite the fact that an invention in itself may provide little economic benefit (e.g., Schumpeter, 1939). For the purpose of this dissertation, I define *an invention as an aggregation of a firm's knowledge with the intention of serving a specific purpose.*

Invention tends to be primarily driven by firms' Research and Development (R&D) organizations (e.g., Argyres & Silverman, 2004; Makri, Hitt, & Lane, 2010; Wu, Levitas, & Priem, 2005) as the focus is largely on the creation of new knowledge and its recombination with existing knowledge. Invention has been described as a process of distant search (e.g., Fleming, 2001; Fleming & Sorenson, 2004; Schumpeter, 1939) where knowledge is recombined from multiple sources that are both new to and exist within the firm.

The invention creation process with its focus on new knowledge generation or combination of different elements of existing knowledge is likely to involve the sharing of highly tacit knowledge (e.g., Grant, 1996). Invention involves the creation of new constructs and ideas for which no pre-existing codified or explicit knowledge may exist. Thus in order to develop an invention, rich communication channels are required to ensure different parties involved in the recombination of existing and new knowledge have the same understanding of the knowledge being shared (Grant, 1996). The issues involved in

invention may be so complex that multiple iterations of knowledge sharing may be required further accentuating the need for rich communication channels and strong intra-organizational knowledge flows. Invention is not a process with clearly defined routines as *ex ante* the solution to a specific inventive problem is not obvious requiring the broad search process described above. If fact scholars have suggested that over-reliance on routines can harm this creative process (e.g., Dougherty & Hardy, 1996).

Stage 2: Development

The second stage of the innovation process involves the development of inventions into final market offerings (e.g., Hitt, Hoskisson, & Nixon, 1993; Katila & Shane, 2005). The process of development consists of multiple activities such as selecting the inventions to be commercialized, supplementing inventions with complementary knowledge to help build final offers, refining inventions so that they can be manufactured at scale and evaluating the potential commercial attractiveness of final offers (e.g., Mitchell & Singh, 1996; Zahra & Nielsen, 2002). Katila and Shane (2005) define development as "a process that begins with an invention, proceeds with the development of the invention, and results in the introduction of a new product, process or service to the marketplace." For the purposes of this dissertation, I define *development as the process of converting an invention into a marketed offering.*

The organizational scope for development is generally much broader than that for invention. Development encompasses a wide range of functions ranging from R&D to marketing to manufacturing (e.g., Dougherty, 2001; Dougherty & Heller, 1994; Stuart & Podolny, 1996). The development of inventions involves a sequence of specific decisions that may pertain to different organizational units thereby requiring specific localized knowledge such as, for example, knowledge of customer needs and specific manufacturing processes. Effectively, invention focuses on the "big picture" and development is primarily about the "details".

Development involves more localized as opposed to distant search (Katila & Ahuja, 2002). Further, development is likely to involve more explicit knowledge based on, for

example, well-defined routines (Nelson & Winter, 1982) such as documented processes. Development is effectively the fine-tuning of an invention and is focused on local search in the area designated by the more distant search processes of invention (e.g., Levinthal, 1997). For example, drug R&D involves broad search in the inventive pre-clinical phase and requires combining the knowledge of chemists, biochemists, physiologists and several other scientific disciplines to develop patented, novel drug candidates and does not generally have a well-defined and documented process that a firm can follow. The development stage involves the clinical development of drugs and comprises smaller modifications to the favored drug target and trials that tend to follow well-documented process often prescribed by bodies such as the Food and Drug Administration (FDA) (e.g., Fleming & Sorenson, 2004; Pisano, 2006).

Due to the fact that the knowledge associated with development is more explicit than that associated with invention, the requirements for the rich communication channels described above are not as great. As a result, organizational interfaces are likely to have less of an adverse effect on the knowledge flows associated with development because of the ability to use explicit communication tools to ensure that a common language is being spoken across an organization (e.g., Grant, 1996).

Stage 3: Commercialization

The third stage of the innovation process involves commercialization. I define *commercialization as the capture of value from firms' newly developed marketed offerings.* Despite the importance of understanding what shapes firms' ability to commercialize their new products this stream of research is a relatively "*fragmented field of study*" (Kirkegaard Sløk-Madsen, Ritter, & Sornn-Friese, 2017) and *"remains poorly understood"* (Datta, Mukherjee, & Jessup, 2015). However, some existing strands of work provide some insight into how firms' organization design attributes could impact their ability to capture value from their new offerings.

Based on the classic work of Lawrence and Lorsch (1967), Burns and Stalker (1961) and more recent simulation-based work undertaken by scholars such as Rivkin and

Siggelkow (2003), organizations need to have a good fit between their designs and the external environment if they are to receive a more positive response to their new offerings. Similarly, Matthyssens, Philippe Gosselin, and André Bauwen (2006) highlight the importance of alignment between organizations' customer management structures and customers' own structures for successful delivery of new offerings.

Christensen and Bower (1996) illustrate that existing customers may limit firms' ability to successfully commercialize their new offerings, opening up opportunities for new entrants to serve smaller, less initially attractive, segments with the relevant marketed offer. However, if firms created stand-alone units they tended to have more success in being able to launch their inventions to the relevant market place as they are less encumbered by current customer needs (e.g., Christensen & Bower, 1996; Tushman et al., 2010). The findings from this work are consistent with studies that have illustrated that firms may struggle to commercialize new offerings that are inconsistent with their current business models (e.g., Kapoor & Klueter, 2015). For example, Xerox has an illustrious history of developing ground-breaking inventions but not successfully commercializing them (Chesbrough & Rosenbloom, 2002). Ultimately, Xerox sought to capture value from new technologies that did not align with their primary business model of leasing printing and copying equipment to corporate clients by spinning-off separate companies. Thus rather that changing or adapting their internal design, Xerox simply created new companies for inventions that did not align with their existing business.

These studies serve to highlight that firms' ability to capture value from their inventions can be influenced by how they are structured. However, this stream of literature is relatively under-developed and offers exciting opportunities for future research.

Organization Design: Definition and Key Elements

How have organization design and structure been defined and described?

Based on the seminal work of Simon (1950), organization design relates to the management of communications and relationships between actors within a firm so that

effective decisions can be made and implemented. Building on this description, scholars have emphasized the role of organization design in enabling actors within organizations *to make* effective decisions through access to relevant information provided through good communication flows (e.g., March & Simon, 1958; Siggelkow & Rivkin, 2005). Organization design thus relates to allocation of decision rights and the means by which communications are channeled through an organization. In terms of *implementing decisions* and in the neo-classical economic spirit, other scholars describe organization design as the means by which the efforts of actors across a firm can be effectively coordinated and aggregated to achieve specific goals (e.g., Child, 1984; Galbraith, 1977). Thus according to this view, organization design relates to the allocation of inter-dependent tasks, and ensuring the effective cooperation and coordination of actors undertaking these tasks (e.g., Puranam et al., 2014). Building on this perspective, Puranam, Raveendran, and Knudsen (2012) describe organization design "*as a means to meet the information processing requirements generated by individuals and groupings of individuals undertaking interdependent activities."* Pulling these strands together and building on the definition of Simon (1950), organization design is a means by which organizations enable effective decision-making through appropriate allocation of decision rights and facilitation of communication flows to decision-right holders. Further, organization design is a means by which interdependent tasks are allocated, divided and coordinated such that these decisions can be effectively implemented.

A tangible manifestation of an organization's design is its structure (e.g., Burton, Obel, & DeSanctis, 2011; Csaszar, 2013; Harris & Raviv, 2002). Building on the classic work of Chandler (1962), the structures of large firms can take multiple forms such as the functional form in which different organizational units undertaking related functional tasks (e.g. Human Resources, Research & Development) are grouped together or the divisional form in which the firm is divided along specific product/service lines in which cross-functional teams work together to achieve organizational goals to name but two. Such structures relate to the formal aspects of organization design which form the focus of the work in this dissertation. However, it should be recognized that recent scholastic attention has shifted to more informal elements of design and the creation of new organizational

forms (e.g., Baker, Nohria, & Eccles, 1992; Brass, Galaskiewicz, Greve, & Tsai, 2004; Kotha & Srikanth, 2013; Tsai, 2002). Ultimately these new forms provide alternative solutions to the standard problems organization design is tasked to address (e.g., Puranam et al., 2012). However, formal design attributes are still of paramount importance to managers (e.g., Siggelkow & Rivkin, 2005).

Such formal structures include an array of design attributes that will ultimately impact how decisions are made and executed. These attributes provide a means of comparing structures across organizations - effectively providing a common currency. Foundational work examining organization structure describes an array of attributes such as centralization, formalization, specialization, standardization (e.g., Child, 1973; Damanpour, 1991). This can create a complex taxonomy of attributes relating to how structures are described. However, returning to the original description of organization design, this myriad of attributes ultimately describe features of the structure that relate to where decisions are made, mechanisms for facilitating communication flows, how tasks are divided and allocated and methods to integrate this activity.

In the context of this dissertation the key structural attribute on which I focus is decentralization. Decentralization/centralization is generally defined as the extent to which decision-making autonomy is dispersed or concentrated in an organization (Pfeffer & Lammerding, 1981). Some scholars take a vertical perspective defining centralization as the degree to which decisions are made higher up the hierarchy within an organization and state it is inversely related to the degree of autonomy of more junior managers which involves greater decentralization (Russell & Russell, 1992; Sathe, 1978). Others take a more horizontal perspective and define the degree of decentralization in terms of whether a corporate function drives key decisions as opposed to strategic business units (see for example Hrebiniak (2013) and Arora et al. (2014)). It is the latter attribute on which I focus in this dissertation.

In addition, different parts of an organization can have higher or lower degrees of decentralization. For example, some functions may be highly centralized (e.g. Finance, Human Resources) and under corporate control whereas others can be highly decentralized

and operate in relatively autonomous business units (e.g. sales and marketing). The ultimate manifestation of such attributes of some functions being centralized and others being decentralized is the classic Matrix-organization (e.g., Galbraith, 1971, 2008). In this dissertation I focus on decentralization of firms' Research and Development (R&D) units as this is the focal unit for firms' invention and development activities. I also examine overall organizational decentralization. By overall organizational decentralization I refer to firms that are more functionally (centralized) or divisionally (decentralized) aligned (Burton et al., 2011).

A broader perspective on organization design

The description of organization design provided above focuses within the firm. However it is silent with respect to what activities and decisions are made within the firm as opposed to outside the firm. Taking the broad description of organization design as the means by which firms make and implement effective decisions, defining whether decisions are made and executed within or outside the focal firm would appear to be a key design choice. This design consideration has traditionally been under the purview of the "Boundaries of the Firm" literature (e.g., Teece, 1980, 1982; Williamson, 1979, 1985a, b) but can be argued to be a key aspect of organization design.

As a result, in this dissertation I take a broader perspective on organization design in that I examine two different organization design choices. First, there are "Boundary Design" choices. Based upon the specific goals and strategies required to achieve these goals, what decisions and tasks should be undertaken within the focal firm and how is coordination and cooperation achieved between the entities undertaking these decisions/tasks (e.g., Puranam et al., 2014)? Second, there are "Internal Design" choices. These choices focus upon how decisions/tasks are divided and allocated within the focal firm and how coordination and cooperation is ensured across all these internal sub-units. These internal design features can ultimately influence firms' innovation outcomes throughout the innovation process.

Chapters 2 and 4 focus exclusively on "internal design" attributes and how they are

related with a variety of innovation outcomes across the entire innovation process from invention to commercialization. In Chapter 3, I examine how firms' internal design features can shape whether they undertake invention activities within the firm or externally through carefully-selected partners i.e. how firms invent or "boundary design" choices. This chapter serves to highlight that internal and boundary design choices are intricately linked and cannot be seen as two independent choices by managers within firms.

Knowledge and Incentives: The Theoretical Underpinnings of this Dissertation

To theoretically examine my two research questions I integrate both a knowledge-based perspective (e.g., Barney, 1991; Grant, 1996) with a more organizational economics inspired incentives-based lens (e.g., Kaplan & Henderson, 2005). Although scholars have historically tended to see these theoretical perspectives as being in opposition, the debate has shifted to integrating these theories (e.g., Argyres, 2011; Argyres, Felin, Foss, & Zenger, 2012; Kapoor & Lim, 2007). However, this recent work has primarily focused on examining the boundaries of the firm with little attention being paid to firms' internal design (e.g., Argyres & Zenger, 2012).

The knowledge-based view of the firm describes the firm as a repository of knowledge (e.g., Grant, 1996; Kogut & Zander, 1992). In this theoretical perspective, the firm is a problem-solver that attempts to recombine its employees' knowledge to address complex technical problems (e.g., Fleming, 2001; Fleming & Sorenson, 2004; Karim & Kaul, 2015; Katila & Ahuja, 2002). In addressing these problems it is important that the organization is designed such that it can optimize intra-organizational knowledge flows to facilitate the recombination of knowledge from across the organization (e.g., Henderson & Cockburn, 1994; Karim & Kaul, 2015). This perspective ultimately provides insights into what firms are *able* to do.

The incentives-based view of the firm sees the firm as a bundle of contracts (Hart & Moore, 1990; Hölmstrom, 1979). Based on this perspective, the firm needs to incentivize the actors within the firm appropriately to ensure effective coordination and cooperation

(e.g., Puranam et al., 2014; Zenger, 1992). In addressing these problems it is important that the organization is designed such that it can optimize the effectiveness of usage of incentives. Further, organization design can shape how resources are allocated across an organization through this incentives-based mechanism (e.g., Stein, 1997). This perspective ultimately provides insights into what firms *choose* to do.

Organization design can influence intra-organizational knowledge flows and the effectiveness of the usage of incentives. For example, greater decentralization into smaller more autonomous units is associated with an increased ability to use higher-powered incentives more effectively (Zenger & Hesterly, 1997). Thus in developing my theoretical arguments I examine how different design elements impact both knowledge flows and incentives.

Beyond their direct effects, incentives and knowledge flows influenced by organization design can also impact how resources are allocated within an organization. Resource allocation can subsequently impact both how firms innovate as well as their innovation outcomes. First, reduced incentives to invent internally driven by shorter-term focused business units can result in more invention being undertaken outside of the boundaries of the firm (Arora et al., 2014). Similarly, a reduced ability to recombine knowledge internally can result in more invention resources being allocated externally (Grigoriou & Rothaermel, 2017). This serves to highlight the point I make above that internal organization design is intricately linked to the boundaries of the firm. I examine this phenomenon in Chapter 3. Second, focusing within the firm, managerial incentives can shape how resources are allocated across different innovation-related projects within a firm (e.g., Stein, 1997). In more decentralized designs, unit managers may actively compete for resources as they are strongly incentivized to ensure their units perform effectively. This can result in good innovation projects not being funded (e.g., Bardolet, Lovallo, & Rumelt, 2010). In contrast in more centralized designs, innovation projects will tend to be assessed at an individual level resulting in a more effective allocation of resources (Bardolet, Fox, & Lovallo, 2011). Effectively, resource allocators will tend to have better knowledge on all projects in a more centralized organization, whereas in the decentralized case unit managers may "play up" their projects potential to garner more resources. I examine this

phenomenon in Chapter 4.

The relative importance of knowledge and incentives is likely to vary throughout the innovation process. During invention and early development more distant search may be required to address the challenging technical problems which are likely to necessitate access to a firm's broader knowledge (e.g., Macher & Boerner, 2006). In contrast, as an invention progresses through development, the type of problems that need to be addressed become less complex and the knowledge required to undertake development tasks becomes more routinized and explicit, thus local search may suffice (e.g., Eisenhardt & Martin, 2000). Incentives are therefore likely to play a greater role in shaping development outcomes as inventions progress through development as firms are likely to be able to access the knowledge they need to undertake later development activities locally or through more explicit communications. Further, prior studies investigating the role of incentives in R&D imply that creating effective incentive schemes for the highly uncertain stages of research and early development is much more challenging than for the more certain later stages of development (e.g., Aghion & Tirole, 1994; Tirole, 1999). Thus higher-powered incentive schemes are likely to be more effective later in the development process.

Thus by combining a process-based view of innovation and the examination of how different design parameters impact knowledge flows and incentives I am able to unpack different aspects of the relationship between organization design and firms' innovation efforts. For example, the same design choice which may facilitate knowledge flows may results in enhanced innovation outcomes at some stages of the process but inferior outcomes at other stages.

Empirical Context for Dissertation

The empirical context for this dissertation is the global pharmaceutical industry. I focus on a sample of 49 leading firms based on annual sales of prescription drugs. This industry provides a highly suitable context for testing my theoretically-driven hypotheses as it has a well-defined innovation process. Starting with drug discovery which corresponds

to invention, through clinical development and ultimate new drug sales, this context maps neatly onto the theoretical framework I propose for the innovation process. Further, there is significant heterogeneity in pharmaceutical firms' organization designs driven by, for example, mergers, acquisitions and divestitures. This enables me to examine how different design elements can impact various facets of innovation.

A key challenge in investigating the impact of organization design on firms' performance is that of omitted variable bias. Namely, firms select into their organization designs and there may be an unobserved factor that correlates with a specific design choice and firms' innovation attributes resulting in misleading inferences as to the relationship between design and innovation. In order to address this issue I do four things.

First, I use propensity score matching to ensure that I am comparing like with like firms (based on observable variables) with different design attributes. This enables me to avoid extrapolating data such that I compare observations of very different firms using regular multiple regression techniques. Second, I undertake a variety of robustness tests to examine whether changes to model specifications impact the main results. These include coarsened exact matching (CEM) and the use of alternate variables. Third, I also execute a variety of supplementary analyses in which I examine the mechanisms through which organization design and various facets of innovation are related. Finally, I supplement my quantitative analyses with interviews with managers from within the pharmaceutical industry to reality test my observations derived from the quantitative analyses using archival data.

Overview of Dissertation

Summary of the three chapters

Error! Reference source not found. summarizes the key elements of each issertation chapter. In Chapter 2, I examine the invention and development stages of the innovation process (see Figure 2). My broad research question is *"How does a firm's organization design shape its innovation outcomes across invention and development?"*

On the one hand, taking a knowledge-based view, more centralized designs are expected to be associated with enhanced intra-organizational knowledge flows, which can enhance innovation. On the other hand, taking an incentives-based perspective, more decentralized designs are associated with higher observability of effort and likely to facilitate the more effective use of incentives, which can increase innovation efforts. I find that greater centralization is associated with the creation of more original inventions and more of these inventions progressing through the earlier stages of development. In contrast, greater decentralization is associated with the creation of more inventions and with more inventions progressing through the later stages of development. These results illustrate that knowledge flows play a more important role further upstream and incentives play a greater relative role further downstream. This study provides a theoretical framework for understanding both where (in the organization) and when (in the innovation process) design choices can facilitate or hinder innovation outcomes, thereby helping to reconcile some of the extant literatures' disparate findings.

In Chapter 3, I focus on the development stage of the innovation process. My broad research question is *"How does a firm's organization design shape its propensity to source inventions internally or externally?"* In their quest to sustain their innovativeness, firms pursue multiple inventions, with only a small proportion of them achieving fruition. In addition to the challenge of commercializing their inventions, firms also face the challenge of replenishing and maintaining the flow of inventions within their pipelines. This replenishment could be done via internally or externally sourced inventions through licensing, alliance or acquisition modes. Existing research has considered this decision to take place at the firm-level and the logic for decision-making at the transaction-level. In this paper the incentive- and knowledge-based views of the firm are integrated to offer a new theory to explain this decision. Within the theory, firms may decentralize such decisions within specific R&D units, and decision-making might operate at the pipeline-level rather than at the individual transaction-level. Thus this study considers different sources of heterogeneity within firms' decision-making processes, and how organization design can have significant implications for firms' invention sourcing. Decentralized designs with multiple R&D units are associated with a higher proportion of externally

sourced inventions. This difference is primarily driven by differences in the propensity to license, and for inventions of moderate novelty. These findings highlight an important linkage between firms' internal organization design and their sourcing of inventions, and in doing so, show how such decision-making is impacted by both managerial incentives and intra-organizational knowledge flows.

Table 1: Summary of how each dissertation chapter aligns to overall dissertation framework and themes

Chp.	Key research question	Steps of knowledge commercialization framework (Figure 2)	Design Element	Innovation Attributes Examined
2	"How does a firm's organization design shape its innovation outcomes across invention and development?"	1. Invention 2. Development	• R&D Decentralization • Corporate Decentralization	• Invention Quantity • Invention Originality • Progression of inventions through development process
3	"How does a firm's organization design shape its propensity to source inventions internally or externally?"	2. Development	• R&D Decentralization	• Proportion of inventions externally sourced • Mode of sourcing externally
4	"How does a firm's organization design impact the commercialization of firms' inventions?"	3. Commercialization	• Corporate Decentralization	• Proportion of sales of new products at different levels of SG&A and concentration of existing product sales

In Chapter 4, I examine the commercialization stage of the innovation process. My broad research question is *"How does a firm's organization design impact the commercialization of firms' inventions?"* In many industries firms' on-going livelihoods

are determined by the continuous commercialization of new products within their innovation pipelines. However, our understanding of what shapes a firm's ability to commercialize its new products appears to be somewhat limited. In this paper, I examine the process of firms' ongoing commercialization of new inventions emerging from their pipelines. I specifically evaluate how firms' organization designs can shape the proportion of a firms' product sales that come from new products. I argue that firms face a delicate balancing act. On the other hand, greater centralization enables more effective allocation of complementary resources which also aids commercialization. Complementary resources such as sales and marketing are critical in enabling firms to sell new offers. I argue that this balance of the benefits and costs of decentralization shifts with the level of complementary resources available and the degree of concentration of sales of firms' existing products. I argue that this is because business units in decentralized firms will tend to over-inflate the opportunities associated with their suite of products to garner more resources or focus such resources on prominent existing products on which they are highly dependent. This results in a less effective resource allocation in decentralized firms across products potentially starving new products of vital supporting resources.

Appendix 1 summarizes the eight hypotheses I test in this dissertation.

Novelty of dissertation

By breaking down the innovation process into more granular stages (e.g., Kapoor & Klueter, 2015; Keum & See, 2017) this dissertation helps to integrate the organization design and innovation literatures more closely. Much prior work in the innovation domain has tended to conflate the various stages of the innovation process (e.g., Garud et al., 2013). Using this approach helps to highlight that the same organization design choice (i.e. increased decentralization) may have different outcomes depending on whether it pertains to firms' invention, development or commercialization activities. This has broader implications for future studies relating to organization design in that the relevant design element must be closely mapped to the specific activities being undertaken. Broad measures of design may not be able to capture how such choices can impact a targeted set

of organizational outcomes, leading to misleading or null inferences. This dissertation can therefore highlight an important additional contingency beyond, for example, the type of innovation, when investigating the relationship between firms' designs and their innovation outcomes, namely the innovation process stage. Thus, it is important to understand where (in organization e.g. R&D) and when (in the relevant process e.g. invention stage) design choices are made. This can help to reconcile the varied findings within the extant literature pertaining to how firms' design choices can impact their innovation outcomes as these studies focus on different aspects of "where" and "when".

This dissertation provides a significant theoretical contribution in that it extends recent work combining both the knowledge-based and organizational economics-based theories (e.g., Argyres, 2011; Argyres et al., 2012; Argyres & Zenger, 2012; Kapoor & Lim, 2007). Whereas previous studies combining both theoretical lenses have focused on the boundaries of the firm, this dissertation uses their integration to examine how internal design features can impact various organizational outcomes.

This dissertation also contributes to the literature on the capability-based view of the firm (e.g., Barney, 1991). I argue that firms' organization designs, such as the extent to which they decentralize certain parts of their organization, can strongly influence firms' access to their broader knowledge base which can, in turn, shape boundary choices associated with different stages of the innovation process. Thus, internal design choices can shape firms' innovation capabilities and influence whether firms undertake these activities in-house or externally. This dissertation can therefore provide some insight into the foundations of firms' capabilities (e.g., Helfat & Peteraf, 2015; Teece, 2007).

This dissertation also helps to shine a light on how internal organization design can shape resource allocation decisions. These internal resource allocation decisions can shape both how firms innovate as well as their innovation outcomes. However, the extant strategy literature has paid "*relatively little attention"* to this topic (Bardolet et al., 2011). I highlight that increasing competition between business units may have unintended consequences in that although these highly incentivized units may exert more effort to sell their new products they are likely to compete intensively with other units for resources to facilitate the sales of new products. This can lead to empire-building and resource accumulation in

units that do not have the best use for these resources. In contrast, in more centralized organizations in which resources are allocated at an individual product level, resources can be allocated based on the merits of each product rather than the business unit. This does not rule out that even in more centralized firms that managers associated with individual products may lobby for more complementary resources than they actually can use effectively but the impact is likely to be greater in more decentralized firms. Thus this study helps to illustrate that beyond inventing and developing inventions, successful innovation, which involves firms capturing value from their new offers, requires effective allocation of complementary resources.

Finally, this dissertation extends recent work investigating how firms' internal design can shape their decision to innovate internally or externally (e.g., Arora et al., 2014; Grigoriou & Rothaermel, 2017). This work has primarily examined the sourcing of knowledge in the form of patents as opposed to more fully refined inventions which forms the focus of this dissertation. Further, this work has not examined the type of knowledge sourced or the sourcing mode. Such an analysis can provide insights into what shapes firms' integration of external inventions addressing a key gap in the open innovation literature as there has been "*a relative dearth of research related to integrating* [External Inventions]" (West & Bogers, 2014).

CHAPTER 2: THE KNOWLEDGE-INCENTIVE TRADE-OFF: UNDERSTANDING THE RELATIONSHIP BETWEEN ORGANIZATION DESIGN AND INNOVATION

Runner up, Knowledge and Innovation IG Best PhD Paper Award, Strategic Management Society Annual Meeting; 2018
Best Paper Proceedings, Academy of Management Annual Meeting; 2018
Finalist, TIM Division Best Student Paper Award, Academy of Management Annual Meeting; 2018

Abstract

Prior studies investigating the relationship between organization design and innovation have generally treated innovation as an outcome rather than a process. In this study, I offer a framework in which I conceptualize the innovation process as consisting of upstream tasks around invention, and downstream tasks around development. This allows me to examine how various facets of organizational decentralization impact innovation through integrating knowledge- and incentives- based views of the firm. On the one hand, greater centralization is associated with enhanced intra-organizational knowledge flows, which enhance innovation. On the other, greater decentralization is associated with higher observability of effort and facilitates the more effective use of incentives increasing innovation efforts. I empirically examine this trade-off in the context of the pharmaceutical industry. I find that greater centralization is associated with the creation of more original inventions and more inventions progressing through early development. In contrast, greater decentralization is associated with the creation of more inventions and more progressing through later development. These results indicate that knowledge flows play a greater role upstream and incentives a greater role downstream. This enables us to understand where and when design choices can impact innovation, thereby helping to reconcile disparate findings in the extant literature.

Introduction

> *"If you look at history, innovation doesn't come just from giving people incentives; it comes from creating environments where their ideas can connect." Steven Johnson, Wired Magazine. 2010*

Innovation is a multi-faceted process (Garud et al., 2013). Within this process firms need to undertake a diverse array of activities ranging from the upstream creation of inventions through to the ultimate commercialization of these inventions further downstream (e.g., Arora et al., 2016; Kapoor & Klueter, 2015). Firms' organization designs can shape how effectively they undertake these activities through influencing both intra-organizational knowledge flows (e.g., Henderson & Cockburn, 1996; Karim & Kaul, 2015) and managerial incentives (e.g., Argyres et al., 2012; Zenger & Hesterly, 1997). The relative importance of knowledge flows and incentives will vary throughout the innovation process as very different activities are undertaken. Thus, the same organization design will differ in its impact on firms' innovation outcomes at each stage of the innovation process.

However, prior studies investigating the relationship between organization design and innovation have tended to treat innovation as an outcome rather than as a process and focused on different stages within the process, such as invention or commercialization, in isolation (e.g., Argyres & Silverman, 2004; Damanpour, 1991; Karim & Kaul, 2015; Tushman et al., 2010). This, in part, can help to explain the varied findings within the extant literature. For example, some studies highlight the benefits of greater decentralization on firms' innovation outcomes (e.g., Damanpour, 1991; Tushman et al., 2010) whereas others highlight the benefits of greater centralization (e.g., Argyres & Silverman, 2004; Arora et al., 2014). As a result of this fragmented approach, we lack a coherent theoretical framework describing how firms' design features can impact innovation throughout this multi-faceted process. It is difficult to evaluate the relationship between firms' organization designs and their innovation without considering the pertinent stage of the innovation process and the associated activities within that stage.

In this study, I examine innovation as a process rather than an outcome to determine how various facets of organizational decentralization can impact different stages of this

process. I do so theoretically through combining a knowledge-based view of the firm, which is represented as repository of knowledge and the fundamental organizational purpose is one of problem-solving (e.g., Grant, 1996; Kogut & Zander, 1992), with an incentives-based view of the firm, which is portrayed as a bundle of contracts and the fundamental organizational purpose is to ensure coordination and cooperation through suitable alignment of incentives (e.g., Kapoor & Lim, 2007; Puranam et al., 2014).

Further upstream in the invention and early development stages of the innovation process, firms undertake search to solve complex technical problems with highly uncertain outcomes (e.g., Fleming, 2001; Fleming & Sorenson, 2004). The focal unit for these stages of the innovation process is Research and Development (R&D) (Argyres & Silverman, 2004). I argue that decentralization of R&D is associated with reduced intra-organizational knowledge flows (e.g., Henderson & Cockburn, 1996; Karim & Kaul, 2015) which can limit distant search thereby reducing the originality of inventions and their progression through the earlier stages of development. However, the tighter alignment between actions, outcomes and incentives enhances local search such that R&D decentralization is associated with the creation of more inventions. In contrast, further downstream in the later development stages of the innovation process, activities are more routinized (e.g., scale-up of manufacturing, development of marketing plans), complex technical issues have been largely addressed and the uncertainty as to whether an invention will reach the market place diminishes (e.g., Aghion & Tirole, 1994; Eisenhardt & Martin, 2000). For these stages of the innovation process, the broader organization beyond R&D is involved (e.g., Dougherty, 1992; Dougherty & Hardy, 1996; Yang & Dougherty, 1993). In this case, I argue that greater decentralization at a corporate level is associated with the progression of more inventions through the later stages of development due to the more effective application of incentives engendering greater managerial effort.

I test these arguments in the context of the pharmaceutical industry using a unique, dataset hand-collected from a variety of archival sources such as company's annual reports and clinical trial databases as well as interviews with managers. This rich dataset enables me both to test my theoretical predictions as well as derive greater insights into the mechanisms through which firms' designs can influence their innovation outcomes. I find

evidence to suggest that firms do face a knowledge-incentive trade-off such that the same design can enhance knowledge flows but limit the effectiveness of incentives. Further, viewing innovation as a process enables me to illustrate that intra-organizational knowledge flows play a greater role further upstream and the role of incentives increases in prominence further downstream.

This study makes three contributions. First, examining innovation as a process rather than an outcome enables a deeper understanding of how organization design can impact firms' innovation outcomes. As a result, this study can help to reconcile some of the disparate findings in the extant literature examining the relationship between decentralization and firms' innovation outcomes. Second, this study contributes to the recent debate concerning the integration of knowledge-based and organizational economics theories. Prior studies have focused on integrating these theories to examine the boundaries of the firm by examining the holdup risks associated with unique assets that are required to create unique capabilities (e.g., Argyres & Zenger, 2012). In contrast, this study highlights that a knowledge-based process is subject to incentives considerations which can shape how internal organization design impacts firms' innovation outcomes. Thus this study extends the debate from the boundaries of the firm to internal organization design. Finally, this study provides insights into how organization design can shape firms' capabilities. Specifically, a firm may have a broad technological knowledge base but its organization design may limit its ability to recombine knowledge across technological domains and generate more original inventions, thereby limiting a firm's product development capabilities.

Theory and Hypotheses

Prior literature

A key organization design element is the degree to which firms centralize their activities within a single unit or decentralize them into multiple, more independent units (e.g., Galbraith, 1977; Lawrence & Lorsch, 1967). For example, Xerox was famous for its

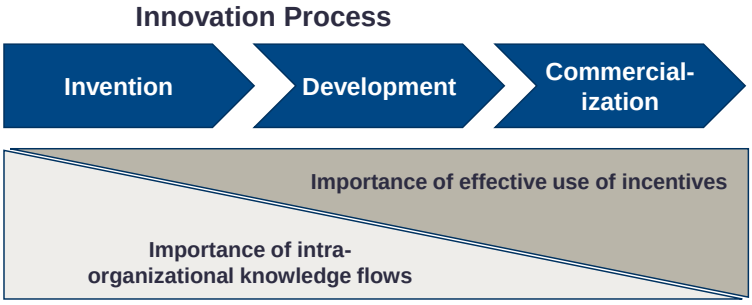
centralized R&D organization centered around its Palo Alto research center (e.g., Chesbrough & Rosenbloom, 2002). Greater centralization has recently been emphasized by iconic firms such as Microsoft and Apple that have functionally-led structures as opposed to dividing into separate business units (Kesler & Kates, 2016). In contrast, companies such as Johnson & Johnson (Galuszka, 2008), ABB (Malone, 2004) and ITW (Conlin, 1999) have more decentralized structures with separate units acting largely independently. Multiple streams within the strategic management literature have examined the relationship between different facets of organizational decentralization and a variety of innovation outcomes. These studies have examined design at a corporate or overall organization level (e.g., Damanpour, 1991) and at a functional unit level such as R&D (e.g., Argyres & Silverman, 2004). Further, decentralization has been examined from a horizontal perspective (e.g., Tushman et al., 2010), in which an organization is divided into more units, and a vertical perspective, in which authority is delegated down the organization (e.g., Keum & See, 2017). Similar variety is observed in the innovation outcomes examined. These outcomes range from patent outputs (e.g., Arora et al., 2014) to product launches (e.g., Puranam et al., 2006).

The mechanisms through which scholars have theorized that organizational decentralization impacts firms' innovation outcomes have broadly fallen into two domains. First, some studies have used a knowledge-based view of the firm, in which a firm's design can shape knowledge flows and how it searches for solutions to innovation problems (e.g., Karim & Kaul, 2015). Second, other studies illustrate that design can shape the incentives managers face during the innovation process. For example, managers may screen out innovation options in their own best interests rather than those of the organization (e.g., Siggelkow & Rivkin, 2006). Argyres and Silverman (2004) illustrate how R&D design can shape the breadth of firms' search processes. Ultimately, some studies illustrate the benefits of greater decentralization (e.g., Damanpour, 1991; Siggelkow & Rivkin, 2006) while others illustrate the benefits of greater centralization (e.g., Argyres & Silverman, 2004; Eggers, 2016). This is perhaps unsurprising given that these studies examine different stages of the innovation process, focus on different facets of decentralization and use different theoretical lenses.

Innovation process: theoretical framework

In this study I take a process-based perspective of innovation (e.g., Garud et al., 2013; Keum & See, 2017). Viewing innovation as a process with a sequence of stages provides two advantages in enabling a more complete understanding of the relationship between decentralization and innovation. First, this approach enables the more precise definition of innovation outcomes and design parameters. This is because different parts of the organization will be involved and different innovation outcomes will be associated with each stage of the process. Second, in developing my theoretical arguments I combine knowledge- and incentives- based views of the firm. Seeing innovation as a process enables me to unpack the relative impact of these factors on firms' innovation outcomes as their relative importance will vary throughout the process.

Figure 3: Theoretical framework



Knowledge focus	Recombination of technical knowledge	Troubleshooting development issues	Market and customer knowledge
Functions involved	R&D	R&D Commercial Functions	Commercial Functions
Decentralization Parameter	R&D Decentralization	Early: R&D Decentralization Late: Corporate Decentralization	Corporate Decentralization
Key Innovation Outcomes	Number of inventions Originality of inventions	Progression of inventions through development	Product launches Sales from new products

Consistent with prior studies, I divide the innovation process into three stages of invention, development and commercialization as illustrated in Figure 3 (e.g., Garud et al.,

2013). First, there is the act of invention (e.g., Arora et al., 2016; Kapoor & Klueter, 2015). Invention is an act of discovery that involves search to solve complex technical problems (e.g., Fleming & Sorenson, 2004) generating novel ideas that in themselves are of limited economic value (Schumpeter, 1939). The creation and subsequent refinement of inventions is a knowledge recombination activity focused on finding solutions to these complex problems (e.g., Fleming, 2001; Fleming & Sorenson, 2004). Rich intra-organizational knowledge flows are therefore critical. The focus is very much on scientific knowledge. Outcomes associated with invention relate to both the quality and quantity of inventions (e.g., Hall, Jaffe, & Trajtenberg, 2001). The organizational unit responsible for a firm's invention activities is R&D (e.g., Fleming & Sorenson, 2004). Thus it is decentralization of R&D (*R&D Decentralization*) that is most relevant design parameter. Invention consists of more of the R in R&D

Second, development is focused on converting an invention into a final product. Development typically consists of multiple activities such as addressing the remaining technical issues associated with an invention, refining and supplementing inventions with complementary knowledge and scaling up for manufacture (e.g., Mitchell & Singh, 1996; Zahra & Nielsen, 2002). The earlier stages of development are still knowledge intensive as firms need to address complex technical problems in converting an invention into a viable product. Again rich intra-organizational knowledge flows are highly important to facilitate this stage of the innovation process. However, in the later stages of development, activities are more routinized and complex technical issues have been largely addressed with more of focus on issues such as resource allocation (e.g., Eisenhardt & Martin, 2000). Further, the identity of the final product and its market potential are much clearer at this stage (e.g., Aghion & Tirole, 1994). Thus the importance of rich knowledge flows diminishes and incentives play a larger relative role as the focus is now on engendering greater effort to get a product over the final hurdles and into the market. Development outcomes pertain to the progression of inventions through development (e.g., Chandy, Hopstaken, Narasimhan, & Prabhu, 2006). For the earlier parts of the development process, which are difficult to distinguish from invention, R&D will again be the focal unit (e.g., DeSanctis, Glass, & Ensing, 2002; Garud et al., 2013; Hansen & Birkinshaw, 2007). Later in the development

process the broader organization is involved, including functions beyond R&D such as marketing (e.g., Dougherty, 1992; Dougherty & Hardy, 1996; Yang & Dougherty, 1993). In R&D the focus is on more of the D. The degree of decentralization (*Corporate Decentralization*) in this context refers to whether the organization is more functionally orientated and focused on its overall portfolio of inventions or more disaggregated into individual business units that are focused on their own sub-set of inventions (e.g., Burton et al., 2011).

Third, there is market launch or commercialization, which relate to firms' value capture from their developed offers. Outcomes from this stage relate to measures such as revenues or profits from new products. This forms the focus of Chapter 4.

It should be noted that the innovation process is often iterative. For example, inventions may need to return to the earlier sub-stages of development. To simplify the theoretical argumentation and empirical analyses, the focus in this paper is on the invention and development stages in isolation, with an emphasis on forward progression. For each stage, I examine how the relevant facet of organizational decentralization influences knowledge flows and incentives, which in turn shapes firms' upstream invention outcomes as well their development outcomes further downstream.

Organizational decentralization and invention

Decentralization in this case relates to dividing R&D into separate units focusing on, for example, different scientific or product domains (Kay, 1988). It is akin to horizontal dis-integration of R&D. These decentralized units may be located within business units or be separate corporate research units reporting to different heads (e.g., Argyres & Silverman, 2004). I distinguish between a single centralized R&D unit and multiple, decentralized units through allocation of decision rights (e.g., Jensen & Meckling, 1992). Managers leading a centralized R&D unit have decision rights across the complete portfolio of firms' inventions and hierarchical authority over the parts of the organization working on these inventions with, for example, the ability to readily shift resources between different R&D projects. In contrast, managers leading decentralized R&D units

only have decision rights for the relevant sub-portfolio of inventions and hierarchical authority over those associated parts of the organization creating and developing those inventions and can shift resources between projects within their sub-portfolios but not across sub-portfolios within different units.

Using two theoretical perspectives I examine managers leading centralized or decentralized R&D units directing their subordinates' efforts. First, using a knowledge-based perspective (e.g., Grant, 1996; Kogut & Zander, 1992), I consider how these managers and associated organization designs can influence intra-organizational knowledge flows thereby impacting how knowledge is recombined to create both new inventions and facilitate their subsequent development. Second, using an incentives-based perspective (e.g., Kapoor & Lim, 2007), I examine how managerial incentives associated with different designs can influence the attention and efforts of managers' subordinates and their subsequent actions.

As described above, the upstream act of invention can be translated into the search for a solution to a specific problem, with search being either primarily local or more distant (e.g., Dosi et al., 2003; Macher, 2006). More distant search is facilitated by rich scientific knowledge flows that enable the recombination of a firm's broader knowledge (e.g., Henderson & Cockburn, 1994; Henderson & Cockburn, 1996; Tsai, 2002; Zhang, Baden-Fuller, & Mangematin, 2007). However, greater decentralization can hinder knowledge flows limiting firms' ability to undertake more distant search for two reasons (e.g., Macher, 2006).

First, leveraging the concept of stickiness of knowledge transfer, both the source and recipient of the knowledge may lack the motivation to transfer or utilize this knowledge (Szulanski, 1996). Increased decentralization of R&D is associated with competition between units pertaining to different areas (Haas & Hansen, 2007; Pfeffer & Sutton, 1999). As a result, managers leading such decentralized units will encourage their subordinates to focus on their units' invention activities rather than sharing knowledge with other units which may provide these units with an advantage. Similarly, managers of decentralized units may encourage their subordinates to not utilize knowledge from other units for fear

of being dependent on these units and thus potentially losing future resources or unit independence. This can often manifest itself as "not-invented-here" syndrome (Katz & Allen, 1982). In contrast, centralization of R&D is associated with reduced competition facilitating knowledge sharing (e.g., Karim & Kaul, 2015). Within a centralized unit the sole hierarchical authority with all-encompassing decision rights can leverage their hierarchical power to encourage different units reporting to them to share knowledge (e.g., Argyres, 1996; Nickerson & Zenger, 2004). These arguments get to the heart of how incentives- and knowledge-based theories can be integrated, namely incentives, combined with hierarchical authority, can shape knowledge flows (e.g., Argyres, 2011).

Second, Grant (1996) highlights that the highly tacit knowledge associated with the creation and refinement of inventions may require rich and frequent communications. If the recipient and source of the relevant knowledge are in separate organizational units, the more distant relationship between these units is likely to result in greater difficulties in the transfer of more tacit knowledge associated with the creation of inventions (Szulanski, 1996). Relatedly, managers within a unit may simply be unaware of the capabilities and knowledge existing in other units and thus may be less able to access them (e.g., O'dell & Grayson, 1998).

Thus, decentralization of R&D into multiple units hinders the flow of knowledge between these units, as compared to within a single centralized R&D unit, limiting distant search. Firms with decentralized R&D units are thus likely to draw on a narrower range of knowledge in developing their inventions, as inventors have access to less of a firm's existing knowledge base. Inventions that draw on a narrower body of knowledge are typically described as being less original (Hall et al., 2001). Originality is one of multiple measures used to measure the quality of an invention (e.g., Ghosh, Martin, Pennings, & Wezel, 2013; Valentini, 2012). Further, prior studies have indicated that inventions that draw on a broader body of knowledge are more successful commercially (Miller, 2006). Thus invention originality is likely to be an innovation outcome of significant concern to managers within firms. Through the argumentation outlined above I hypothesize:

H1: Firms with decentralized R&D are associated with the generation of inventions that are less original than those of firms with centralized R&D.

As outlined above, recombination of knowledge associated with more distant search is more critical for complex, unstructured problems and the creation of more original inventions (e.g., Macher & Boerner, 2012; Nickerson & Zenger, 2004). In contrast, for the solution of less complex problems, local search may suffice and rich intra-organizational knowledge flows may not be as critical. However, increased managerial effort can facilitate the creation of more inventions that draw on a narrower body of knowledge.

In a centralized R&D unit, the lead manager who is responsible for the complete portfolio of inventions can shift resources from one sub-portfolio to another. In contrast, for firms with decentralized R&D units, resources are less able to be shifted from one sub-portfolio to another. For example, a centralized Head of R&D may easily shift resources between two sub-portfolios (A and B) under their direct control. However, if R&D is decentralized with one unit responsible for sub-portfolio A and another responsible for sub-portfolio B these resources are less easily shifted. As a result, the managers responsible for sub-portfolios A and B in two separate decentralized R&D units have more control of their sub-portfolios than otherwise equivalent managers in a centralized R&D unit. This makes the usage of higher-powered incentives for such sub-portfolio managers more effective in the decentralized case (e.g., Holmstrom & Milgrom, 1994; Zenger & Hesterly, 1997).

Further, higher-powered incentives can be more effectively aligned to managerial effort and outcomes in multiple, decentralized units as compared to an otherwise equivalent, aggregated centralized unit (Argyres, 1996; Zenger & Hesterly, 1997). This is because such disaggregation enables the unique contributions of managers to be more readily observed, and there is a resultant clearer line of accountability. For example, compare a centralized R&D unit working on projects A and B against two separate, decentralized R&D units working on projects A and B respectively. In the decentralized case, there is a clearer demarcation in that managers work on A or B, allowing the effective use of higher-powered incentives. In the centralized case, managers may work on both A and B (especially if resources are shared), making allocation of rewards based on one project succeeding and the other failing more difficult. Ultimately, in decentralized units the likelihood of free-riding is reduced because of this clearer linkage between effort and outcomes (Zenger & Hesterly, 1997).

These arguments highlight that higher-powered incentives can be utilized more effectively in more decentralized organizations than more centralized ones. As a result, managers responsible for each sub-portfolio engender more effort in their respective decentralized units as compared to when aggregated into a centralized R&D unit and this trickles down to greater efforts further down the organization (Zenger, 1994). Further, decentralized units are less likely to be prone to inertia due to their smaller size (e.g., Hannan & Freeman, 1984; Kaplan & Henderson, 2005). These inertial pressures may slow decision making, as decision rights are not localized close to where knowledge lies (e.g., Macher, 2006). Thus, any enhanced effort in more decentralized units is likely to be more effective due to these reduced inertial pressures.

Higher powered incentives are also likely to be more effective in inducing greater effort for easily measurable outcomes (e.g., Gibbons, 1998). The quantity of inventions produced is much easier to measure than their quality, which is subjective and may require additional time to be suitably revealed. Similarly, incentives are likely to be less effective to increase knowledge sharing due to difficulties in its measurement (e.g., Taylor, 2006). Thus the additional effort spurred by incentives is likely to be associated with the creation of an increased number of inventions. These arguments suggest that managers will exert greater effort in invention tasks when in multiple, decentralized units as compared to a single, centralized unit. Further, the impact of managers' efforts in decentralized units is also likely to be greater. Ultimately this greater effort will lead to more comprehensive local search, meaning more varied knowledge may be recombined *within* the local domain, but less knowledge recombined *across* domains (as implied earlier for Hypothesis 1). As managers are more likely to be incentivized by the quantity of inventions, this increased effort should be realized in the form of a higher number of inventions for firms with decentralized R&D. Thus:

> *H2: Firms with decentralized R&D are associated with the generation of more inventions than firms with centralized R&D.*

Organizational decentralization and development

Further downstream, in the early stages of the development process R&D will

continue to be the focal unit (e.g., Hansen & Birkinshaw, 2007). It is often difficult to distinguish the early stages of development from invention. A firm is still trying to understand how an invention works as well as refining its design. Further, significant technical challenges may be involved in the initial stages of converting a "raw" invention into an offering that can ultimately be commercialized. Thus, during early development a firm may need to access its broader knowledge base in order to address challenging technical problems (e.g., Macher & Boerner, 2006).

As outlined in the previous section, decentralization limits intra-organizational knowledge flows. Such knowledge flows can provide significant benefits to the refinement of firms' inventions early in development. For example, managers are more able to solve technical problems through accessing a firms' broader knowledge as well as develop more creative solutions to problems (e.g., Haas & Hansen, 2005). In addition, such enhanced knowledge flows can provide access to a firm's set of best practices (Szulanski, 1996) and help to limit fruitless work such as "reinventing the wheel" (Hansen, Nohria, & Tierney, 1999). Ultimately, despite the greater managerial effort induced through more effective usage of incentives in decentralized R&D units, this effort may be fruitless. This is because the knowledge required to address technical issues early in development may lie in other decentralized R&D units and not be readily accessible. In contrast, in centralized R&D units the breadth of a firm's knowledge is more readily accessible, enabling technical issues to be addressed.[1] This will result in a decreased number of inventions progressing through these earlier stages of development, as technical failures are less able to be avoided when firms decentralize R&D. Thus:

> *H3: Firms with decentralized R&D are associated with the progression of fewer inventions through the earlier stages of development than firms with centralized R&D.*

As an invention progresses downstream through development, the type of technical problems that need to be addressed become less complex and the knowledge required to

[1] This argumentation assumes that both decentralized and centralized R&D units are developing inventions of similar quality. This is controlled for empirically using various measures of portfolio composition

undertake development tasks becomes more routinized and explicit (e.g., Eisenhardt & Martin, 2000). For example, the focus is on well-honed routines such as scaling up a product and preparing distribution channels. As a result, the requirement for rich, tacit, intra-organizational knowledge flows diminishes as the compartmentalized knowledge in a specific sub-unit will be sufficient to facilitate the progression of an invention. Further, access to codified information on inventions (e.g., Spencer, 2003) and process tools can help to reduce the uncertainty of the later stages of development (e.g., Grönlund, Sjödin, & Frishammar, 2010). Incentives and the greater managerial effort that they engender are therefore likely to play a greater relative role in shaping development outcomes as inventions progress. This is because firms are likely to be able to access the knowledge they need to undertake later development locally or through more explicit communications. Further, the extant literature also highlights the limitations of incentives for invention and early development due to its inherent uncertainty and the difficulty in designing suitable compensation schemes (e.g., Aghion & Tirole, 1994; Ederer & Manso, 2013; Manso, 2011). In contrast, for the later stages of development, there is a clearer link between effort and performance.

The degree of decentralization (*Corporate Decentralization*) in this context refers to whether the organization is more functionally orientated and focused on its overall portfolio of inventions or more disaggregated into individual business units that are focused on their own sub-set of inventions (e.g., Burton et al., 2011). The outputs of a business unit can be readily observed and outcomes attributed to specific managerial effort more clearly than in a more integrated functional structure (Zenger & Hesterly, 1997). Thus, higher-powered incentives can be utilized more effectively in a decentralized structure. As the progression of inventions through development is readily observable, managers are likely to be incentivized based on some form of this metric.

Analogous to the logic for Hypothesis 2, I argue that managers in more decentralized firms will exert more effort to progress inventions through the later stages of development as compared to managers in more centralized organizations. Thus each individual decentralized unit will progress more of their own sub-set of inventions to ensure some inventions can be launched into the market place. This will result in more inventions

progressing for the entire firm as compared to a more centralized organization. Further, the concern associated with not progressing any individual invention is mitigated in more centralized organizations due to the pooling of risk across the firms' entire portfolio, potentially further lessening the effort undertaken to progress individual inventions through the later stages of development. Thus, firms that are more decentralized will be associated with the progression of more inventions through the later stages of the development process:

> *H4: Greater corporate decentralization is associated with the progression of more inventions through the later stages of development.*

Methods

Research context and sample

The context for this study is the global pharmaceutical industry over the period 1995 to 2015. This industry provides a suitable context for this study for three primary reasons. First, the industry has a well-defined innovation process (e.g., Henderson & Cockburn, 1994; Henderson & Cockburn, 1996; Hess & Rothaermel, 2011; Kapoor & Klueter, 2015). This enables the determination of clear measures of invention and development. Second, there is heterogeneity in the organization designs of the firms within this industry driven by a variety of factors such as merger and acquisition activity and changes in senior leadership. Third, focusing on a single industry enables me to unpack the degree of diversification of a firm from its organization design. Diversified firms are likely to be more decentralized and the degree of diversification may also impact firms' innovation outcomes. Thus focusing on a single industry enables me to control for this issue.

The study sample consists of 49 leading pharmaceutical firms over the period 1995 to 2015. Focusing on larger pharmaceutical firms that are responsible for the majority of innovation within the industry is common within the strategic management literature (e.g., Anand, Oriani, & Vassolo, 2010; Gunther McGrath & Nerkar, 2004; Kapoor & Klueter, 2015). The sample is based on 2004-6 annual prescription drug sales as defined by the

Pharmaceutical Executive magazine's Top 50 Pharmaceutical companies (e.g., Klueter, Monteiro, & Dunlap, 2017). [2] In this period 64 separate firms appeared in the Top 50 in one or more years. The 15 firms over that period that are excluded are either private firms or did not provide sufficient information on their organizational structures in their public filings. These excluded firms were in the lower half (26-50 ranking in terms of pharmaceutical sales) in one or more of the three years in the 2004-6 period. Using the mid-point of the sample enables the examination of firms that have at least 10 years of history within the sample time-frame prior to any significant M&A event. 33 out of the 49 sample firms are still in the top 50 pharmaceutical firms in 2015, 13 firms had been acquired by other firms in the sample and 3 firms had divested their pharmaceutical businesses to firms not in the sample. Upon acquisition or divestment of their pharmaceutical business these 15 firms dropped out of the sample. Compared to a universal sample of listed pharmaceutical firms from Compustat, the sample dataset of firms is significantly larger and more profitable on average.

Invention measures are created using patent data (e.g., Fleming & Sorenson, 2004). Patent data is obtained from the European Patent Office (EPO) Worldwide Patent Statistical (PatStat) database (e.g., Conti, Gambardella, & Mariani, 2013). This database provides good coverage across multiple patent-granting jurisdictions (Kang & Tarasconi, 2016). This is especially important for the sample of firms in this study which includes multiple non-US firms. Using patent data to measure firms' inventive output suffers from multiple limitations such as not all inventions may get patented (e.g, Levin et al., 1987), patents may not always correspond to products (e.g., Hall et al., 2001) and patents may be filed for strategic rather than knowledge capture purposes (e.g., Spender & Grant, 1996). However, some of these limitations are mitigated within the pharmaceutical industry as firms patent a large proportion of their inventions and these patents closely relate to final products (e.g., Dushnitsky & Shaver, 2009; Gunther McGrath & Nerkar, 2004).

With its well-defined industry-wide milestones (e.g., Chandy et al., 2006; Kapoor & Klueter, 2015), the progression of drug candidates through clinical trials provides a

[2] The top 20 pharmaceutical firms by R&D spend represented 60 % of industry R&D spend and the top 20 pharmaceutical firms by prescription sales represented 64 % of industry sales in 2015 (EvaluatePharma, 2016).

means with which to compare firms' development outcomes. Such development data is collected from the Pharmaprojects database (e.g., Chandy et al., 2006; Kapoor & Klueter, 2015). Further, the theoretical simplification made above in which the innovation process is assumed to be non-iterative is more likely to be appropriate in this context. It is unlikely that, for example, drug-candidates that pass from Phase 1 to 2 will then return to Phase 1 unless they are used in new indications (i.e. to treat a different condition) which generally represent separate inventions.

Organizational structural data is hand-collected from company 10-K, 20-F, DEF14A SEC filings and annual reports. Financial data is obtained from Compustat.

Two datasets are developed. The first (invention) dataset enables Hypotheses 1 and 2 to be tested. This data exists at the firm-year level. The second (development) dataset enables Hypotheses 3 and 4 to be tested. This data exists at the firm-year-clinical phase level. T-tests reveal that for each clinical phase the sample means for each independent and control variable at a firm-year level are not statistically different and also not statistically different from the sample means for the corresponding variables in the first "invention" dataset. This analysis is supplemented with 61 interviews with mid- and senior-level executives in strategy and R&D roles from 28 of the sample firms and industry experts. The interviews were semi-structured based on an interview guide and lasted between 30 and 90 minutes. The focus of these interviews was to evaluate the validity of the organization design measures, to determine how different clinical phase transitions map to the hypotheses and to discuss how various forms of decentralization can impact knowledge flows and incentives. Appendix 3 provides further details of these interviews.

Measures

Dependent variables. *Invention Measures:* A key challenge in using patent-based measures is ensuring accurate assignment of the patent assignee. Although EPO's Patstat database has undertaken a significant amount of effort to standardize assignee names through the field DOC_STD_NAME, there are still multiple variants of the same assignee

name. A two-fold process is pursued in order to obtain accurate patent assignee names.[3] Both approaches used to develop standardized names provide similar results with 99.7 % matching. Those patents that did not match using both methods were manually checked and assigned appropriately. Appendix 2 provides further details.

To measure the quantity of inventions (*Quantity)*, the number of patent families filed by firms annually is estimated.[4] Patent family counts are used to avoid double counting of patents filed in multiple jurisdictions. Patents assigned in the European Community statistical classification of economic activities category (NACE2) 21 (manufacture of basic pharmaceutical products and pharmaceutical preparations) are used. The year in which a patent family is developed is defined as the earliest filing date of a patent in that family.

To measure the breadth of knowledge from which patents draw (Argyres & Silverman, 2004) or patent originality (Hall et al., 2001), the International Patent Classification (IPC) 4-digit technical classifications of the citations made by a focal patent are examined. Measures of originality produced by the OECD are utilized (Squicciarini, Dernis, & Criscuolo, 2013). This Originality measure is developed using the approach recommended by Hall et al. (2001). The larger the value, the more original a patent is as it draws from a broader array of technologies. The maximum originality patent in a family is assigned as the originality for that family. These values are then used to estimate an average originality per patent family for each firm-year (*Originality*).

Development Measures: This measure is built using the number of drug candidates progressing through the various phases of clinical development per firm-year. The initial risk set of drug candidates are those entering pre-clinical trials. Using data from the Pharmaprojects clinical trials database, a panel dataset by drug candidate -year is developed in which parent firms are assigned to each drug candidate and the clinical phase which a drug has reached at the end of the relevant year is captured. Assigning drug candidates in

[3] First, manual matching of assignees to sample firms is conducted using text strings with correction for merger and acquisition activity. Second, the assignee-matching process utilized by Arora et al. (2014) is also pursued. Further details are provided in Appendix 2.

[4] According to the European Patent Office a patent family *"is a set of either patent applications or publications taken in multiple countries to protect a single invention by a common inventor(s)."*

the Pharmaprojects database to parent firms requires a careful assessment of individual deals between firms in which a specific drug candidate may be sold to another firm, a firm may acquire or merge with another firm or drug candidates may be developed through alliances with other firms. Using data from both the Pharmaprojects "Overview" section and the Recap database, firms can be assigned to each specific drug candidate.[5] Appendix 2 provides further details.

The number of drug candidates in a firm's portfolio moving from pre-clinical trials (phase 0) to phase 1 (variable - *prog1*), phase 1 to phase 2 *(prog2*), phase 2 to phase 3 clinical trials *(prog3)* and phase 3 clinical trials to pre-registration (PR) (*prog4*) per year are measured. As a result, four dependent variables representing how effectively firms progress drug candidates through the development process are created. Pre-clinical trials are still very much in the spirit of discovery and include both *in-vitro* and *in-vivo* testing to evaluate items such as drug safety, dose response, method of delivery of a drug molecule, pharmokinetics (the study of drug movement through the body), pharmodynamics (how the drug is likely to work in the body) and how to manufacture drug-candidates at small-scale (Petrova, 2014). At this stage scientists are still looking at multiple variants of a drug candidate and trying to understand its mode of action. Phase 1 clinical trials are generally the first human trials and are focused on testing safety and dosage levels. These tend to be undertaken with a small number (10s) of healthy volunteers. Phase 2 clinical trials tend to involve larger numbers of patients (100s) with the target disease condition and the focus is on testing the efficacy of drug candidates and their side effects. Phase 3 clinical trials involve larger numbers of patients (1000s) and the focus is on efficacy and monitoring for adverse reactions. In parallel with phases 1-3, scientists will continue to investigate items such as different drug delivery technologies, pharmodynamics, pharmokinetics and manufacturing approaches for the relevant drug-candidates. Further, effective clinical trial design in these phases is critically important and can reap rewards (e.g., Patel, Antoni, Freedman, Levesque, & Sundy, 2017; Petrova, 2014). Towards the later parts of phase 2, commercial functions such as marketing and sales will start to play a larger role in market

[5] Drug candidates that are inactive for a period of greater than three years are assumed to have been dropped by the focal firm and no longer contribute to the drug candidate portfolio unless evidence of later progression is observed in the data.

planning.

For this study, earlier stage development is defined as the progression from pre-clinical to phase 1 and later stage development as the progression from phase 2 to phase 3. As described above the pre-clinical phase is still knowledge rich and involves addressing complex technical problems. The Phase 2 to 3 transition is a particularly important transition as it involves a significant increase in the level of investment by the focal firm (Sertkaya, Wong, Jessup, & Beleche, 2016).

Independent variables: The independent variables relate to two specific measures of organizational decentralization, R&D and Corporate. These measures are developed using top management team data available from company 10-K/20-F/DEF 14A SEC filings and Annual Reports. The use of top management team data to develop high-level organizational structural measures has been used recently in the strategic management literature (e.g., Albert, 2018; Girod & Whittington, 2015; Guadalupe, Li, & Wulf, 2014).

Such high-level design measures may be limited in that for firms with the same high-level structure there are design differences below this high level. For example, a centralized R&D unit may be geographically dispersed and decentralized R&D units may be co-located and have integrative sub-units designed to share information. However, my theoretical argumentation is made at this higher organizational level and thus these measures are appropriate to test my hypotheses. Further, the managers within the sample firms interviewed confirmed that the structure of the top management team (TMT) provides an accurate reflection of their firms' structures, specifically the key business units and how R&D is designed.

A database of 15,129 executive and extended executive team roles for the sample of 49 firms over the period 1995-2015 is developed. This results in a total of 898 firm-years of data and an average of 16.8 executive and extended executive roles per firm-year (standard deviation = 11.1). Coding of roles and various facets of organizational decentralization are undertaken by the author through careful review of the management

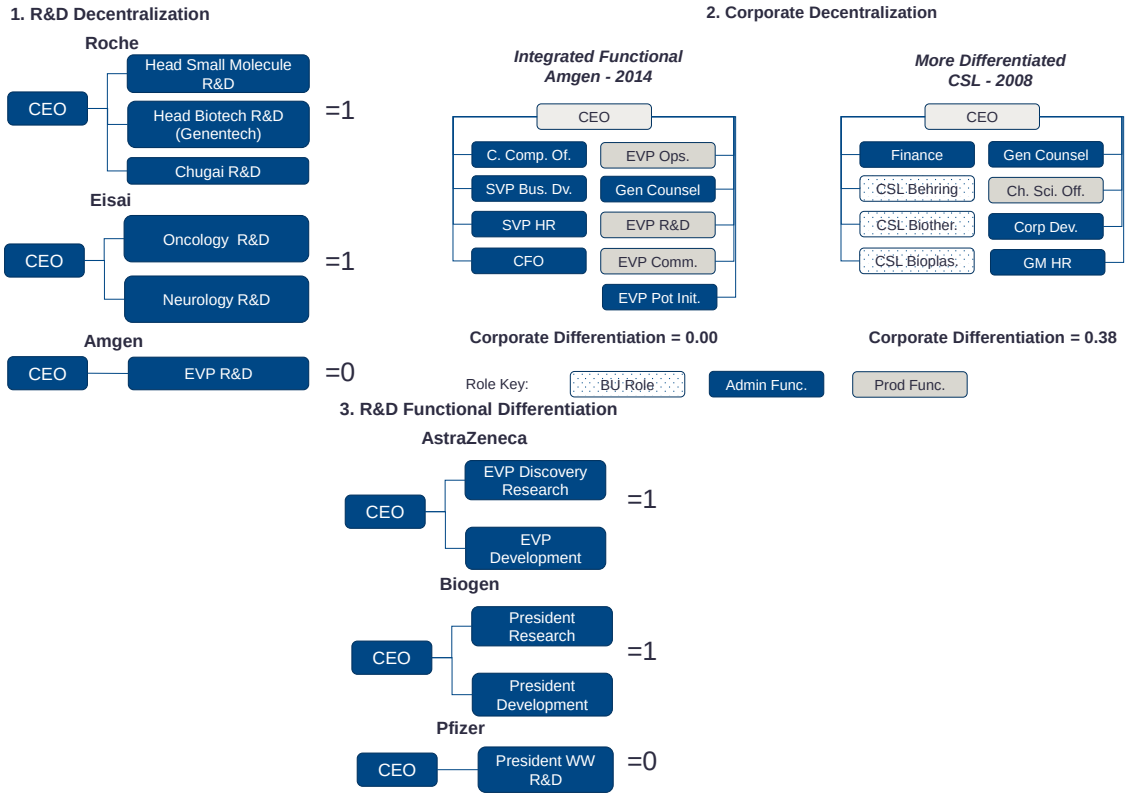
roles in each organization and further validated through review of organizational descriptions from companies' filings (e.g. CEO's letter to shareholders). For 28 out of the 49 firms, interviews with strategy and R&D managers were conducted to confirm whether the measures developed were accurate. Appendix 3 provides further interview details.

First, to evaluate decentralization of R&D, it was determined whether firms' R&D or Research (in the case of functionally separate R&D) is organized into a single or multiple units. For diversified firms which operate beyond pharmaceuticals, R&D units that pertain to pharmaceuticals were focused upon and R&D units dedicated to areas such as consumer products were excluded in order to control for the level of diversification. Using this approach, the variable *R&D Decentralization* is defined as a binary variable set to 1 if there are multiple R&D or research groups reporting to separate heads within the TMT covering different pharmaceutical domains or to leads of business units and 0 if the firm has a single integrated pharmaceutical R&D or research group reporting to a single TMT lead. 12.3 % of the sample firm-years have *R&D Decentralization* = 1.

It is recognized that although the variable *R&D Decentralization* is binary, firms may have "hybrid" R&D organizations (e.g., Argyres & Silverman, 2004; Arora et al., 2014). In order to partly control for this I develop a control variable, *R&D Functional Differentiation*, which measures whether firms' R&D is integrated into one unit or has separate research and development units. It is akin to vertical dis-integration of R&D as compared to the horizontal dis-integration associated with *R&D Decentralization*. I use this control variable as some aspects of R&D may be more centralized (e.g. research) and others more decentralized (e.g. development). This binary variable is coded as 1 if there are separate research and development heads reporting to the CEO and 0 if R&D is integrated. Decision rights are split between research and development activities and there are separate hierarchical reporting lines pertaining to each function if *R&D Functional Differentiation* = 1. In contrast, a functionally integrated R&D unit is associated with decision rights over the complete R&D process and has a single associated hierarchical authority covering all R&D. Firms' descriptions of R&D in their financial filings are also examined to clarify whether R&D is integrated. 22 % of the sample firm-years have *R&D Functional Differentiation* = 1. Appendix 2 provides more details on this process.

In order to develop a measure of corporate decentralization, TMT members are categorized as general managers, administrative functional managers or product functional managers using the approach developed by Guadalupe et al. (2014). The independent variable *Corporate Decentralization* is therefore determined as a proportion, namely the number of general manager roles in the TMT divided by the TMT size (excluding CEO) (Albert, 2018). These general manager roles relate to managers who are responsible for the performance of a defined sub-section of the business which may be a geographical or a specific product area. To account for firms operating in non-pharmaceutical domains, business unit leads in these areas are excluded. The higher the value of this variable, the more decentralized a firm is.[6] Examples of all the measures are illustrated in Figure 4.

Figure 4: Illustrative examples of structural measures



[6] Firm fixed effect regressions of the number of general manager, administrative functional and product functional roles (dependent variables) versus firm size (independent variable) illustrated no relationship between the number of each type of role and firm-size. Further, examining a sub-sample of firms of different size further illustrated no relationship between the number of each type of role and firm size. For example, AstraZenece (2005) had 2 general manager roles, 2 administrative functional roles and 4 product functional roles with a total of 65,300 employees. In contrast, CSL (2008) had 3 general managers, 4 administrative functional roles and 1 product functional roles with a total of 9,300 employees.

Control variables: Table 2 illustrates the control variables used. Further, a variety of fixed effects are used to control for other sources of unobserved heterogeneity. Descriptive statistics and correlation tables are presented in Table 3 (H1-2) and Table 4 (H3-4) for all the variables. Appendix 4 provides further details on descriptive statistics.

Table 2: Summary of control variables used in this analysis. All firm-year level.

Variable	Description	Rationale
1. Diversification controls		
Business Segment Dummy Fixed Effects	Series of dummy variables representing whether a firm has operating segments in categories beyond pharmaceuticals. Specifically: consumer goods, medical devices, animal medication, bulk chemicals, nutrition. Also have dummy if firm has a generics business. These can vary by firm-year as firm acquires or divests specific businesses.	Control for diversification of firms' businesses beyond pharmaceuticals
SBU	Reflects the total number of business units within a firm – namely the number of operating segments that report separate financial statements in their annual reporting documents	Controls for general firm diversification. International Financial Reporting Standard (IFRS) 8[7] requires that firms disclose information about their operating segments, these represent distinct profit centers within a firm and are used by senior management to make strategic decisions.
Tech. diversity	Measure of technological diversity of firms' R&D efforts. For invention this is measured using a Herfindahl measure. The sum of the squared proportions of patent families filed in a focal year that pertain to each therapeutic class is subtracted from 1. Similarly for development, the sum of the squared proportions of drug candidates in each therapeutic class in a firm's portfolio within a specific phase in a focal year is subtracted from 1. Note, however this measure does not control for the coherence of the R&D efforts but simply measures diversity.	Controls for the level of technological diversity of a firm's R&D activities. Provides a measure of the diversity of knowledge within a firm thereby controlling for firms' knowledge recombination capabilities. Firms undertaking a broader array of technological activities are more likely to differentiate their R&D efforts (either by technical domain or function) as well as fragment into more business units. Also firms will have a broader range of technical knowledge from which to draw.
2. Firm-level controls		
Firm-fixed effects	Series of dummy variables for each firm	Control for a range of sources of unobserved heterogeneity
R&D Intensity	The annual spend on R&D by a firm as a proportion of annual revenues	Firms that spend a higher proportion of their sales on R&D may potentially see higher inventive and innovative output (e.g., Mairesse & Mohnen, 2005).
Size	Natural log of the annual sales of each firm in the study sample	Larger firms may potentially generate more innovation outputs as they have access to more

[7] https://www.iasplus.com/en/standards/ifrs/ifrs8

Variable	Description	Rationale
		resources such as a broader knowledge base. They are also likely to be more differentiated.
Performance	The annual return on assets of the firm (Richard et al., 2009)	Higher performing firms may potentially develop a higher volume of higher quality innovations
slack	Current Ratio	Prior studies have indicated greater slack may help to drive the development of new technologies (Greve, 2003).
Patent stock	Discounted total quantity of patent families filed by focal firm (Arora et al., 2014). Measured in 000s.	Controls for firms' existing knowledge collected over a period of time which will impact innovation outcomes. Also can control for firms' invention capabilities.
SG&A	Natural log of a firm's selling, general and administrative (SG&A) expenses	Potentially those firms with higher values of SG&A are more innovation focused and need to spend more on sales expenses to educate customers about the benefits of their new products.
CEO	A dummy variable set to 1 if a new CEO was appointed in a specific firm-year	May be the catalyst for a reorganization or uptick in performance.
3. Competition controls		
competition	Measure of competition firms face across their development portfolios. Sum of squared "market shares" (by drug-candidate count) of drug-candidates within all development phases per therapeutic class weighted by proportion of overall portfolio subtracted from 1. Higher value signifies firms operate in more competitive therapeutic classes	Controls for the degree of competition firms face across their portfolio of drug-candidates. Firms in more competitive markets may be incentivized to innovate and organize differently.
4. Portfolio level controls		
portfolio	Number of drug candidates in drug pipeline at particular stage in clinical development (e.g. Phase 0)	A larger portfolio is likely to be strongly correlated with the number of inventions that progress through the commercialization process.
external	Proportion of externally-sourced drugs in portfolio at specific stage of clinical development	Externally-sourced drug-candidates may be more difficult to commercialize due to issues such as not invented here syndrome (Katz & Allen, 1982).
bio	Proportion of portfolio at specific stage of clinical development that are biologics	High level control for firms that tend to focus on biotechnology as opposed to small molecules.
NCE	Proportion of portfolio at specific stage of clinical development that are new chemical entities (NCE)	Indication of degree of novelty of portfolio. NCEs include no component that has been previously approved by the FDA. NCE designation from the US Food and Drug Administration (FDA) provides firms with five years of marketing exclusivity.[8]
Novelty	This takes a value between 0 and 2. If the mechanism of action and origin of material in the relevant broad therapeutic domain are new to the firm the value is set at 2, if one of these is new it is set as 1, and if neither are new it is set to 0. An average of this variable is then calculated across a firm's complete portfolio per firm-year.	This provides an alternative measure (Klueter, 2013) to *bio* and *NCE* to measure the novelty of a firm's development portfolio as novelty could be correlated with both design and innovation outcomes.
Other Controls		
Year fixed effects	Series of dummies for each year in sample	

[8] https://www.fda.gov/downloads/drugs/guidancecomplianceregulatoryinformation/guidances/ucm386685.pdf

Table 3: Descriptive statistics and correlation matrix for invention analyses (H1-2: unit of analysis - firm-year). N=803

Variable	Mean	SD	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1.Quantity	230.2	249.4	1.00														
2.Originality	0.575	0.195	0.01	1.00													
3.R&D Decentralization	0.123	0.329	0.10	-0.09	1.00												
4.R&D Functional Differentiation	0.223	0.416	0.04	0.02	-0.13	1.00											
5.Corporate Decentralization	0.258	0.244	0.18	0.05	0.04	-0.16	1.00										
6.performance	0.078	0.087	0.22	-0.02	-0.04	-0.04	0.02	1.00									
7.R&D Intensity	0.178	0.223	-0.11	0.08	0.08	0.15	-0.17	-0.54	1.00								
8.SG&A	7.831	1.386	0.68	-0.18	0.07	-0.00	0.14	0.26	-0.08	1.00							
9.size	8.650	1.494	0.65	-0.23	0.06	-0.04	0.18	0.37	-0.36	0.91	1.00						
10.slack	2.476	1.644	-0.26	0.09	-0.02	0.17	-0.20	-0.08	0.31	-0.39	-0.49	1.00					
11.CEO	0.111	0.314	0.03	-0.03	-0.02	-0.02	0.00	-0.03	-0.03	0.07	0.07	-0.03	1.00				
12.SBU	2.487	1.274	0.10	-0.02	-0.03	-0.10	0.29	-0.15	-0.23	0.01	0.10	-0.15	-0.04	1.00			
13.tech. diversity	0.762	0.104	0.26	-0.01	0.01	0.03	0.16	0.05	0.03	0.35	0.33	-0.03	0.06	-0.02	1.00		
14.patent stock	1.137	1.290	0.87	-0.17	0.06	0.03	0.14	0.18	-0.09	0.74	0.70	-0.25	0.04	0.09	0.36	1.00	
15.competition	0.959	0.029	-0.60	0.01	-0.06	0.05	-0.17	-0.19	0.04	-0.57	-0.52	0.21	-0.03	-0.01	-0.24	-0.62	1.00

Table 4: Descriptive statistics and correlation matrix for development analyses (H3-4: unit of analysis - firm-year-clinical phase)

	Phase 0 to 1		Phase 1 to 2		Phase 2 to 3		Phase 3 to 4																				
Variable	Mean	SD	Mean	SD	Mean	SD	Mean	SD	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1.prog	4.536	5.622	2.304	2.730	1.446	1.693	1.516	1.752	1.00																		
2.drop	5.562	7.108	2.067	3.214	2.541	3.456	1.130	1.659	0.56	1.00																	
3.R&D Decentralization	0.123	0.329	0.134	0.340	0.126	0.332	0.122	0.328	0.01	0.04	1.00																
4.R&D Functional Diffn.	0.225	0.418	0.233	0.423	0.231	0.422	0.229	0.421	-0.03	-0.05	-0.12	1.00															
5.Corporate Decent.	0.261	0.246	0.256	0.244	0.267	0.245	0.265	0.245	0.12	0.10	0.05	-0.16	1.00														
6.performance	0.080	0.089	0.080	0.089	0.081	0.085	0.082	0.081	0.15	0.11	-0.01	-0.05	0.02	1.00													
7.size	8.724	1.486	8.772	1.464	8.770	1.469	8.741	1.448	0.39	0.39	0.07	-0.07	0.17	0.35	1.00												
8.SG&A	7.909	1.373	7.958	1.346	7.961	1.354	7.913	1.372	0.44	0.42	0.07	-0.03	0.13	0.26	0.92	1.00											
9.slack	2.440	1.650	2.431	1.643	2.417	1.609	2.459	1.642	-0.17	-0.17	-0.02	0.18	-0.22	-0.10	-0.49	-0.40	1.00										
10.R&D Intensity	0.181	0.224	0.184	0.226	0.179	0.205	0.172	0.186	-0.03	-0.04	0.05	0.16	-0.19	-0.52	-0.38	-0.12	0.33	1.00									
11.patent stock	1.187	1.308	1.220	1.313	1.222	1.315	1.191	1.307	0.47	0.42	0.06	0.01	0.12	0.17	0.70	0.74	-0.25	-0.10	1.00								
12.competition	0.958	0.028	0.958	0.027	0.957	0.028	0.958	0.028	-0.45	-0.43	-0.06	0.07	-0.15	-0.18	-0.50	-0.56	0.20	0.06	-0.61	1.00							
13.CEO	0.112	0.315	0.114	0.318	0.117	0.321	0.112	0.316	0.03	0.07	-0.03	-0.02	0.01	-0.04	0.06	0.06	-0.03	-0.03	0.03	-0.01	1.00						
14.portfolio	30.27	30.09	12.75	13.71	15.58	14.76	9.972	8.746	0.73	0.81	0.05	-0.04	0.15	0.16	0.49	0.53	-0.22	-0.05	0.56	-0.59	0.04	1.00					
15.external	0.468	0.249	0.484	0.278	0.537	0.248	0.648	0.250	-0.18	-0.20	0.04	-0.04	-0.09	-0.02	-0.12	-0.14	0.08	-0.01	-0.13	0.10	-0.03	-0.24	1.00				
16.NCE	0.524	0.256	0.540	0.296	0.523	0.268	0.449	0.282	0.15	0.17	-0.01	0.02	0.12	0.03	0.16	0.17	-0.05	-0.02	0.15	-0.14	0.00	0.19	-0.27	1.00			
17.bio	0.257	0.233	0.243	0.246	0.253	0.227	0.235	0.266	-0.05	-0.05	-0.06	0.12	-0.11	0.02	0.02	0.03	-0.02	0.05	-0.05	0.10	-0.00	-0.06	0.13	-0.60	1.00		
18.tech. diversity	0.693	0.236	0.608	0.267	0.671	0.228	0.605	0.285	0.36	0.36	0.00	-0.00	0.24	0.12	0.50	0.54	-0.27	-0.07	0.45	-0.39	0.04	0.47	-0.26	0.37	-0.24	1.00	
19.SBU	2.483	1.293	2.466	1.272	2.476	1.276	2.483	1.290	-0.02	0.04	-0.03	-0.11	0.30	-0.15	0.10	0.02	-0.15	-0.24	0.10	-0.01	-0.04	0.03	-0.11	0.05	-0.11	0.11	1.00
Number of observations	787		764		762		785																				

Analysis approach

The analysis approach used varies with the nature of the dependent variable and is conducted at the firm-year or firm-year-clinical phase level. The independent variable *Originality* (H1) is bounded between 0 and 1. The main analyses use the fractional logit approach (Papke & Wooldridge, 1996; Papke & Wooldridge, 2008). To avoid issues with over-dispersion using count variables, for the dependent variables *quantity* (H2), and *prog1-4* (H3-4) negative binomial regression analyses are used (Long & Freese, 2006).[9]

An empirical concern associated with examining firms' organization designs relates to omitted variable bias. In order to start to address this issue a variety of control variables are utilized. As the main analyses, Propensity Score Matching (PSM) (e.g., Caliendo & Kopeinig, 2008) is used to generate matched samples of observations for decentralized and centralized firms through these control variables. This helps to reduce the possibility that the results are driven by the inherent differences between decentralized and less decentralized firms. In the first stage, a logit regression is used to estimate the likelihood that a firm is "treated". For the invention and early development hypotheses (H1-3), the "treatment" variable is *R&D Decentralization* i.e. whether the firm has decentralized R&D. For later stage development (H4), the "treatment" is a dichotomized (around the median) version of *Corporate Decentralization*.[10] In this logit regression all the covariates in Table 5 are regressed against *R&D Decentralization* alongside a year-grouping variable (i.e. 1995-1999 is set as 1 etc.) in the test of H1 and H2. In the test of H3 all the covariates in Table 6 are regressed against *R&D Decentralization* alongside a year-grouping variable. In the test of H4 all the covariates in Table 7 are regressed against the dichotomized *Corporate Decentralization.* In the second stage, regressions are conducted using only observations that are successfully matched using the logit regression. Propensity score matching using both nearest neighbor and caliper matching methods is used with

[9] Initially SG&A and SBU were included in the regressions. However as SG&A is so strongly correlated with size (correlation coefficient = 0.91) and the number of business units is largely reflected through the business segment controls, these two controls were excluded to minimize multicollinearity. As a result the Variance Inflation Factors (VIFs) for both regressions were below 2.5, below the recommended level of 10 (Hair, Anderson, Tatham, & Black, 1998).

[10] Various cut-off points between 0.2 and 0.6 were used to dichotomize *Corporate Decentralization* as an additional robustness check. Similar results were observed for each cut-off point.

similar results being obtained regardless of the approach.[11] Coarsened Exact Matching (CEM) (e.g., Iacus, King, & Porro, 2011)[12] is also used as a further robustness check. Appendix 5 provides further details on the matching procedures followed in this chapter. This appendix illustrates the first stage propensity matching models in which the relevant organization design parameter is used as the dependent variable. Further, this appendix illustrates the matching of observations for the relevant structural variables (e.g. centralized R&D and decentralized R&D) across a variety of observable variables.

A variety of fixed effects are also used. However, firm-fixed effects are limited in examining H1-H3 due to the low variation of *R&D Decentralization* over time (31/49 firms do not change *R&D decentralization*). For the 18 firms which do change *R&D Decentralization*, I find support for H1-3 using firm-fixed effects. I undertake firm-fixed effect analyses in the tests of H4 as *Corporate Decentralization* has more temporal variation (Allison & Waterman, 2002).

Results

Invention: Hypotheses 1 and 2

Table 5 illustrates the main analyses that are used to test H1 and H2. Models 1 – 3 focus on *originality* as the dependent variable. Across models 2 - 3 *R&D Decentralization* has a statistically significant negative coefficient. Thus firms with decentralized R&D are associated with less original inventions. On average, *R&D Decentralization* is associated with patents that have 0.07 lower originality (0.36 standard deviation lower value of *originality*).[13] Interviews with R&D managers highlighted that the creation of patented inventions required knowledge from a variety of sources to be combined. For example, the interviews indicated that in the invention stage, the focus is on screening a large number

[11] Further details on the propensity score matching approach are provided in the Appendix 5 i.e. first stage logit regression results and post-matching balance tables.
[12] The CEM STATA Routine (http://gking.harvard.edu/cem) is used to perform this analysis.
[13] Similar results are obtained for alternative patent measures similar to originality, namely radicalness and generality. The latter result using patent generality is consistent with the work of Argyres and Silverman (2004). Further details are presented in the online appendix to this paper.

of potential molecules as well as understanding their modes of action to identify target groups of molecules that show promise. In order to identify potential lead molecules and develop a better understanding of the mode of action of such molecules, scientists may need to draw from a wide variety of disciplines in order to create an invention. Managers also highlighted how organization design could impact intra-organizational knowledge flows. For example: [14]

> *"We have three separate R&D units that are deliberately siloed from each other so as to encourage competition between these units. They don't tend to share any of their knowledge with each other."*

It appears that in a centralized R&D unit a firm's broader knowledge base is more accessible enabling the creation of more original inventions consistent with H1.

Models 4 – 6 focus on *quantity* as the dependent variable. Consistent with H2, models 5 -6 indicate that firms with decentralized R&D are associated with the creation of more inventions than firms with centralized R&D units as illustrated by the statistically significant positive coefficients for *R&D Decentralization*. On average, decentralization of R&D is associated with the generation of 51 more patent families per firm-year (0.21 standard deviation higher value of *quantity*). This helps to explain prior findings by Henderson and Cockburn (1994). They found evidence to suggest that firms that were more decentralized with respect to resource allocation are associated with increased patent output which is alignment with the findings pertaining to H2. Interviews also highlighted how incentives could shape the quantity of inventions:

> *"You get what you incentivize and are able to measure. Volume of output and numbers are easier to measure than quality and that is what we tend to reward. It is all about getting targets and pushing candidates through the various milestones of the development process"*

[14] Due to confidentiality agreements with the firms whose managers are interviewed, comments cannot be attributed to individual firms or managers.

Table 5: Regression analyses relating to invention hypotheses (H1-2).

Dependent Variable	**H1: originality**			**H2: quantity**		
	Fractional Logit Regression			**Negative Binomial Regression**		
Model	**1**	**2**	**3**	**4**	**5**	**6**
R&D Decentralization		**-0.167****	**-0.311****		**0.228**$^{+}$	**0.207***
		(0.0553)	**(0.105)**		**(0.136)**	**(0.0945)**
R&D Functional Differentiation		0.0398	-0.172		0.109	0.0436
		(0.0603)	(0.112)		(0.0950)	(0.0955)
Corporate Decentralization		0.122	0.362^{+}		-0.0319	0.101
		(0.118)	(0.207)		(0.149)	(0.219)
performance	-0.413	-0.413	-0.913	0.160	0.181	1.762^{+}
	(0.350)	(0.345)	(0.619)	(0.605)	(0.613)	(0.918)
R&D Intensity	-0.0315	0.0116	0.753	0.245	0.187	1.692^{+}
	(0.141)	(0.142)	(0.567)	(0.266)	(0.271)	(0.948)
size	-0.00688	0.00181	0.0469	0.326**	0.316**	0.407**
	(0.0439)	(0.0451)	(0.101)	(0.0629)	(0.0603)	(0.0868)
slack	0.00473	0.00684	0.0276	0.00487	-0.00195	0.0115
	(0.0208)	(0.0201)	(0.0331)	(0.0302)	(0.0296)	(0.0421)
CEO	-0.0619	-0.0642	-0.276^{+}	0.0156	0.0295	0.0281
	(0.0534)	(0.0538)	(0.142)	(0.0582)	(0.0578)	(0.0990)
tech. diversity	0.942**	0.895**	0.857	1.749**	1.798**	2.467*
	(0.342)	(0.339)	(0.650)	(0.672)	(0.646)	(1.224)
patent stock	-0.00864	-0.0118	-0.0388	0.468**	0.463**	0.388**
	(0.0402)	(0.0399)	(0.0672)	(0.0685)	(0.0657)	(0.0655)
competition	-2.541*	-2.497*	-5.722**	-2.991^{+}	-3.158^{+}	-3.426^{+}
	(1.196)	(1.166)	(1.979)	(1.638)	(1.645)	(1.925)
Year Fixed Effects	Y	Y	Y	Y	Y	Y
Firm Fixed Effects	N	N	N	N	N	N
Business Segment Fixed Effects	Y	Y	Y	Y	Y	Y
Matching	N	N	PSM	N	N	PSM
Matching – Treatment variable	-	-	R&D Decent.	-	-	R&D Decent.
N	803	803	144	803	803	150
Pseudo-R^2	0.0626	0.0632	0.0751	0.131	0.132	0.183
Log Likelihood	-513.3	-513.0	-95.40	-4488.4	-4479.9	-790.1

Standard errors in parentheses: $^{+}$ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$. Standard errors clustered at the firm-level. For H1 and H2, firm-years matched with R&D Decentralization=1 and 0 using caliper radius 0.00035. Similar results obtained using various caliper and nearest neighbor matching approaches. PSM – Propensity Score Matching

Development: Hypotheses 3 and 4

Table 6 and Table 7 illustrate the main analyses used to test H3 and H4. Support for H3 is illustrated by the statistically significant negative coefficients for *R&D Decentralization* in Models 2 -3 in Table 6. Decentralization of R&D is associated with the progression of 0.89 fewer drug candidates from pre-clinical to phase 1 (0.16 standard deviations). The interviews with R&D managers highlighted the benefits of R&D centralization in the earlier stages of development:

> *"The early stages of development are difficult to distinguish from discovery. That is why organizing to ensure greater integration across therapeutic areas is important as an idea in one area may be able to be translated into another therapeutic area. Often the best ideas are those which start in one area but move to another"*

Prior studies have illustrated that drug-candidates fail to progress through clinical trials primarily because of efficacy, strategic and operational issues as opposed to safety (Harrison, 2016). It is precisely these more technical issues that enhanced intra-organizational knowledge flows can help to overcome. Later in the development process in the phase 2 to 3 transition, H4 receives support in that greater *Corporate Decentralization* is associated with the progression of more inventions (Models 2-3 in Table 7). This is exhibited by the statistically significant positive coefficient for *Corporate Decentralization*. A one standard deviation increase in *Corporate Decentralization* (0.27) is associated with 0.15 more drug candidates progressing from Phase 2 to 3 in a year on average (0.09 standard deviation higher number of drug candidates progressing). Interviews highlighted that for the phase 2 to 3 transition a broader range of functions are generally involved unlike prior transitions:

> *"Pre-clinical and Phase 1 are R&D heavy with limited commercial input. Marketing and other commercial functions don't tend to be significantly involved in the drug development process till it comes to the Phase 2 to 3 transition, prior to that it is mainly R&D driven"*

The impact of decentralization on incentives was also raised by several

interviewees:

> *"A more corporate* [centralized] *structure lacks the provision of good incentives as you tend to under-reward good performance and over-look poor performance. It is harder to pin down who is responsible for what"*

There is some evidence to suggest that decentralization of R&D hinders the progression of drug-candidates from Phase 2 to 3. However, for the Phase 1 to 2 and Phase 3 to Pre-registration transitions no evidence was observed to suggest that decentralization of R&D is associated with the progression of fewer drug-candidates. This provides some tentative evidence to suggest that the importance of knowledge flows declines through development. Interviews highlighted:[15]

> *"Early on it is important to get a wide range of technical eyes on a problem with scientists from many disciplines exchanging ideas. Later on in clinical development everything is so therapeutic area specific that little can be gained from, for example, a cardiovascular team talking to an oncology team"*

[15] I also conduct Wald tests comparing the coefficients for R&D decentralization across clinical phase transitions. I find that the coefficients are significantly larger for the Pre-clinical to Phase 1 and Phase 2 to 3 transitions than for the Phase 1 to 2 and Phase 3 to Pre-registration transitions (which are not significantly different from zero). Thus it appears that knowledge flows are critical for the pre-clinical to Phase 1 and Phase 2 to 3 transitions but not the other two transitions. This provides some tentative evidence to suggest that the importance of knowledge flows declines through development but for the critical Phase 2 to 3 transition they appear to still play a role. It is likely that firms are still working on addressing technical issues such as scaling up manufacturing and understanding pharmodynamics and pharmokinetics where intra-organizational knowledge flows may help.

Table 6: Negative binomial regression analyses relating to development hypothesis (H3)

Dependent Variable	**Number of inventions progressing to next phase (prog)**					
Clinical Phase Transition	**H3: Phase 0 to 1**			**Supplemental Analysis: Ph. 1 to 2**		
Model	**1**	**2**	**3**	**4**	**5**	**6**
R&D Decentralization		**-0.223***	**-0.196***		-0.144*	-0.0181
		(0.0947)	**(0.0855)**		(0.0728)	(0.179)
R&D Functional Differentiation		-0.0755	-0.134		**0.142+**	**0.276****
		(0.0766)	(0.148)		**(0.0780)**	**(0.0989)**
Corporate Decentralization		0.153	0.126		0.113	0.167
		(0.127)	(0.252)		(0.180)	(0.253)
performance	0.0383	0.00508	0.00399	0.736*	0.619+	0.669
	(0.431)	(0.408)	(0.589)	(0.371)	(0.358)	(0.751)
R&D Intensity	0.528*	0.596**	0.669**	0.290	0.300	0.385
	(0.213)	(0.200)	(0.209)	(0.209)	(0.200)	(0.383)
size	0.274**	0.285**	0.278**	0.0772	0.0901+	0.0522
	(0.0555)	(0.0506)	(0.0800)	(0.0504)	(0.0473)	(0.0704)
slack	0.0334	0.0401*	0.0595*	-0.00653	-0.0108	-0.0335
	(0.0213)	(0.0204)	(0.0297)	(0.0254)	(0.0264)	(0.0469)
CEO	0.00871	-0.00334	-0.210*	0.00894	0.00629	0.00881
	(0.0703)	(0.0703)	(0.0854)	(0.0720)	(0.0734)	(0.142)
patent stock	0.0976*	0.0982*	0.113*	0.0170	0.0129	0.00165
	(0.0399)	(0.0385)	(0.0475)	(0.0351)	(0.0356)	(0.0609)
portfolio	0.00765**	0.00744**	0.00912**	0.0265**	0.0286**	0.0397**
	(0.00224)	(0.00250)	(0.00297)	(0.00612)	(0.00592)	(0.00796)
external	-0.638**	-0.662**	-0.319	0.0819	0.115	0.132
	(0.186)	(0.186)	(0.302)	(0.152)	(0.164)	(0.242)
NCE	-0.580**	-0.600**	-0.604+	0.343+	0.293	0.219
	(0.208)	(0.208)	(0.319)	(0.192)	(0.188)	(0.260)
bio	0.393	0.391	0.318	0.972**	0.875**	0.901*
	(0.256)	(0.253)	(0.347)	(0.252)	(0.258)	(0.413)
tech. diversity	1.953**	1.913**	1.334**	1.980**	1.896**	1.709**
	(0.261)	(0.249)	(0.289)	(0.264)	(0.252)	(0.432)
competition	-5.832**	-6.035**	-8.185**	-2.326	-1.581	-3.774
	(1.701)	(1.860)	(2.503)	(2.446)	(2.296)	(2.976)
Year Fixed Effects	Y	Y	Y	Y	Y	Y
Firm Fixed Effects	N	N	N	N	N	N
Bus. Seg. Fixed Effects	Y	Y	Y	Y	Y	Y
Matching	N	N	PSM	N	N	PSM
Matching – Treatment variable	-	-	R&D Decent.	-	-	R&D Functional Diff.
N	787	787	309	764	764	310
Pseudo-R^2	0.237	0.241	0.264	0.224	0.227	0.238
Log Likelihood	-1568.3	-1561.8	-593.1	-1199.8	-1195.6	-444.7

Standard errors in parentheses: $^{+}$ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$. Standard errors clustered at the firm-level.
H3: Firm-years matched with R&D Decentralization=1 and 0 using 3 nearest neighbors. Similar results obtained using various caliper and nearest neighbor matching approaches. Supplemental Analysis: Firm-years matched with R&D Functional Differentiation =1 and 0 using a caliper matching radius = 0.008. Similar results obtained using various caliper and nearest neighbor matching approaches. PSM – Propensity Score Matching

Table 7: Negative binomial regression analyses relating to development hypothesis (H4)

Dependent Variable	**Number of inventions progressing to next phase (prog)**		
Clinical Phase Transition	**H4: Phase 2 to 3**		
Model	**1**	**2**	**3**
R&D Decentralization		-0.204^{+}	-1.364**
		(0.104)	(0.331)
R&D Functional Differentiation		-0.0876	0.147
		(0.0919)	(0.396)
Corporate Decentralization		**0.330***	**0.843****
		(0.166)	**(0.202)**
performance	0.478	0.432	-1.359
	(0.460)	(0.429)	(1.871)
R&D Intensity	0.308	0.328	4.111^{+}
	(0.253)	(0.336)	(2.154)
size	0.143**	0.123	-0.0220
	(0.0519)	(0.115)	(0.779)
slack	0.00275	-0.0534	0.135
	(0.0313)	(0.0442)	(0.174)
CEO	-0.00706	-0.0146	0.727**
	(0.0784)	(0.0824)	(0.237)
patent stock	0.0871*	-0.00291	-0.455
	(0.0439)	(0.0609)	(0.338)
portfolio	0.0172**	0.0261**	0.0589**
	(0.00366)	(0.00399)	(0.0158)
external	0.185	0.0743	1.639*
	(0.215)	(0.254)	(0.813)
NCE	-0.205	-0.760*	-2.518*
	(0.251)	(0.343)	(1.230)
bio	0.166	-0.278	-4.086**
	(0.302)	(0.412)	(1.138)
tech. diversity	1.445**	1.145**	-1.785
	(0.362)	(0.397)	(1.861)
competition	-2.644	-3.176	-10.30
	(2.013)	(2.421)	(16.51)
Year Fixed Effects	Y	Y	Y
Firm Fixed Effects	N	Y	Y
Business Segment Fixed Effects	Y	Y	Y
Matching	N	N	PSM
Matching – Treatment variable	-	-	Corporate Dec. dichot.
N	762	762	124
Pseudo-R^2	0.191	0.220	0.444
Log Likelihood	-1013.2	-977.3	-125.6

Standard errors in parentheses: $^{+}$ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$. Standard errors clustered at the firm-level. H4: Firm-years matched with dichotomized Corporate Decentralization = 1 and 0 using caliper matching radius = 0.0002. Similar results obtained using various caliper and nearest neighbor matching approaches. PSM – Propensity Score Matching

Robustness tests

Six robustness tests are undertaken (Table 8). First, the analyses are repeated using Coarsened Exact Matching (CEM). For H1-3 *R&D Decentralization* is used as the treatment variable and for H4 the "treatment" is a dichotomized (around the median) version of *Corporate Decentralization.* Observations are matched using all the independent variables in Table 5 (H1-2), Table 6 (H3) and Table 7 (H4) respectively. These variables are all coarsened into 2-5 strata. Second, alternate regression models are used to test all four hypotheses. OLS linear regression models are used with dependent variables of *originality* (H1) and log(*quantity)* (H2). For H3 and 4, both zero-inflated negative binomial and Poisson regressions were utilized (Model 2, Table 8). Third, as an alternative test of H3 and H4, the unit of analysis is changed to the drug-candidate-year with the dependent variable being a binary variable set to 1 if the drug-candidate progresses from pre-clinical to phase 1 (H3) or phase 2 to 3 (H4) (Model 3, Table 8). The likelihood of inventions progressing to the next phase is estimated using logit models with a linear time-varying co-variable (Allison, 1982). This enables me to control for individual drug-specific characteristics (e.g. NCE status, source, whether biotech or anti-cancer drug). Fourth, as an alternative to *NCE* and *bio* as measures of the novelty of a firm's development portfolio, the variable *novelty* is used to test H3 and H4 (Model 4, Table 8). Fifth, firms may vary in their geographical coverage of their R&D (Model 5, Table 8).[16] An additional control is included in the main analysis with the number of countries that a firm's inventors come from per year to account for this dispersion. Propensity-scoring matched models are undertaken (Table 5 models 3 and 6). All five tests provide further support for H1-4.

Finally, analyses are conducted using 1-year lagged values and three-year rolling average values of the two structural measures (Model 6). These analyses are conducted primarily to rule out reverse causality. Support is found for H1 and H3 but the degree of statistical significance drops due to a reduction in power due to the loss of a year's worth of data. H2 is now marginally statistically insignificant ($0.1<p<0.18$). However, H4 is no

[16] Firms with decentralized R&D on average have inventors in 19.1 countries versus 15.7 countries for firms with centralized R&D. This difference is statistically significant (p=0.004). This provides some confidence in the measure of R&D decentralization as firms that are more decentralized are likely to be more geographically dispersed. Thus, there is a risk that this variable of the number of countries in which firms invent is a "bad control" (Angrist & Pischke, 2008). As a result it is only used in robustness tests and not the main analyses.

longer supported. This is consistent with additional functions being brought in at the end of the Phase 2. It is likely the increased effort associated with the greater number of drug candidates progressing occurs towards the end of the phase. Further details of these robustness tests are provided in Appendix 6.

Table 8: Robustness tests of main hypotheses: key results

Relevant Independent Variable	Hyp.	Coefficients (p-values)						
		1. CEM	2. Alternate specifi-cation	3. Drug-candidate - year analysis	4. Alternate novelty measure	5. R&D geog. control	6a. Lagged IV	6b. Rolling average IV
R&D Decentralization	1	-0.190 (0.011)	-0.037 (0.007)	-	-	-0.207 (0.012)	-0.162 (0.023)	-0.161 (0.022)
R&D Decentralization	2	0.279 (0.000)	0.246 (0.100)	-	-	0.184 (0.047)	0.186 (0.172)	0.224 (0.156)
R&D Decentralization	3	-0.216 (0.019)	-0.150 (0.034)	-0.263 (0.006)	-0.213 (0.038)	-	-0.133 (0.176)	-0.237 (0.037)
Corporate Decentralization	4	0.216 (0.025)	0.328 (0.047)	0.259 (0.084)	0.299 (0.071)	-	0.144 (0.437)	0.073 (0.673)

Analysis of mechanisms

Six additional analyses are conducted to explore the validity of the knowledge flow and incentives mechanisms through which organization design is hypothesized to impact innovation outcomes (also see Appendix 7). First, how firms' pre-existing breadth of knowledge (*tech. diversity)* moderates the association between *R&D Decentralization* and the progression of inventions through the early stages of the development process is examined (Phase 0 to 1 as tested for H3). If the knowledge flow mechanism is pertinent, firms with a broader array of knowledge will benefit more from centralization of R&D as these enhanced knowledge flows will provide an even greater array of knowledge for managers to tackle technical issues. Support for this argumentation is provided through an extended version of model 2 in Table 6, which includes an additional term, *tech. diversity* x *R&D Decentralization*, which is negative and statistically significant at the 99% confidence level. This result is graphically illustrated in Figure 5a. It can be seen that for low levels of *tech diversity* (narrower knowledge base), firms with decentralized R&D progress more inventions. However, for higher levels of *tech. diversity* firms with

centralized R&D progress more inventions. This clearly illustrates the knowledge-incentive trade-off. At low levels of *tech. diversity* incentives outweigh knowledge flows but this relationship reverses at higher values of *tech. diversity* where knowledge flows play a larger role.

Second, firms with a greater proportion of more novel inventions in their early development portfolio (as estimated using *NCE*) are likely to benefit more from a greater degree of R&D centralization. This is because such inventions will require greater access to firms' knowledge bases to address the more challenging technical issues. This argumentation is supported using an extended version of model 2 in Table 6 which includes the interaction term, *NCE* x *R&D Decentralization*, which is negative and statistically significant at the 99 % confidence level. This relationship is illustrated in Figure 5b. For more basic portfolios with fewer NCEs, intra-organizational knowledge flows may not be as critical as the technical issues associated with these portfolios can be addressed using local knowledge within a specific R&D unit. Thus firms with decentralized R&D may be able to progress more inventions through early development. This is because of the greater effort and effectiveness of this effort associated with decentralized R&D units overcoming reduced knowledge flows.[17] Similar results are also obtained using *novelty* (Figure 5c).

Third**,** an additional R&D design element pertains to whether this group is integrated into one unit or split into separate research and development units (*R&D functional differentiation*). It is akin to vertical dis-integration of R&D. Decision rights are split between R&D activities and there are separate hierarchical reporting lines for each function. In contrast, a functionally integrated R&D unit is associated with decision rights over the complete R&D process. A key innovation stage involves the handover of inventions from research to development (e.g., Kapoor & Klueter, 2015). In line with an incentive-based argumentation, functional differentiation of R&D is likely to be associated with the progression of more inventions. This is because in separate units, research managers will exert greater effort to ensure more inventions progress to development as

[17] Further, consistent with the theoretical argumentation provided above, the interaction term *NCE x R&D Decentralization* is only statistically significant for the phase 0 to 1 transition where the benefits of rich technical knowledge flows are likely to be the greatest in the development process.

the outputs of their actions are more observable enabling more effective use of incentives. To test this logic, the coefficient for the variable *R&D Functional Differentiation* is examined at different development stages. For the Phase 1 to 2 transition, this coefficient is positive and statistically significant indicating that separation into individual R&D units is associated with the progression of more drug-candidates (Models 5 and 6 in Table 6). Functional differentiation of R&D is associated with 0.43 more inventions progressing from Phase 1 to 2 (0.16 standard deviations). Interviews highlighted:

> *"Research managers are incentivized by the number of drugs that they can get into Phase 2 (Proof of Concept), which means a lot of questionable candidates may get thrown over the fence into Phase 2"*

Review of companies' filings suggests that for functionally separate research and development units, research undertakes early stage (Phase 1) clinical trials. Interviews highlighted that functional integration of R&D was associated with a single budget as opposed to separate research and development budgets. Managers suggested that this could result in a shift of resources to later development. This in turn can lead to fewer drug candidates progressing from Phase 1 to 2. Further details are provided in Appendix 7.

Fourth, an indirect route to examine the incentives-based mechanisms involves the evaluation of the time lag between the date of filing of firms' patents and their eventual grant date. Régibeau and Rockett (2010) indicate that this lag is dependent on the efforts made by the filing organization. Thus a lower grant lag can indicate that firms exert more effort to get granted, patented inventions (Harhoff & Wagner, 2009). As a result, the mean grant lag for firms' granted patent families per year is regressed against the variables in Table 3 (including originality) with two additional controls pertaining to the average number of claims and non-patent citations per patent within a patent family. These controls are focused on ensuring like with like patents are compared for centralized and decentralized R&D units. As illustrated in Table 9a, the coefficient for *R&D Decentralization* is negative and significant at the 95 % confidence level. This analysis indicates that firms with decentralized R&D are associated with patent grant lags that are 50 days shorter (Sample mean is 1212 days) than firms with centralized R&D units. This result is consistent with the incentives-based argumentation that managers in decentralized

R&D units expand more effort to create and patent inventions.

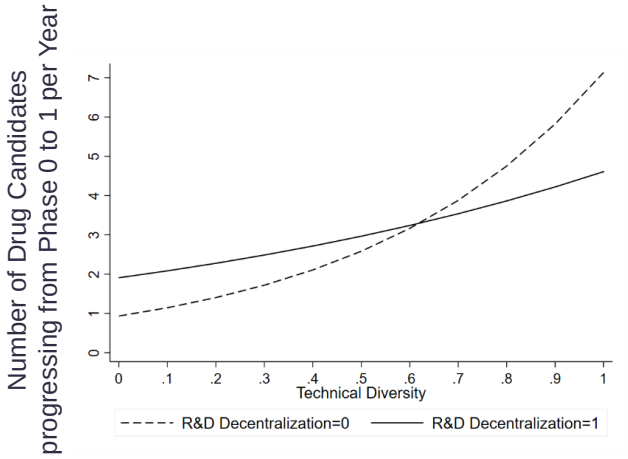
Fifth, it may be the case that more inventions are progressed in development because managers progress lower quality inventions rather than exerting greater effort. This alternative explanation is examined through evaluating the likelihood of inventions that enter phase 2 and 3 progressing to phase 3 and Pre-registration respectively using both cox proportional hazards and logit models with a time-varying co-variable (Allison, 1982). If lower quality inventions are progressed, there will be a reduced likelihood of these inventions progressing through the later stages of development as, for example, reduced efficacy becomes more apparent. No evidence is observed (Table 9b) to suggest that firms with functionally differentiated R&D units and firms with higher values of *Corporate Decentralization* progress lower quality inventions as the inventions progressed in these firms are as likely to progress through the later stages as those in firms that are functionally integrated across R&D and with lower *Corporate Differentiation*. The non-significance of the coefficients for *R&D Functional Differentiation* at the time drug candidates move from phase 1 to 2 and *Corporate Decentralization* at the time when drug candidates move from phase 2 to 3 support this assertion.

Finally, if managers exert greater effort then it is likely that inventions will progress through the development process more rapidly. In order to examine this assertion, the average time for drug-candidates to progress through phase 2 into phase 3 is examined over the 20-year time period and regressed against the mean level of *Corporate Decentralization* over this period for each firm alongside a set of control variables to control for differences in firms' size, diversification and portfolio composition. As illustrated in Table 9c, a statistically significant negative coefficient is observed for *Corporate Decentralization* suggesting that, after controlling for key firm and portfolio differences (e.g. proportion of NCEs in portfolio), firms that are more decentralized at the corporate level are associated with the more rapid progression of drug-candidates through later development (phase 2 to 3). This is again consistent with an incentives-based argumentation.[18]

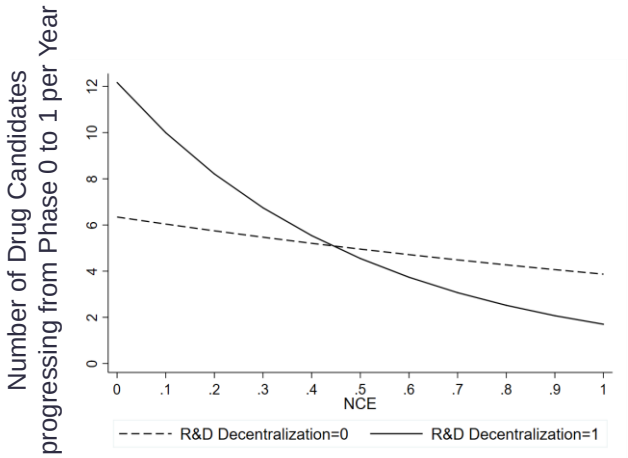
[18] Additionally beyond the analyses presented, I find some limited evidence to suggest that the heads of functionally integrated R&D units receive less total compensation that the heads of separate research and development units. Also I find some evidence to suggest that top management team executives in firms with higher values of *Corporate Decentralization* tend to have a lower fixed component

Figure 5: Examination of knowledge-flow mechanism. Charts illustrating interaction between *R&D Decentralization* and (a) *tech. diversity* and (b) *NCE* (c) *Novelty.*

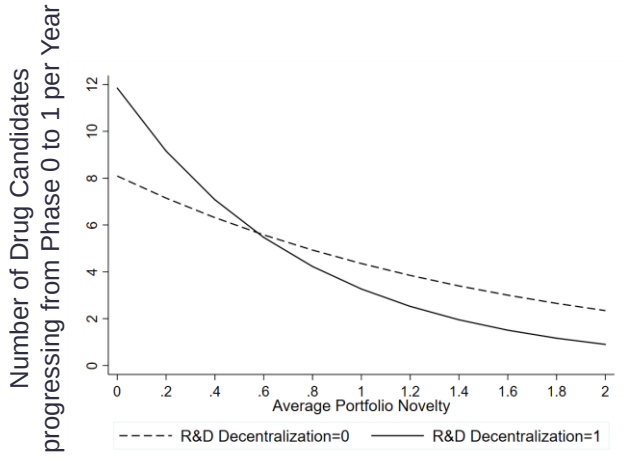
(a)



(b)



(c)



of their total compensation but similar overall, total compensation to executives in firms with lower values of *Corporate Decentralization*. Both provide some indirect, tentative evidence to suggest that greater decentralization is associated with higher-powered incentives. See Appendix 7 for further details.

Table 9: Incentives mechanism analyses (a) patent grant-lag; (b) likelihood of progression of drug-candidates to next clinical phase; (c) time to progress through phase 2 trials

(a) DV=Patent grant-lag (Days) - OLS regression	Model 1	Model 2
R&D Decentralization	**-81.65****	**-50.20***
	(28.72)	**(20.03)**
R&D Functional Differentiation	63.20^{+}	15.69
	(33.63)	(29.00)
Corporate Decentralization	61.68	70.18
	(63.94)	(63.00)
Main Control Variables (Table 3)	Y	Y
Patent-level controls (e.g. originality)	Y	Y
Business Segment Fixed Effects	Y	Y
Year Fixed Effects	Y	Y
Firm Fixed Effects	N	Y
N	782	782
R^2	0.618	0.644

(b) Likelihood of drug progression	Logit – linear time function		Cox Proportional Hazards model	
Progression Model	**Phase 2 to 3 1**	**Phase 3 to PR 2**	**Phase 2 to 3 3**	**Phase 3 to PR 4**
R&D Functional Differentiation when drug moved into Phase 2	**0.0916 (0.255)**		**0.0868 (0.175)**	
Corporate Decentralization when drug moved into Phase 3		**0.107 (0.379)**		**-0.0747 (0.320)**
Firm-year level controls	Y	Y	Y	Y
Business Segment Fixed Effects	Y	Y	Y	Y
Year Fixed Effects	Y	Y	Y	Y
Drug-level controls	Y	Y	Y	Y
Therapeutic Area Fixed Effects	Y	Y	Y	Y
N	5168	3578	4473	2712
Log Likelihood	-1289.2	-1334.8	-2063.2	-2055.5

(c) DV= Time to progress from Phase 2 to 3 (years) OLS regression	Model 1 (No Structural Controls)	Model 2 (With Structural Controls)
Mean Corporate Decentralization	**-1.898***	**-1.741**$^{+}$
	(0.899)	**(0.937)**
Main Control Variables (Table 4)	Y	Y
N	47	47
R^2	0.277	0.294

Standard errors in parentheses: $^{+}$ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$. Standard errors clustered at the firm-level.

Discussion and Conclusion

This study examines the relationship between firms' organization designs and their innovation outcomes through integrating knowledge- and incentive-based theoretical lenses. Firms face a knowledge-incentive trade-off with respect to the relationship between their organization designs and innovation outcomes that varies in its impact through the innovation process. First, during the invention stage, decentralization of R&D is associated with the creation of more inventions, but these inventions are less original. This is because greater decentralization is associated with reduced intra-organizational knowledge flows limiting the breadth of knowledge that can be accessed. However, for inventions that draw on local search only requiring knowledge within an organizational unit, decentralization enables the more effective use of incentives, which engenders greater managerial effort and also is associated with greater efficacy of this effort, thus facilitating the creation of more inventions. Second, greater R&D decentralization during the earlier stages of development is associated with the progression of fewer inventions as firms struggle to address complex technical issues, as they are unable to draw on their broader knowledge bases. However, later in development when complex technical issues have been largely resolved, greater corporate decentralization facilitates the progression of more inventions. Ultimately, greater decentralization can engender greater managerial effort due to the more effective utilization of higher-powered incentives, however it limits access to a firm's broader knowledge base. In order to address challenging technical problems the cost of reduced knowledge flows can outweigh greater effort. However, when dealing with less complex problems this greater effort is more effective.

Consistent with the work of Argyres and Zenger (2012) that focused on the boundaries of the firm, incentives and intra-organizational knowledge flows are intertwined. The higher powered incentives associated with greater decentralization can decrease motivation to share or utilize shared knowledge thereby reducing intra-organizational knowledge flows. Further, the greater organizational "distance" between sub-units in a more decentralized design can hinder the transfer of highly tacit, complex knowledge. Without combining the knowledge- and incentives-based perspectives, it is not possible to fully explain the relationship between organization design and firms' innovation

outcomes. Viewing innovation as a process enables me to unpack these two mechanisms as their relative impact on innovation will vary through the innovation process.

This study highlights that in a desire to create more nimble, autonomous units, with greater decision rights, managers may limit the benefits associated with the scope of knowledge within their firms. With the reduced intra-organizational knowledge flows associated with decentralized R&D, firms may limit themselves to local search and miss out on rich knowledge recombination opportunities associated with more original inventions. Further, by reducing access to their broader knowledge firms may struggle to progress more inventions through the technically-complex earlier stages of development. This was experienced by Procter & Gamble when they decentralized R&D as part of their "Organization 2005" efforts (Mandlowitz & O'Brien, 2012). Although more products hit the market, they were less original, with analysts stating that P&G was "*reformulating and not inventing."* This was in large part driven by the fact that in the decentralized structure scientists from different parts of the business were less able to share knowledge. As senior P&G managers noted:

> *"We knew that most of P&G's best innovations had come from connecting ideas across internal businesses." Huston and Sakkab (2006)*

However, for later stage development where intra-organizational knowledge flows are less pertinent and the knowledge required to progress inventions is more compartmentalized, firms can benefit from more autonomous units. This is consistent with the ambidexterity and disruptive innovation literatures (e.g., Christensen & Bower, 1996; Lavie, Stettner, & Tushman, 2010; Tushman et al., 2010).

Together these results contribute to the strategic management literature in three important ways. First, by conceptualizing innovation as a process rather than as an outcome (e.g., Kapoor & Klueter, 2015; Keum & See, 2017) this study helps to integrate the organization design and innovation literatures more closely. Much prior work in the innovation domain has tended to conflate the various stages of the innovation process (e.g., Garud et al., 2013). This approach therefore helps to highlight that different facets of

organization design play a greater or lesser role throughout the innovation process. For example, in the initial knowledge-rich invention and early development stages, decentralization of R&D is most pertinent. However, as an invention gets closer to market, the degree of corporate decentralization is most relevant. This enables me to theorize and observe that similar organization design elements (i.e., increased or reduced decentralization) may result in different outcomes depending on whether they pertain to firms' invention or development activities. Thus it is important to understand where (in the organization, e.g., R&D) and when (in the relevant process, e.g., invention stage) design choices are made in order to fully appreciate the role of design on organizational performance. This may help to reconcile the varied findings within the extant literature pertaining to how decentralization can impact innovation, as these studies focus on different aspects of "where" and "when." For example, work examining centralization of R&D has focused on invention (e.g., Argyres & Silverman, 2004; Arora et al., 2014), whereas the ambidexterity literature has tended to examine later development and launch (e.g., Tushman et al., 2010). This process-based approach also suggests that certain organization designs may be better fits for different innovation strategies. For example, greater decentralization can facilitate the creation of more incremental inventions that can be readily translated into final products. Whereas greater centralization of R&D can help to create more original inventions that are able to make it through early development.

Second, this study adds to the debate regarding the importance of integrating capabilities-based with organizational economics-based theories (e.g., Argyres, 2011; Argyres et al., 2012; Argyres & Zenger, 2012; Dosi et al., 2003; Kapoor & Lim, 2007). Prior work has focused on examining the boundaries of the firm rather than looking within the "Black Box" that is the firm. These studies have tended to focus on the holdup risks associated with unique assets that are required to create unique capabilities (e.g., Argyres & Zenger, 2012). In contrast, this study highlights that a knowledge-based process is subject to incentives considerations which can shape how internal organization design impacts firms' innovation. Namely, firms need to manage a delicate trade-off between rich intra-organizational knowledge flows and effective use of incentives with respect to their designs. This study therefore answers the call to leverage both capability and organizational

economics perspectives in examining internal organization design (Argyres & Zenger, 2012).

Finally, this study also contributes to the literature on the capability-based view of the firm (e.g., Barney, 1991). Firms cannot be assumed to be unitary actors (e.g., Bidwell, 2012) and firms' designs, such as the extent to which they decentralize certain parts of their organizations, can strongly influence access to their broader knowledge bases. For example, this study illustrates that in the early stages of development, decentralization of R&D is associated with the progression of fewer inventions, with the benefits of centralization being enhanced when a firm has a broader knowledge base. Thus, by being able to access their broader knowledge base, managers within centralized R&D units can more effectively address the technical challenges that they are likely to face during the early stages of development. This study therefore highlights that although a firm may have a broad knowledge base, it may not always translate into superior performance simply because this knowledge may not be accessible to the parts of a firm undertaking key activities. Thus, two firms with the same knowledge base can experience very different innovation outcomes based on their designs. This can therefore provide some insight into the foundations of firms' product development capabilities (e.g., Brown & Eisenhardt, 1995; Eisenhardt & Martin, 2000). From an organization design perspective, greater centralization or integration can facilitate rich intra-organizational knowledge flows, thereby enhancing capabilities associated with the creation of original inventions that can be progressed effectively through the early stages of development. In contrast, decentralizing to maximize the efficacy of incentives can facilitate capabilities associated with the creation of a higher volume of inventions and more effective progression of these inventions through later development.

In conclusion, this paper highlights that firms' organization design can influence both knowledge flows and incentives. This helps to illuminate an inherent trade-off firms face in that greater decentralization is associated with more effective usage of incentives, yet limits knowledge flows. Through conceptualizing innovation as a process I am able to unpack the impact of organization design on knowledge flows and incentives. This enables me to highlight the boundary conditions pertaining to where greater decentralization may

enhance or reduce firms' innovation outcomes as well as how organization design can shape firms' innovation capabilities.

CHAPTER 3: MIND THE GAPS: HOW ORGANIZATION DESIGN SHAPES THE SOURCING OF INVENTIONS

Finalist, Strategic Management Society Annual Meeting Best Conference PhD Paper Prize; 2018

Abstract

In their quest to sustain their innovativeness, firms pursue multiple inventions, with only a small proportion of them achieving fruition. In addition to the challenge of commercializing their inventions, firms also face the challenge of replenishing and maintaining the flow of inventions within their pipelines. This replenishment could be done via internally or externally sourced inventions through licensing, alliance or acquisition modes. Existing research has considered this decision to take place at the firm-level and the logic for decision-making at the transaction-level. I integrate the incentive- and knowledge-based views of the firm to offer a new theory to explain this decision. Within the theory, I consider that firms may decentralize such decisions within specific R&D units, and that the decision-making might operate at the pipeline-level rather than at the individual transaction-level. This allows me to consider different sources of heterogeneity within firms' decision-making processes, and show how organization design can have significant implications for firms' invention sourcing. I explore these arguments using a novel dataset of firms' invention sourcing decisions in the pharmaceutical industry between 1995 and 2015. I find that decentralized designs with multiple R&D units are associated with a higher proportion of externally sourced inventions. This difference is primarily driven by differences in the propensity to license, and for inventions of moderate novelty. These findings highlight an important linkage between firms' internal organization designs and their sourcing of inventions, and in doing so, show how such decision-making is impacted by both managerial incentives and intra-organizational knowledge flows.

Introduction

> *"In terms of things that keep me awake at night, I would say that I'm actually less concerned about this quarter and how we're doing, as I am about keeping our innovation pipeline full,"* Clifton Pemble, Garmin CEO 2018

> *"We allocate resources across the best internal and external opportunities we assess. The balance of internal R&D coupled with external programs and collaborations has generated the successful portfolio of current medicines and pipeline candidates we have today",* Robert A Bradway, CEO Amgen 2016

As illustrated by the quotes above, firms' invention pipelines are critical to their competitiveness. Sustaining the flow of inventions through their pipelines requires continuous replenishment with new inventions as existing inventions are weeded out or reach fruition (e.g., Chan, Nickerson, & Owan, 2007; Klingebiel & Rammer, 2014). This replenishment can be undertaken via internally generated inventions or externally sourced inventions through licensing, alliances or acquisition modes (e.g., Cassiman & Veugelers, 2006; Rothaermel & Alexandre, 2009).

Prior studies have tended to examine the sourcing decision at the level of the individual transaction made by the focal firm (e.g., Argyres & Liebeskind, 1999; Bidwell, 2012; Weigelt & Miller, 2013). However, because of the uncertainty surrounding the generation and the commercialization of inventions, the decision to replenish pipelines is typically not undertaken at the individual transactional level but rather at the overall pipeline level (e.g., Chan et al., 2007; Nishimura & Okada, 2014). This is because the problem of replenishment is associated with the efficiency of knowledge generation with respect to both the timing and the alignment with the firm's existing pipeline whereas the problem of sourcing is associated with the efficiency of coordination for a specific transaction. Further, firms may vary in terms of how they are internally organized for innovation (e.g., Argyres & Silverman, 2004). A centralized organization design is typically associated with creating and managing a universal invention pipeline that feeds different businesses or markets. In contrast, a decentralized design is typically associated with the creation and management of a set of invention pipelines specific to different businesses or markets.

In this study, I offer a framework in which I view firms' sourcing of inventions as a process of replenishing their invention pipelines, and I consider this decision based on how the focal firm is internally organized for innovation, distinguishing between centralized and decentralized designs. The framework is premised on the notion that centralized and decentralized designs may vary in terms of managerial incentives around replenishment as well as in terms of intra-organizational knowledge flows impacting the discovery of inventions (e.g., Argyres et al., 2012; Argyres & Zenger, 2012). Specifically, I explore the relationship between a firm's internal organization design and the proportion of inventions in its pipeline that are sourced externally, and how this relationship varies with the mode of external sourcing.

I argue that managers within decentralized Research and Development (R&D) units face greater pressures to ensure a steady flow of inventions for a specific business unit. They are thus more incentivized towards moving inventions through the development process rather than developing internal capabilities (DeSanctis et al., 2002). Sourcing inventions externally can help overcome internal capability constraints and ensure a steady flow in the pipeline (e.g., Leiblein & Miller, 2003). In contrast, centralized R&D units have greater freedom to work on cross-organizational technologies and build internal capabilities (e.g., Argyres & Silverman, 2004). As a result, managers in decentralized R&D units are more likely to source inventions externally than those in centralized units. Moreover, given that this relationship is premised on accessing inventions rather than capabilities, I expect it to be primarily driven by differences in the propensities for licensing than those for alliances and acquisitions.

I test these arguments within the context of the global pharmaceutical industry using a novel dataset of 12,016 drug candidates sourced or created by 49 leading firms over the period 1996-2015. I supplement this data with 61 interviews with managers from 28 of these firms to probe the mechanisms through which design choices can influence sourcing decisions and to validate the structural measures I utilize. This industry provides a suitable context for this study as the sourcing of externally created drug candidates for subsequent development by other firms is well-established (e.g., Macher & Boerner, 2012; Rothaermel & Alexandre, 2009). Further, I am able to observe firms' full drug development pipelines

over an extended period of time and develop specific measures of firms' organization designs that enable me to test my theoretical arguments.

On average, 37% of drug-candidates used to replenish firms' pipelines in a typical year are sourced externally. Consistent with my arguments, this proportion is 35.6% for R&D organized in a centralized manner and 41.3% for when it is organized in a decentralized manner. This difference in the propensity to replenish pipelines via external inventions is confirmed via multivariate regression analysis. Further, this difference is driven by the propensity to license and not by the propensities for acquisitions and alliances, and by inventions of intermediate novelty. These results are robust to a variety of alternate specifications and strategies to control for omitted variable bias.

This study makes three primary contributions to the strategy and the innovation literatures. First, the study helps to extend the theoretical considerations associated with the make versus buy decision pertaining to inventions which firms subsequently develop into final products. I add to existing theory in this domain by highlighting that firms' internal design can shape both managerial incentives and their firms' invention creation capabilities which, in turn, influence the propensity of firms to source inventions externally. Further, in contrast to previous work that has tended to examine individual make-buy decisions in isolation, I argue that firms make this decision in the context of supplementing their stock of inventions and enhancing the flow of inventions through the development pipeline. Second, I build on recent work that has examined how firms' internal design choices can shape their decision to source ideas externally or create them internally (e.g., Arora et al., 2014; Grigoriou & Rothaermel, 2017; Leiponen & Helfat, 2011). This study extends this work by providing a holistic theoretical perspective and by illustrating that design choices can also influence the mode through which firms source inventions as well as the novelty of inventions sourced. Third, this study suggests an important linkage between firms' internal design and the composition of markets for technologies. This could prove fertile ground for future cross-industry studies. For example, do industries that have well-developed markets for technologies have a higher prevalence of firms with decentralized R&D, whereas those with thinner technology markets tend to have firms with centralized R&D units?

Theory and Hypotheses

Theoretical framework

The innovation process can be divided into three stages (e.g., Garud et al., 2013). First, there is the act of invention (e.g., Arora et al., 2016; Kapoor & Klueter, 2015). Invention involves the creation of novel ideas that in themselves are of limited economic value (Schumpeter, 1939). The key outputs of this stage are inventions, namely tangible ideas that need to be further developed. Second, development is focused on converting an invention into a final product that can yield commercial value. Third, there is market launch or commercialization, which relate to firms' value appropriation from their developed offerings. In crafting the theoretical arguments, I focus upon the development stage of the innovation process.

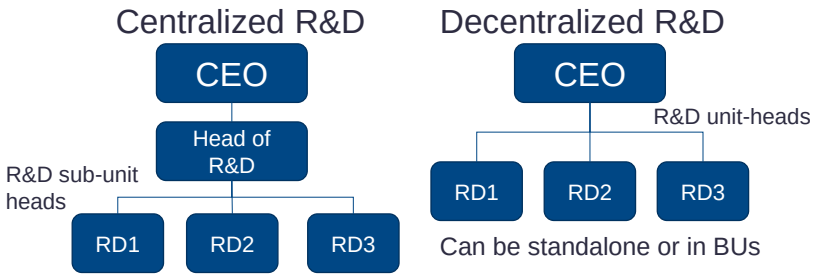
To ensure a continuous flow of new products to the market place, firms generally manage a development pipeline of inventions (e.g., Chan et al., 2007; Grönlund et al., 2010; Klingebiel & Rammer, 2014). As firms develop these inventions, some are ultimately unsuccessful, and some make it to market. As a result of this depletion of inventions in the pipeline, firms need to continually replenish their pipeline with new inventions. Firms can supplement their development pipeline with inventions that have been created through an internal invention process or can choose to bypass internal invention and source inventions externally via a variety of different modes such as licensing, acquisitions or alliances incorporating them directly into the internal development process (Arora, Fosuri, & Gambarella, 2001; Arora & Gambardella, 2010). In this study, I focus on the decision managers make as to where to source inventions to replenish their pipelines and how this may be influenced by their firms' organization designs.

Prior studies examining the decision by firms to source externally or make internally have tended to do so through two lenses. First, the focus of previous work has been at the individual transaction level neglecting the impact of firms' existing pipelines of inventions (e.g., Argyres & Liebeskind, 1999). Second, extant work has focused on a single locus of where these decisions are made in organizations (e.g., Weigelt & Miller, 2013; Williamson, 1985a, b). However, otherwise identical firms may make very different

choices for a specific transaction if one has a depleted stock of inventions under development with limited flow as compared to another firm with a well-stocked and distributed pipeline. Further, firms may manage their pipeline of inventions as a single entity that feeds different businesses or firms may have multiple pipelines dedicated to different parts of the business meaning decisions to make or buy are dispersed.

In developing my theoretical arguments, I build on prior work that highlights that the management of firms' pipelines of inventions is generally undertaken by Research and Development (R&D) (e.g., Mikkola, 2001). I focus on how firms' R&D designs can shape managers decisions with respect to how they replenish their invention pipelines. Firms can centralize R&D to obtain scale and scope benefits as well as undertake non-business unit specific R&D (e.g., Argyres & Silverman, 2004; Henderson & Cockburn, 1996). Alternatively, firms can decentralize R&D to enable the R&D units to focus on business-specific problems and be closer to end-markets and customers (e.g., Arora et al., 2014). Figure 6 illustrates these two differing designs.

Figure 6: Two models of pipeline management associated with different R&D structures



Key Sourcing Decision Maker	Head of R&D	R&D unit-heads (Larger transactions may go up to CEO)
Rationale for design (e.g., Henderson and Cockburn 1996; Argyres and Silverman 2004)	Knowledge scale and scope benefits Greater control over resource allocation Develop cross-business innovations	Closer to business and customers More responsive Develop business –focused innovations
Level of pipeline management	Overall firm pipeline	Unit level pipeline
Incentives (e.g., Argyres 1996; Zenger & Hesterly, 1997)	Head of R&D – Higher powered R&D sub-unit heads – lower powered	R&D unit heads – Higher powered
Focus (e.g., DeSanctis, Glass et al. 2002)	Build capabilities to facilitate the creation of inventions internally Exploration focus	Deliver products to business tied to their specific needs Exploitation focus

In developing a set of hypotheses I draw on both knowledge- and incentives-based theories. Recently scholars have illustrated how these two broad theoretical areas can be integrated to provide rich insights into important organizational phenomena (e.g., Argyres et al., 2012). I argue that organization design can shape managerial incentives and intra-organizational knowledge flows which in turn can shape how resources are allocated across internal and external invention activities. This ultimately shapes the proportion of inventions sourced externally for subsequent internal development by the focal firm.

R&D decentralization and the sourcing of external inventions

For the purposes of the theoretical development in this paper, a key difference between the two R&D designs is the level at which the pipeline of inventions is managed (Figure 6). In the centralized case, the Head of R&D typically manages the complete firm-pipeline and guides R&D sub-unit leads to develop a variety of inventions. Due to this reduced control of R&D activities sub-unit heads in the centralized R&D model, these managers are more likely to have lower powered incentives (Argyres & Silverman, 2004; Bardolet et al., 2010). In contrast, in the decentralized R&D design, the R&D unit heads typically manage their own pipelines for their respective units, and due to the stronger linkage between effort, outcomes and consequences will tend to face higher-powered incentives (Zenger & Hesterly, 1997). As highlighted by Adner and Levinthal (2004), the R&D unit heads in the decentralized design are likely to be unaware of the broader set of invention options available to the firm in contrast to the Head of R&D in the centralized design. They will also face greater career consequences from the failures associated with their specific units' pipelines. In contrast, in the centralized R&D model, the Head of R&D benefits from the risk pooling associated with managing the entire firm's pipeline of inventions (e.g., Hill & Hansen, 1991). In managing their pipelines, managers evaluate their firms' capabilities in being able to create new inventions. They also track the stock of inventions in their pipelines and the distribution of inventions within the pipeline or flow of inventions through the pipeline i.e. how close or far to the market place they are (e.g., Klingebiel & Rammer, 2014; Nishimura & Okada, 2014).

In the decentralized R&D model, managers face greater pressure to ensure a steady flow of inventions to the market (e.g., Arora et al., 2014; DeSanctis et al., 2002). This is because such R&D units are designed to support their respective business units and are thus beholden to their respective business units for resources such as financial funding (e.g., Argyres, 1996; Argyres & Silverman, 2004). Commercial managers in these decentralized business units are reliant on the steady flow of inventions to market to ensure they receive sufficient resources to make their business units viable entities. These commercial managers will strongly influence R&D managers to ensure a steady flow of inventions to market rather than helping the R&D unit develop capabilities for internal creation of inventions (e.g., DeSanctis et al., 2002). This highlights the intricate inter-play between firms' capabilities and managerial incentives (e.g., Argyres & Zenger, 2012). Finally, in firms with decentralized R&D, highly incentivized unit heads are less likely to share inventions as they are effectively competing against each other or do not want to expend resources sharing inventions with other units (e.g., Karim & Kaul, 2015). Thus managers in decentralized R&D units are less likely to have access to their firms' full suite of inventions as unit heads will seek to secure more organizational resources for their own units by limiting access to their own units' inventions. Similarly, unit managers may be less inclined to utilize other unit's inventions for fear of being seen as reliant on these other units potentially limiting access to future resources or the longer term viability of the relevant business unit. This is akin to not invented here syndrome (Katz & Allen, 1982).

In contrast, within the centralized R&D model, R&D Heads manage their firms' entire invention development pipelines. R&D Heads will tend to face less pressure from business units with respect to their innovation activities due to, for example, direct corporate funding or no direct reporting line of R&D to commercial functions (DeSanctis et al., 2002). As a result, heads of centralized R&D units are more able to focus on building cross-organizational inventions and technologies as well as internal capabilities associated with the creation of new inventions in the longer term (e.g., Argyres & Silverman, 2004; DeSanctis et al., 2002). Further, heads of centralized R&D units have greater discretion to reallocate resources across the complete organizational pipeline of inventions under development which helps to facilitate a steady flow of inventions to market. For example,

a firm with centralized R&D with four inventions in two areas A and B, two of which progress in area A and two fail in area B, may replenish the portfolio internally with two internal inventions, one from area A and one from area B. The Head of R&D may then reallocate resources from area B to A. In contrast, if the firm has two decentralized R&D units that focus on areas A and B and faces the same scenario, unit A has three inventions moving forward, whereas B only has one. Unit B faces a greater risk of eventually having no inventions in its pipeline (thereby losing future resources) and thus is more likely to source externally to bolster its thin pipeline. This steadier flow of inventions through the development process in centralized R&D units is also facilitated by the sharing of inventions across R&D sub-units. Managers of R&D sub-units within firms that have centralized R&D units will thus have greater access to their firms' stock of inventions than managers within decentralized R&D units.

These arguments indicate that managers within decentralized R&D units are more likely to replenish their pipelines of inventions with external inventions. This is because they are less incentivized to build internal capabilities associated with the creation of new inventions and are more focused on pushing inventions through development. External inventions provide a route to build both the stock and flow of inventions of decentralized R&D units' pipelines. Further, managers in decentralized R&D units have reduced access to their firms' broader internal invention stock for subsequent development also leading to them accessing relatively more external inventions. Effectively, creating inventions internally can take too long for heavily pressurized managers of decentralized R&D units and in order to meet on-going commercial needs, these managers look to source a greater proportion of inventions externally. Thus, at an overall firm level:

> *H1: Firms with decentralized R&D will source a higher proportion of inventions externally than firms with centralized R&D.*

R&D decentralization and the mode of sourcing of inventions

Firms can access inventions from external markets through a variety of modes such as alliances, acquisitions, and licensing (Arora & Gambardella, 2010; Van de Vrande, Lemmens, & Vanhaverbeke, 2006). These modes of sourcing external technologies are

associated with different degrees of investment and risk and can be used to help build capabilities or simply be used to introduce an invention that a firm subsequently develops and commercializes (e.g., Vanhaverbeke, Duysters, & Noorderhaven, 2002).

As outlined above, the primary focus of managers within decentralized R&D units is upon invention development rather than capability building. In contrast, heads of centralized R&D units will tend to have a greater focus on capability development (e.g., Argyres, 1996; Argyres & Silverman, 2004). In addition, managers of decentralized R&D units will tend to have access to fewer resources than heads of centralized R&D units. This is because of a pooling of resources across the centralized R&D unit enables the Head of the R&D unit to focus these resources on the areas of most need of attention. Whereas in the decentralized R&D units, resources are dispersed across the organization with units actively competing for resources, potentially resulting in good invention projects potentially not securing sufficient resourcing.

Licensing new inventions involves low commitment and is generally reversible (Vanhaverbeke et al., 2002). Licensing is also more transactional with limited knowledge sharing between the licensee and licensor and is thus primarily focused on providing firms with inventions to subsequently develop as opposed to building capabilities (Steensma & Corley, 2000). Licensing requires limited resources for their active management as inventions sourced in this manner can simply be slipped into firms' pipelines (e.g., Deloitte, 2017). Licensing could be seen as a low touch alliance, however for the purposes of this paper we define alliances as highly integrated arrangements in which firms work together to develop an invention. The structure of licensing agreements can also be highly flexible with multiple options available such as up-front payments, milestone payments as the invention meets specific development milestones and royalty payments based on a percentage of sales revenues or profits (e.g., Arora & Fosfuri, 2003; Arora et al., 2001; Arora & Gambardella, 2010; Van de Vrande et al., 2006).

In contrast, acquisitions and alliances with their associated richer knowledge-flows enable firms to build their capabilities (e.g., Sears & Hoetker, 2014; Steensma & Corley, 2000). Acquisitions are associated with large up-front lump-sum cash or equity payments

which may be beyond the resources of an individual R&D unit and require cross-organizational buy-in to ensure that a specific deal can go through. Alliances tend to be more resource-intensive in terms of administrative overhead as two separate organizations have to be coordinated and information needs to flow freely between both organizations which may require significant incremental effort (Steensma & Corley, 2000). Such resources may be beyond an individual business unit and managers of such units may need cross-organizational support to access the larger levels of resources required to undertake acquisitions or alliances.

Thus, licensing provides a low resource, low risk means through which managers in decentralized R&D units can access new inventions. Such licensed inventions can be readily utilized to improve both the stock of inventions to which a manager in a decentralized unit has access but also enables such managers to "plug gaps" in their invention development portfolios. Due to these specific advantages, unit heads of decentralized R&D units are more likely to choose licensing over acquisitions or alliances for sourcing inventions externally. Further, centralized R&D units focused on knowledge- and capability building will find acquisitions and alliances relatively more attractive than licensing. Compared to managers in decentralized R&D units, access to inventions through alliances and acquisitions may also be greater for centralized R&D heads. This is because with a focus on a firm's entire development portfolio such centralized R&D heads can pool all their R&D resources and use these to access inventions through these more costly modes. In contrast, with resources dispersed across R&D units in a decentralized model, there is more of a challenge for managers in decentralized units to access sufficient resources to enable inventions to be sourced vial alliances or acquisitions.

Thus, I hypothesize that the gap in the proportion of inventions sourced externally between firms with centralized and decentralized R&D is driven by licensing:

> *H2: The difference in the proportion of inventions sourced externally between firms with decentralized R&D and centralized R&D will be greater for licensing as compared to acquisitions or alliances.*

Methods

Research context

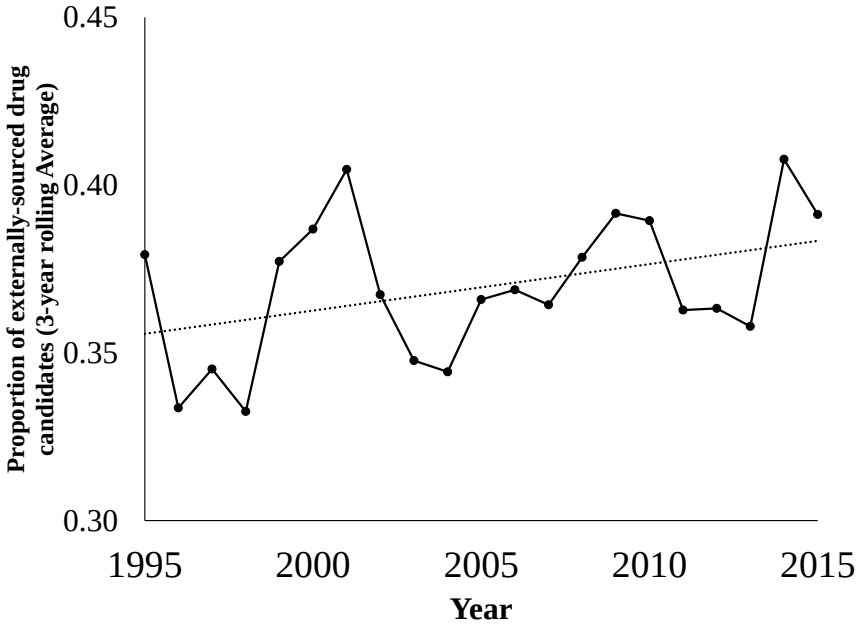
The context for this study is the pharmaceutical industry over the 20-year period 1995 to 2015. This industry has a well-established product development process consisting of a sequence of *in-vitro* discovery activities and *in-vitro* as well as *in-vivo* development tasks that consist of multiple phases of clinical trials (e.g., Kapoor & Klueter, 2015; Petrova, 2014). During the development process drug-candidates are both tested for safety and efficacy and further developed through, for example, evaluation of their mechanisms of action and optimization of their delivery to target areas of patients' bodies. In this study an invention is defined as a drug-candidate within a firm's development pipeline ranging from pre-clinical to Phase 3 clinical trials (Petrova, 2014). Drug-candidates are largely patented (e.g., Dushnitsky & Shaver, 2009; Gunther McGrath & Nerkar, 2004) and represent a potential new offering that firms can launch into the relevant market.

This context provides a rich domain for testing the hypotheses described above for three key reasons. First, there is an increasing dependence of pharmaceutical firms on external inventions created by a variety of organizations such as small entrepreneurial biotech companies and universities (e.g., Kapoor & Klueter, 2015; Pisano, 1991; Schweizer, 2005). In the sample used in this study, the rolling three-year average of the proportion of externally sourced drug-candidates increased from approximately 33 % in 1996 to 40 % in 2015 (Figure 7).

Second, external inventions can be sourced via multiple modes such as licensing, acquisitions, and alliances (Arora et al., 2001) enabling further analyses into which mode firms tend to select when sourcing inventions externally. Similarly inventions can be sourced at different stages of development. This is an important consideration, as generally internally developed drug-candidates have to go through the full gamut of discovery and development stages unless it is a drug-candidate developed previously being used in a new indication (i.e. to treat a different disease) whereas externally sourced drug-candidates can be acquired at later stages of development. However, as the risk associated with these later

stage drug-candidates not making it to market is significantly lower such drug-candidates are significantly more costly to obtain.

Figure 7: Proportion of externally sourced drug candidates used to replenish firms' pipelines (average across all firms in a focal year) over the period 1995-2015



Finally, the conversion of drug-candidates into final marketed products forms the lifeblood of large global pharmaceutical companies ensuring that senior managers pay close attention to their drug development pipelines. With only a limited period of exclusivity afforded by patent protection, these firms are continuously looking to develop new drugs as well as examine new opportunities for drugs whose patents have expired such as new forms of drug delivery or new indications. This focus on new product development is illustrated by the large proportion of revenues that are dedicated to funding research and development compared to other industries, with healthcare R&D spending set to outstrip all other industries' R&D spending in 2018 (Strategy &, 2016).

Interviews (for further details refer to Data and Sample section) with R&D managers support the key assumption made within my theoretical argumentation that firms

with centralized R&D manage a single portfolio and firms with decentralized R&D split their portfolios across the various R&D units. For example:

> *"Our three R&D units have separate business development activities and focus on optimizing their own pipelines though corporate business development can provide support to each of these units"* [19]

> *"We tended to see each asset team* [R&D unit] *as a silo with limited communication across silos"*

Further, interviews with senior R&D and business development managers indicate that firms do not look at transactions associated with individual inventions in isolation but as part of their broader pipeline of inventions under development. For example:

> *"The decision to source externally is moderately to strongly driven by gaps in the pipeline considered in the context of expected attrition rates and desired future product launches in the therapeutic areas of focus"*

Data and sample

In this study I use a mixed methods approach to test the hypotheses and understand their underlying mechanisms (Creswell & Clark, 2011). The sample consists of 49 leading pharmaceutical firms over the period 1995 to 2015. The sample is developed using 2004-6 annual prescription drug sales as defined by the Pharmaceutical Executive magazine's Top 50 Pharmaceutical companies (e.g., Klueter et al., 2017). Over this period, 64 firms appear in the Top 50 list. The 15 excluded firms are either private firms or do not provide sufficient information on key variables in their public filings. These excluded firms are in the lower half (26-50 ranking in terms of pharmaceutical sales) in one or more of the three years in the 2004-6 period. Using the mid-point of the sample enables the examination of firms that have at least 10 years of history within the sample time-frame prior to any significant M&A event. 33 out of the 49 sample firms are still in the top 50 pharmaceutical firms in 2015, 13 firms had been acquired by other firms in the sample and 3 firms had

[19] Due to confidentiality agreements with firms interviewed we are unable to reveal the specific sources of these quotations.

divested their pharmaceutical businesses. Upon acquisition or divestment of their pharmaceutical business these 16 firms dropped out of the sample.

The dataset consists of 12,016 drug-candidates entering the sample firms' pipelines over the period 1996-2015. 1995 data is used to create one-year lagged values for some of the variables. The primary data is sourced from the Pharmaprojects clinical trial database (e.g., Chandy et al., 2006; Kapoor & Klueter, 2015). This database provides an overview of the drug development pipelines of large pharmaceutical and smaller biotechnology firms highlighting variables such as the stage of clinical development per calendar year, the therapeutic class of the drug-candidate, whether the firm developing the drug is an originator or licensee and more technical aspects such as the mode of action of the focal drug.

This data is supplemented with patent data from the European Patent Office Patstat database (e.g., Conti et al., 2013), company annual reports/financial filings and financial data from Compustat. The unit of analysis is the firm-year, with the proportion of drug candidates in various categories entering firms' invention development pipelines being the dependent variables in this study (see below for further details).

To enrich the quantitative analysis, 61 interviews were conducted with managers within 28 firms from the sample and with multiple industry experts. The managers interviewed were senior level R&D or strategy managers who had a good understanding of the internal creation and external sourcing of drug-candidates through multiple modes (e.g. M&A, acquisition of single drug-candidate and alliances). The focus of the interviews was around understanding the factors that shape the decision to source drug-candidates externally or create them internally, identifying which parts of the organization are responsible for making such decisions and validating the organization design measures,. The interviews were conducted via teleconference and each interview typically lasted between 30 and 90 minutes with outline questions distributed to the respondents in advance to enable suitable preparation. In some cases, follow-up clarification questions were conducted post-interview through email. See Appendix 3 for more details.

Measures

Dependent Variable: To test Hypothesis 1, the key dependent variable pertains to the proportion of inventions entering a firm's development pipeline sourced externally in a focal year (*external)*. Defining whether a drug-candidate is internally created or externally sourced using the Pharmaprojects database requires a careful assessment of individual deals between firms in which an individual drug candidate may be sold to another firm, a firm may acquire or merge with another firm or drug-candidates may be developed through alliances with other firms or through licensing agreements.

A structured process is followed to determine this key variable. First, the originators and licensees of each drug-candidate provided by the Pharmaprojects database are examined to provide an initial indication of whether a drug is internally developed or licensed from another firm. Second, to ensure that a drug candidate is allocated to the appropriate firm, other drug candidate transactions not captured by Pharmaprojects are examined using the Recap database to ensure that the allocated originators for a specific drug-candidate did originally create the invention. The Recap database provides a comprehensive database of key transactions between firms at both the overall organizational level (i.e. mergers and acquisitions) and at the individual drug level. Further details on the origin of the drug candidate are available from the "Overview" section of the Pharmaprojects database. This information can be used to help further validate whether a drug-candidate was created by the allocated originator or sourced via an acquisition or alliance. If no evidence was obtained from either Recap or the "Overview" section that a drug-candidate was sourced externally then it was designated as internally created. Further, if the drug-candidate was externally sourced, drug-candidates were then allocated to one of three sub-categories (acquisition, alliance, licensed) based on the information from the Recap database and the "Overview" section of the Pharmaprojects database. See Appendix 2 for more details.

To test Hypothesis 2, three related dependent variables are developed; the proportion of drug-candidates sourced via licensing (*license)*, via acquisition (*acquisition*) and alliances (*alliance*). These variables are estimated by dividing the number of drug-candidates entering a firm's pipeline in a focal year via a particular external mode by the

total number of drug-candidates entering a firm's pipeline in that year. Acquisition refers to whether a drug-candidate enters a firm's pipeline via acquisition of a complete firm or a single drug-candidate.

In a supplemental analysis three related dependent variables are developed that measure the proportion of externally-sourced drug candidates that fall into different novelty categories. Two approaches are used to estimate the degree of novelty of the drug-candidates. First, I develop a variable which takes on the value of 0, 1 or 2, with the higher the number the higher the degree of novelty of the drug candidate (Klueter, 2013). If the mechanism of action and origin of material in the broad therapeutic domain are new to the firm the value is set at 2, if one of these is new it is set as 1, and if neither are new it is set to 0. The proportion of externally sourced drug candidates with novelty values 0 (*low novelty*), 1 (*medium novelty*) and 2 (*high novelty*) are estimated for each firm-year. In the second approach, I measure the proportion of drug-candidates that are sourced externally that are new chemical entities (*nce*) and the proportion of externally sourced drug-candidates that are not new chemical entities (*non-nce*). New chemical entities (NCE) include no component that has been previously approved by the FDA. NCE designation from the US Food and Drug Administration (FDA) provides firms with five years of marketing exclusivity.

Independent Variables: To test the two hypotheses, a single independent variable is developed, *R&D Decentralization* (more details are provided in Appendix 2). This measure estimates the degree of decentralization of R&D across various domains (e.g. therapeutic or scientific areas) and is determined by examining whether firms' R&D or Research (in the case of functionally separate R&D) is organized into a single or multiple units. This is determined through a careful evaluation of company's annual reports, 10-Ks, 20-Fs and DEF 14As. These data sources are used to develop a database of 15,129 executive and extended executive team roles for the sample of 49 firms over the period 1995-2015. This results in a total of 898 firm-years of data and an average of 16.8 executive and extended executive roles per firm-year (standard deviation = 11.1). For diversified

firms which operate beyond pharmaceuticals, R&D units that pertain to pharmaceuticals were focused upon and R&D units dedicated to areas such as consumer products were excluded. This method of developing structural measures is consistent with recent empirical approaches using Top Management Team (TMT) data to examine how firms' design choices influence a variety of organizational outcomes (e.g., Albert, 2018; Girod & Whittington, 2015; Guadalupe et al., 2014).

The variable *R&D Decentralization* is defined as a binary variable set to 1 if there are multiple R&D or research groups reporting to separate heads within the TMT covering different domains or to leads of business units within the pharmaceutical domain and 0 if the firm has a single centralized R&D or research group reporting to a single TMT lead. I recognize that firms can have hybrid R&D structures which are partially centralized or decentralized (Argyres & Silverman, 2004). However, this measure is intended to dichotomize whether firms' R&D units are more or less decentralized. I recognize that this measure does potentially suffer from some limitations but interviews with R&D managers in a sub-sample of firms indicated that the measure I use is indicative of firms' R&D structures.

Control Variables: The control variables and justification for their use are summarized in Table 10. Five sets of control variables are used in the regression analyses. First, additional structural design controls are used at the firm-year level such as the degree of corporate decentralization of the firm. Second, a variety of firm-specific controls such as R&D intensity and the stock of patents are utilized. Third, the degree of market competition firms' face in their respective therapeutic areas of focus is also controlled for. Fourth, controls pertaining to the degree of diversification of the firm across therapeutic classes in its invention pipeline as well as its overall business are estimated. Finally, a series of controls are used relating to the properties of firms' drug-candidate pipelines under development. A variety of fixed effects are used to control for other sources of unobserved heterogeneity. These fixed effects controls include year, therapeutic category and business category.

Table 10: Summary of control variables used in this study

Variable	Description	Rationale
1. Organizational Design controls (non-lagged, use one-year lagged as robustness test)		
R&D functional Differentiation	This variable represents whether firms' research and development units are integrated across both functions -research and development or are separated into individual research and development units. This is developed using companies' TMT compositions and set to 0 if R&D is functionally integrated under a single Head or 1 if it is functionally disintegrated into separate research and development units with separate heads in the top management team.	Firms with separate research and development units may have different preferences for sourcing drug-candidates externally. For example, separate research units may have a greater preference for creating inventions internally thereby leveraging their key resources and capabilities. In contrast in a functionally integrated R&D unit, there may be more pressure from development to source inventions externally.
Corporate Decentralization	This variable represents whether a firm is more functionally aligned or more divisionally aligned. This variable is estimated using the composition of firms' TMTs (excluding CEO) and dividing the number of business unit leads by the total size of the top management team. The greater the value of this variable, the more decentralized a firm (Albert, 2018).	More decentralized firms with multiple business units with well-defined innovation targets may place more pressure on R&D to build the stock and flow of their pipelines driving up the likelihood of replenishing the pipeline with externally sourced inventions.
Business Development Role	A dummy set to 1 if the focal firm has a business development manager role within the top management team in the relevant year.	Firms with dedicated business development units may have access to more external sourcing opportunities.
2. Firm-level controls (lagged one year)		
Performance	The annual return on assets of the firm (Richard et al., 2009)	Higher performing firms may potentially develop a higher volume of innovations
R&D Intensity	The annual spend on R&D by a firm as a proportion of annual revenues	Firms that spend a higher proportion of their sales on R&D may potentially see higher inventive and innovative output internally (e.g., Mairesse & Mohnen, 2005).
SG&A	Natural log of a firm's selling, general and administrative (SG&A) expenses	Potentially those firms with higher values of SG&A are more innovation focused and need to spend more on sales expenses to educate customers about the benefits of their new products.
Size	Natural log of the annual sales of each firm in the study sample	Larger firms may potentially generate more innovation outputs as they have access to more resources such as a broader knowledge base. They are also likely to be more differentiated.
Slack	Current Ratio	Prior studies have indicated greater slack may help to drive the development of new technologies (Greve, 2003).
New CEO	A dummy variable set to 1 if a new CEO was appointed in a specific firm-year	May be the catalyst for a reorganization or uptick in performance through, for example, accelerated sourcing of external drug candidates.
Total Patent Stock	Discounted total quantity of patent families granted by focal firm (Arora et al., 2014). A 15 % discount rate is used. Similar "stock" measures of a firm's experience in a specific knowledge domain have been used in prior studies (e.g., Henderson & Cockburn, 1994; Hoang & Rothaermel, 2010).	Controls for firms' existing knowledge collected over a period of time which will impact whether firms decide to make or buy a specific invention. Also helps to control for firms' internal inventive capability.
Patent family count	Number of patent families filed by firm in a specific focal year (e.g., Arora et al., 2014)	Firms filing more patents may be less likely to source inventions externally as

Variable	Description	Rationale
		they may have a more readily available source of internal inventions.
3. Competition controls (lagged one year)		
Competition	Measure of competition firms face across their development portfolios. Sum of squared market shares (by drug-candidate count) of drug-candidates within all development phases per therapeutic class weighted by contribution to portfolio (i.e. proportion of firms' portfolio a therapeutic class represents across all phases) subtracted from 1. Higher value signifies firms operate in more competitive therapeutic classes	Controls for the degree of competition firms face across their portfolio of drug-candidates. Firms in more competitive markets may be incentivized to innovate and organize differently, also competition for external drug candidates could be greater limiting supply of available candidates.
4. Diversification Controls (lagged one year)		
SBU	Reflects the total number of business units within a firm – namely the number of operating segments that report separate financials statements in their annual reporting documents	Controls for general firm diversification. More diversified firms may limit R&D in pharmaceuticals and rely more on external sourcing of inventions. International Financial Reporting Standard (IFRS) 8[20] requires that firms disclose information about their operating segments, these represent distinct profit centers within a firm and are used by senior management to make strategic decisions.
Technical Diversification	Measure of technological diversity of firms' R&D efforts. This is estimated using the sum of the squared proportions of drug candidates in each therapeutic class in a firm's portfolio within a focal year and subtracted from 1. The larger the value the more diversified a firm's portfolio is across therapeutic classes in a specific year.	Controls for the level of technological diversity of a firm's R&D activities. Firms undertaking a broader array of technological activities are more likely to differentiate their R&D efforts (either by technical domain or function) as well as fragment into more business units, potentially increasing the likelihood of externally sourcing drug candidates. Also firms will have a broader range of technical knowledge from which to draw.
Category Dummy Fixed Effects	Series of dummy variables representing whether a firm has operating segments in categories beyond pharmaceuticals. Specifically: consumer goods, medical devices, animal medication, bulk chemicals, nutrition. Also have dummy if firm has a generics business. These can vary by firm-year as firm acquires or divests specific businesses.	Control for diversification of firms' businesses beyond pharmaceuticals
5. Portfolio level controls (lagged one year)		
Clinical Experience	Total stock of clinical trials across all phases estimated using the methodology described by Macher and Boerner (2012). However, the total stock of clinical trials (not just successful trials) across pre-clinical to phase 3 is used with a 15 % discount rate.	Greater clinical trial experience in a therapeutic class may be another form of absorptive capacity (Cohen & Levinthal, 1990) that may influence the make versus buy decision.
Internal Overall Portfolio	Total number of internally-sourced drug-candidates across all therapeutic classes.	Controls for the size of the existing portfolio and whether firms have a proclivity to source externally
External Overall Portfolio	Total number of externally-sourced drug-candidates across all therapeutic classes.	
Bio	Proportion of firms' portfolio that are biotechnology candidates.	Firms focusing on biotechnology may source more externally due to access to many biotechnology start-ups.

[20] https://www.iasplus.com/en/standards/ifrs/ifrs8

Variable	Description	Rationale
Therapeutic Category Fixed effects	Series of dummies for each therapeutic category indicating whether a firm is actively developing drugs in this therapeutic category.	
6. Other Controls		
Year fixed effects	Series of dummies for each year in sample	

Analysis approach.

As the dependent variables are proportions and bounded between 0 and 1, I use the fractional logit analytical approach to test all three hypotheses (Papke & Wooldridge, 1996; Papke & Wooldridge, 2008). I also use linear probability models for some robustness tests. To control for unobserved heterogeneity a variety of fixed effects are used such as business category and in some robustness tests, firm-fixed effects. Due to the fact that many firms do not change their R&D organizational structures significantly over time (31 out of 49 firms in the sample maintained the same structure), firm fixed effects significantly reduce the statistical power associated with testing Hypotheses 1 to 3.

To further control for omitted variable bias, I also test our hypotheses using propensity score matching models – PSM (e.g., Caliendo & Kopeinig, 2008). Such an approach uses matched samples of observations for decentralized and centralized R&D based on the control variables outlined in Table 10. This helps to reduce the possibility that the results are driven by the inherent differences between firms with decentralized and less decentralized R&D as regular regressions are estimated only on observably equivalent groups. In addition, I also undertake Coarsened Exact matching (CEM) as a further robustness test of the hypotheses (Iacus et al., 2011).[21] Again I match firm-years using all covariates in Table 10 as for the propensity score matching analysis. These variables are coarsened into 2-5 strata. Observations for firms with centralized and decentralized R&D are then matched using the coarsened values of these covariates. Observations are dropped from the sample if there are no corresponding observations associated with the other R&D design in a strata associated with any covariate in the initial matching step. I then conduct

[21] We use the cem STATA Routine (http://gking.harvard.edu/cem) to perform this analysis.

the regression analyses on these matched observations. Standard errors are clustered at the firm-level (Petersen, 2009). Appendix 5 provides further details on the matching process.

To test Hypothesis 2, separate regressions are run for the three dependent variables associated with this hypothesis (i.e. H2: *license, acquisition* and *alliance).* Wald tests are then conducted to test whether the coefficients for each of the three models for the variable *R&D Decentralization* associated with Hypothesis 2 are equal.

Results

Descriptive statistics

Table 11 illustrates the descriptive statistics for the sample of firm-years in this study. 37 % of drug-candidate inventions entering a firm's portfolio are externally sourced over this period. This level of external sourcing of drug candidates is consistent with other studies of the pharmaceutical industry (e.g., Hoang & Rothaermel, 2010; Pfrang, Dealhoy, Heller, & Shah, 2017). Figure 7 illustrates that there has been a moderate increase in the proportion of externally sourced inventions over this time period. Consistent with Hypothesis 1, the proportion of drug-candidates sourced externally is 35.6% for R&D organized in a centralized manner and 41.3% for when it is organized in a decentralized manner. From Table 11, it can also be seen that licensing is the main mode through which external drug candidates are sourced, followed by alliances and acquisitions. Consistent with Hypothesis 2, I observe a strong correlation between the proportion of drug-candidates sourced by licensing and R&D decentralization. I also observe that as the novelty of drug-candidates increases the proportion of drug-candidates sourced externally increases.

12.6 % of firm-year observations have decentralized R&D units, with 29.1 % of these observations having a business development role within the top management team. The prevalence of Business development roles within the top management team has increased substantially from 12 % of firms in 1995 to 41 % of firms in 2015. It appears that as sourcing of external drug-candidates becomes increasingly important for firms, firms have decided to build their associated capabilities associated with sourcing external

inventions through creating dedicated business development units (e.g., Kale, Dyer, & Singh, 2002). Appendix 4 provides further details on the descriptive statistics results.

Main analysis

Table 12 illustrates the main analyses used to test Hypothesis 1. We observe that firms with a higher number of internal inventions within their pipelines, facing more competitive markets in their respective therapeutic areas and with more novel portfolios are less likely to source inventions externally. It seems that firms which have historically developed more internal inventions will continue to do so. Further, potentially firms operating in more competitive markets have less access to external inventions as there are simply more buyers for these technologies and as a result firms may have to rely more on creating inventions internally. Models 2 and 3 provide some tentative evidence to support Hypothesis 1 with the coefficient for *R&D Decentralization* being marginally significant ($0.05<p<0.1$) in the fractional logit model (Model 2) and marginally insignificant ($0.1<p<0.11$) in the linear probability model (Model 3). Using both PSM (both caliper and nearest neighbor) and CEM, we see stronger support for Hypothesis 1 in that firms with decentralized R&D units tend to be associated with sourcing a greater proportion of external inventions. Using the matched samples, we find that the proportion of externally sourced inventions for firms with decentralized R&D is 43 % as compared to 38 % for firms with centralized R&D, a difference of five percentage points, consistent with the descriptive statistics outlined above.

Table 13 illustrates the analyses undertaken to test Hypothesis 2. It appears that firms with a larger internal pipeline of inventions source a lower proportion of inventions through alliances and acquisitions, but not through licensing. Similarly, firms with more novel pipelines appear to be associated with sourcing fewer inventions through acquisitions and licensing but not alliances. This is not unsurprising as firms are more likely to form alliances to create more novel inventions due to the rich knowledge transfer between organizations (e.g., Vanhaverbeke et al., 2002; Zhang et al., 2007).

Table 11: Descriptive statistics (unit of analysis drug candidate-year). N=808 firm-years

Variable	MEAN	SD	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
1.External	0.370	0.224	1.00																										
2.License	0.160	0.159	0.51	1.00																									
3.Alliance	0.120	0.144	0.42	-0.19	1.00																								
4.Acquisition	0.091	0.155	0.53	-0.11	-0.13	1.00																							
5.Low Novelty	0.390	0.317	0.61	0.27	0.24	0.32	1.00																						
6.Medium Novelty	0.474	0.296	0.72	0.30	0.28	0.39	0.26	1.00																					
7.High Novelty	0.591	0.419	0.47	0.23	0.20	0.22	0.15	0.24	1.00																				
8.R&D Decentralization	0.126	0.332	0.07	0.12	-0.07	0.04	0.12	0.07	-0.04	1.00																			
9.R&D functional differentiation	0.225	0.418	-0.04	-0.05	0.10	-0.10	-0.03	-0.01	-0.01	-0.12	1.00																		
10.Corporate Decentralization	0.260	0.244	0.04	0.17	-0.06	-0.05	-0.01	-0.04	0.03	0.04	-0.16	1.00																	
11.Business Development Role	0.291	0.454	0.05	0.05	0.02	0.00	0.01	-0.06	-0.02	0.09	-0.02	0.06	1.00																
12.Performance	0.079	0.088	-0.00	0.03	0.01	-0.04	-0.03	-0.04	-0.03	-0.04	-0.03	0.02	-0.05	1.00															
13.R&D Intensity	0.179	0.221	-0.02	-0.06	0.04	0.00	0.00	-0.02	-0.04	0.08	0.15	-0.19	0.11	-0.54	1.00														
14.SG&A	7.875	1.374	0.06	0.12	0.04	-0.07	-0.05	-0.19	-0.09	0.06	-0.01	0.13	0.09	0.25	-0.10	1.00													
15.Size	8.693	1.484	0.06	0.14	0.00	-0.06	-0.03	-0.16	-0.05	0.06	-0.05	0.17	0.03	0.37	-0.37	0.91	1.00												
16.Slack	2.491	1.684	-0.04	-0.08	-0.02	0.04	0.08	0.09	0.02	-0.02	0.17	-0.21	-0.03	-0.09	0.30	-0.40	-0.49	1.00											
17.New CEO	0.113	0.316	-0.03	-0.00	-0.01	-0.03	-0.06	-0.08	-0.01	-0.03	-0.02	0.01	-0.01	-0.04	-0.03	0.06	0.06	-0.04	1.00										
18.Total Patent Stock	1.487	1.897	0.05	0.13	-0.07	-0.01	-0.02	-0.15	-0.08	0.05	-0.02	0.09	0.07	0.13	-0.07	0.72	0.68	-0.24	0.03	1.00									
19.Patent Family Count	0.232	0.250	0.05	0.15	-0.01	-0.08	-0.04	-0.18	-0.06	0.09	0.02	0.17	0.01	0.20	-0.11	0.67	0.64	-0.27	0.02	0.74	1.00								
20.Competition	0.959	0.028	-0.13	-0.06	0.02	-0.15	0.00	0.11	0.05	-0.06	0.06	-0.16	-0.06	-0.18	0.05	-0.56	-0.51	0.23	-0.01	-0.61	-0.59	1.00							
21.SBU	2.479	1.282	-0.06	0.03	-0.08	-0.05	-0.06	-0.09	-0.02	-0.03	-0.10	0.29	-0.08	-0.14	-0.24	0.01	0.09	-0.14	-0.04	0.09	0.11	-0.00	1.00						
22.Technical Diversification	0.749	0.178	0.04	0.07	0.05	-0.07	-0.11	-0.25	-0.08	-0.00	0.00	0.26	0.17	0.07	-0.02	0.48	0.42	-0.23	0.02	0.33	0.43	-0.34	0.16	1.00					
23.Clinical Experience	0.333	0.330	0.06	0.12	-0.03	-0.00	-0.04	-0.18	-0.07	0.08	-0.05	0.16	0.13	0.19	-0.05	0.76	0.70	-0.29	0.04	0.87	0.72	-0.72	0.05	0.42	1.00				
24.Internal Overall Portfolio	35.627	37.665	-0.06	0.06	-0.05	-0.09	-0.15	-0.29	-0.14	0.05	-0.02	0.20	0.07	0.20	-0.05	0.65	0.59	-0.30	0.06	0.63	0.74	-0.74	0.05	0.47	0.81	1.00			
25.External Overall Portfolio	30.296	27.790	0.22	0.11	0.06	0.14	0.06	-0.05	-0.00	0.07	-0.06	0.16	0.06	0.21	-0.06	0.70	0.64	-0.28	0.05	0.70	0.69	-0.73	0.01	0.42	0.87	0.79	1.00		
26.Portfolio Novelty	1.024	0.245	-0.11	-0.15	0.07	-0.08	0.01	0.12	0.03	-0.07	-0.00	-0.15	-0.11	-0.16	0.08	-0.69	-0.67	0.34	-0.03	-0.60	-0.53	0.56	-0.01	-0.39	-0.67	-0.56	-0.61	1.00	
27.Bio	0.242	0.195	0.07	0.08	0.10	-0.07	-0.05	0.13	0.07	-0.10	0.14	-0.12	-0.01	0.02	0.02	0.05	0.04	-0.05	0.01	-0.01	-0.11	0.12	-0.12	-0.35	-0.01	-0.11	-0.01	-0.06	1.00

In Table 13 I observe that the difference in the proportion of inventions sourced by different modes between firms with centralized and decentralized R&D units is only significant for licensing and not for acquisitions and alliances. Comparing the coefficients for *R&D Decentralization* across models, I find that the coefficient is higher for licensing as compared to both alliances and acquisitions ($p < 0.001$) consistent with Hypothesis 2.

Using propensity score matching I observe that the proportion of drug-candidates sourced via licensing is five percentage points higher for firms with decentralized R&D as compared to firms with centralized R&D units. Thus licensing appears to be responsible for the full difference in the proportion of inventions sourced externally between firms with centralized and decentralized R&D units described in Hypothesis 1.

The interviews with pharmaceutical company executives provide some support to suggest that the decision to source inventions externally through licensing could be undertaken at an R&D unit level, whereas bigger deals such as acquisition require cross-organizational support and sign-off. For example:

> *"Deals to obtain external drug candidates can vary tremendously in size. Smaller decisions such as licensing deals can be made at the local R&D unit level, whereas major acquisitions go all the way up to the board"*

> *"The decision-making and process and governing body varies with the stage and size of the deal…For much smaller collaborations/deals approvals can be delegated to R&D Managers 2-3 levels below the CEO"*

Thus it appears that for licensing, especially for early development stage drug-candidates, the decision can be made at an individual unit level, thereby explaining the greater preponderance for licensing when R&D is decentralized but no differences in alliances and acquisitions. Therefore, licensing enables the focal firm to more immediately supplement its portfolio than alliances or acquisitions as partners have to be engaged/integrated and the way of operating agreed which can cause potential delays and complications in converting the drug-candidate into a final product. In contrast, drug-candidates sourced via licensing can more readily be incorporated into a firm's pipeline and potentially be able to be converted into final products in a more timely manner.

Table 12: Main analysis - tests of Hypothesis 1. Fractional Logit (FL) and OLS regressions. Sample drops from 808 to 769 due to lagging of independent variables by one-year

DV = External Type of Model	Model 1 FL	Model 2 FL	Model 3 OLS	Model 4 FL PSM	Model 5 CEM OLS
R&D Decentralization		**0.172**$^{+}$	**0.0387**	**0.227***	**0.0673****
		(0.0984)	**(0.0237)**	**(0.0951)**	**(0.0207)**
R&D Functional Differentiation		-0.105	-0.0213	-0.0259	-0.0590*
		(0.0646)	(0.0151)	(0.188)	(0.0234)
Corporate Decentralization		0.244	0.0623^{+}	-0.584^{+}	0.0992^{+}
		(0.154)	(0.0350)	(0.312)	(0.0535)
Business Development Role	0.0510	0.0214	0.00908	-0.0392	0.0243
	(0.0740)	(0.0747)	(0.0170)	(0.169)	(0.0200)
Performance	-0.358	-0.357	-0.0747	2.701**	0.235
	(0.639)	(0.634)	(0.143)	(0.712)	(0.219)
R&D Intensity	-0.0914	-0.106	-0.0225	0.640^{+}	0.120
	(0.242)	(0.235)	(0.0524)	(0.360)	(0.163)
SG&A	-0.0767	-0.0654	-0.0150	-0.196	-0.0659^{+}
	(0.0843)	(0.0853)	(0.0188)	(0.169)	(0.0371)
Size	0.130	0.119	0.0278	0.237	0.0557
	(0.0995)	(0.102)	(0.0226)	(0.204)	(0.0396)
Slack	0.0229	0.0296	0.00725	-0.125	0.00414
	(0.0350)	(0.0354)	(0.00793)	(0.0831)	(0.0124)
New CEO	-0.200*	-0.199*	-0.0421^{+}	0.423*	-0.0853*
	(0.0945)	(0.0969)	(0.0220)	(0.173)	(0.0409)
Total Patent Stock	-0.0329	-0.00128	-0.00197	-0.0300	0.0386^{+}
	(0.0489)	(0.0509)	(0.0114)	(0.0819)	(0.0215)
Patent Family Count	0.136	0.103	0.0200	-0.900*	-0.128
	(0.293)	(0.308)	(0.0706)	(0.404)	(0.104)
Competition	-4.911^{+}	-5.180^{+}	-1.130	-11.16^{+}	-0.664
	(2.751)	(2.813)	(0.681)	(6.300)	(0.944)
SBU	0.0107	-0.0466	-0.0499	74.36	-0.0420
	(0.0955)	(0.104)	(0.0345)	(63.50)	(0.0353)
Technical Differentiation	-0.188	-0.204	-0.0497	2.937**	0.0334
	(0.410)	(0.396)	(0.0824)	(0.851)	(0.161)
Clinical Experience	-0.363	-0.537	-0.119	-0.169	-0.134
	(0.369)	(0.393)	(0.0798)	(0.540)	(0.125)
Internal Overall Portfolio	-0.00895**	-0.00829**	-0.00187**	-0.00945**	-0.00207*
	(0.00205)	(0.00211)	(0.000478)	(0.00331)	(0.000776)
External Overall Portfolio	0.00817*	0.00850*	0.00189*	-0.00185	0.00254*
	(0.00340)	(0.00352)	(0.000808)	(0.00570)	(0.000983)
Portfolio Novelty	-1.081**	-1.002**	-0.227**	-1.238*	-0.120
	(0.383)	(0.367)	(0.0782)	(0.576)	(0.0913)
Bio	0.249	0.315	0.0664	0.0563	0.0813
	(0.301)	(0.288)	(0.0667)	(0.780)	(0.118)
Year Fixed Effects	Y	Y	Y	Y	Y
Business Category Fixed Effects	Y	Y	Y	Y	Y
Therapeutic Category Fixed Effects	Y	Y	Y	Y	Y
N	769	769	769	165	486
R^2	0.0305	0.0314	0.198	0.0777	0.330
Log Likelihood	-489.6	-489.1	163.8	-109.7	198.2

Standard errors in parentheses:$^{+}$ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$; Errors clustered at firm level
FL – Fractional Logit, PSM – Propensity Score Matching; CEM – Coarsened Exact Matching

Table 13: Main analysis - tests of Hypothesis 2. Sample drops from 808 to 769 due to lagging of variables by one-year. DVs proportion of drug candidates sourced via mode

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9
	Acquisition			Alliance			License		
Type of Model	**FL**	**FL PSM**	**OLS CEM**	**FL**	**FL PSM**	**OLS CEM**	**FL**	**FL PSM**	**OLS CEM**
R&D Decentralization	**-0.0781 (0.221)**	**-0.627 (0.393)**	**-0.00089 (0.0189)**	**-0.152 (0.136)**	**-0.216 (0.166)**	**-0.0259 (0.0155)**	**0.360** (0.125)**	**0.448** (0.158)**	**0.111** (0.0174)**
R&D Functional Differentiation	-0.255 (0.186)	-0.471 (0.594)	-0.0258 (0.0250)	0.132 (0.128)	0.979** (0.364)	0.00823 (0.0239)	-0.134 (0.129)	-0.567^{+} (0.299)	-0.0610* (0.0266)
Corporate Decentralization	-0.214 (0.353)	-0.546 (0.804)	-0.0217 (0.0394)	0.0452 (0.255)	-0.959* (0.453)	0.0553 (0.0415)	0.665** (0.220)	0.188 (0.661)	0.0807* (0.0306)
Business Development Role	-0.0314 (0.153)	-0.779 (0.492)	-0.00433 (0.0166)	-0.0687 (0.130)	-0.408^{+} (0.246)	-0.00165 (0.0167)	0.112 (0.113)	0.0826 (0.253)	0.0222 (0.0198)
Performance	-0.695 (1.202)	2.947 (2.127)	0.0929 (0.194)	0.263 (0.770)	-0.726 (1.458)	0.0515 (0.119)	-0.399 (0.676)	4.401** (1.535)	0.0855 (0.117)
R&D Intensity	0.0933 (0.362)	0.343 (1.216)	0.0947 (0.148)	0.467 (0.308)	-1.351 (1.136)	0.146 (0.109)	-0.713^{+} (0.383)	2.404* (1.095)	-0.156 (0.148)
SG&A	-0.148 (0.170)	0.639 (0.625)	-0.00358 (0.0288)	0.0964 (0.122)	0.0930 (0.306)	-0.00727 (0.0224)	-0.118 (0.164)	-0.666** (0.228)	-0.0406 (0.0303)
Size	0.0549 (0.208)	-0.950 (0.650)	-0.0331 (0.0328)	0.209^{+} (0.127)	-0.0483 (0.278)	0.0428^{+} (0.0239)	-0.00459 (0.161)	0.653* (0.263)	0.0223 (0.0307)
Slack	0.0681 (0.0460)	0.0392 (0.167)	0.0108 (0.0096)	-0.00379 (0.0569)	0.0627 (0.119)	0.00568 (0.0096)	0.00337 (0.0461)	-0.0628 (0.0864)	-0.00579 (0.0086)
New CEO	-0.466^{+} (0.266)	0.355 (0.529)	-0.120* (0.0516)	0.0316 (0.163)	0.410 (0.360)	-0.0823^{+} (0.0463)	-0.0805 (0.106)	0.0689 (0.270)	0.114** (0.0407)
Total Patent Stock	0.130 (0.0808)	-0.207 (0.235)	0.0164 (0.0108)	-0.108 (0.0884)	-0.286* (0.144)	-0.00322 (0.0079)	0.0209 (0.0609)	0.0991 (0.168)	0.0150 (0.0122)
Patent Family Count	-0.852 (0.527)	-0.0514 (1.113)	-0.0761 (0.0717)	-0.221 (0.356)	-0.580 (0.860)	-0.0295 (0.0448)	0.626 (0.407)	-0.573 (0.797)	-0.0147 (0.0732)
Competition	-13.77** (4.026)	-2.425 (11.10)	-0.0769 (1.277)	1.872 (3.081)	-20.34^{+} (10.59)	-0.346 (0.683)	8.247* (3.324)	-1.402 (7.920)	0.919 (0.965)
SBU	-1.692 (1.372)	489.9** (71.68)	-0.105** (0.0344)	0.165 (0.339)	-41.07 (62.40)	0.0518^{+} (0.0300)	-0.920** (0.278)	-310.1** (61.78)	0.0102 (0.0338)
Technical Differentiation	-0.806 (0.861)	-3.880 (2.392)	0.0259 (0.0920)	1.127 (0.871)	8.168** (2.389)	0.0383 (0.101)	-0.517 (0.666)	3.548 (2.286)	-0.00980 (0.116)
Clinical Experience	-0.780 (0.642)	1.357 (2.151)	-0.104 (0.110)	0.612 (0.678)	3.736** (1.180)	-0.0697 (0.0805)	-0.625^{+} (0.335)	-1.251 (0.937)	0.0345 (0.0982)
Internal Overall Portfolio	-0.0146** (0.0049)	-0.0229* (0.0111)	-0.0013^{+} (0.0008)	-0.0070** (0.0027)	-0.0217* (0.001)	-0.00043 (0.0006)	0.00284 (0.0025)	0.00318 (0.0057)	0.000938 (0.0007)
External Overall Portfolio	0.0159* (0.0079)	0.0348** (0.0132)	0.00300* (0.0011)	0.00468 (0.006)	-0.0259* (0.0129)	0.00115 (0.0007)	0.00369 (0.0034)	0.00362 (0.0099)	-0.00061 (0.0007)
Portfolio Novelty	-1.875** (0.571)	-0.533 (1.414)	-0.271** (0.0750)	0.278 (0.598)	1.024 (0.971)	0.106 (0.106)	-0.744^{+} (0.440)	-0.845 (0.906)	0.00894 (0.0669)
Bio	-0.214 (0.555)	-2.164 (1.620)	0.0919 (0.0936)	1.116* (0.516)	3.993** (1.165)	-0.0329 (0.0773)	-0.0492 (0.399)	-0.503 (1.322)	0.0361 (0.0686)
Year Fixed Effects	Y	Y	Y	Y	Y	Y	Y	Y	Y
Business Category Fixed Effects	Y	Y	Y	Y	Y	Y	Y	Y	Y
Therapeutic Cat. Fixed Effects	Y	Y	Y	Y	Y	Y	Y	Y	Y
N	769	158	454	769	158	454	769	158	454
R^2	0.0882	0.220	0.331	0.0739	0.155	0.430	0.0468	0.0962	0.406
Log Likelihood	-211.7	-42.11	322.4	-258.2	-51.57	402.2	-320.1	-73.88	365.3

Standard errors in parentheses: $^{+}$ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$; Errors clustered at firm level.
PSM – Propensity Score Matching, FL – Fractional Logit, CEM – Coarsened Exact Matching

Robustness tests

I undertake three separate robustness tests of our main results. Further details are provided in Appendix 6. First, I lag all three of the structural variables (*R&D Centralization*, *R&D Functional Differentiation* and *Organizational Decentralization*) one-year. This is undertaken because the decision to source internally or externally may take an extended period of time. Using the lagged variables I observe the same results as my main results for Hypothesis 1, with the coefficient for R&D Decentralization (lagged) being 0.18 ($p < 0.05$) as compared to 0.227 for the non-lagged analysis as illustrated in Table 40 (Appendix 6). I observe that R&D Decentralization is only statistically significant ($p < 0.05$) and positive for the proportion of drug candidates sourced externally via licensing but not for alliances or acquisitions consistent with Hypothesis 2.

Second, I undertake all the analyses using firm fixed effects fractional logit models. Firm fixed effects are limited in that I observe limited temporal variation in *R&D Decentralization* across firms (31 out of the 49 sample firms do not change *R&D Decentralization* over the study time-period). As illustrated in Table 14, I observe that the associated loss of statistical power with only 18 sample firms changing structure over the study time period results in the coefficient for *R&D Decentralization* becoming insignificant for Hypothesis 1. However, I observe similar outcomes for Hypothesis 2. Namely licensing is the only external mode associated with a higher proportion of externally sourced inventions for firms with decentralized R&D as opposed to centralized R&D. These observations continue to provide some support for the main theoretical arguments.

Third, I change the unit of analysis to the individual drug-candidate level being used to replenish a firm's development pipeline (Table 15). This results in 12,016 drug-candidates being incorporated into pipelines over the 1996 to 2015 period. This enables me to use individual drug-level controls (e.g. therapeutic area fixed effects) to control for additional sources of heterogeneity. I observe that firms with decentralized R&D units are associated with a 3.8% higher likelihood of sourcing drugs externally than those with single, integrated R&D units. This is consistent with the main observations.

Table 14: Robustness tests of main hypotheses using firm-fixed effects fractional logit models

	Model 1	Model 2	Model 3	Model 4
Dependent Variable	**External**	**Acquisition**	**Alliance**	**License**
R&D Decentralization	**0.0233**	**-0.595***	**-0.0528**	**0.387****
	(0.122)	**(0.254)**	**(0.160)**	**(0.103)**
R&D Functional Differentiation	0.0264	-0.184	0.139	0.0559
	(0.0947)	(0.237)	(0.164)	(0.120)
Corporate Decentralization	0.0840	-0.402	0.0786	0.285
	(0.152)	(0.453)	(0.288)	(0.201)
Business Development Role	-0.0823	-0.0838	-0.214+	-0.0388
	(0.0835)	(0.155)	(0.116)	(0.126)
Performance	-0.520	-0.0422	-0.252	-1.116
	(0.631)	(1.029)	(0.882)	(0.732)
R&D Intensity	-0.0806	0.274	0.304	-0.688*
	(0.259)	(0.317)	(0.322)	(0.351)
SG&A	-0.00618	-0.0848	-0.266	0.0547
	(0.116)	(0.219)	(0.177)	(0.109)
Size	0.135	0.174	0.355*	-0.147
	(0.142)	(0.205)	(0.174)	(0.136)
Slack	0.0696+	0.103+	0.0702	0.0224
	(0.0414)	(0.0531)	(0.0634)	(0.0414)
New CEO	-0.208*	-0.435+	0.0354	-0.157
	(0.0982)	(0.237)	(0.153)	(0.102)
Total Patent Stock	0.127	0.486*	0.00730	0.0135
	(0.0945)	(0.192)	(0.114)	(0.0613)
Patent Family Count	-0.441	-2.260**	-0.252	0.290
	(0.352)	(0.734)	(0.390)	(0.427)
Competition	-7.631*	-29.53**	2.073	10.75**
	(3.192)	(5.289)	(2.869)	(3.701)
SBU	0.270	-0.611	-0.550	0.326
	(0.194)	(1.487)	(0.343)	(0.224)
Technical Differentiation	0.373	2.233*	0.303	-0.436
	(0.590)	(1.109)	(1.220)	(0.821)
Clinical Experience	-1.172+	-4.147**	0.405	-0.225
	(0.645)	(1.233)	(0.859)	(0.554)
Internal Overall Portfolio	-0.00617*	-0.00869+	-0.00697*	0.00331
	(0.00240)	(0.00478)	(0.00331)	(0.00297)
External Overall Portfolio	0.000591	-0.00262	0.00230	0.00128
	(0.00293)	(0.00854)	(0.00460)	(0.00299)
Portfolio Novelty	-1.628*	-0.204	-0.700	-1.946**
	(0.649)	(1.002)	(0.824)	(0.676)
Bio	0.865	1.467	-0.470	0.895
	(0.603)	(1.430)	(0.808)	(0.742)
Year Fixed Effects	Y	Y	Y	Y
Business Category Fixed Effects	Y	Y	Y	Y
Therapeutic Category Fixed Eff.	Y	Y	Y	Y
Firm Fixed Effects	Y	Y	Y	Y
N	769	769	769	769
R^2	0.0540	0.150	0.112	0.0840
Log Likelihood	-477.7	-197.3	-247.7	-307.6

Standard errors in parentheses: + $p < 0.1$, * $p < 0.05$, ** $p < 0.01$; Errors clustered at firm level

I also undertake multinomial logit regressions at the drug-candidate level of analysis to examine differences across modes of externally sourcing inventions, namely whether inventions are sourced via alliances, licensing deals or acquisitions (Table 16). In this multinomial logit analysis, the baseline category is internal creation of inventions. Consistent with Hypothesis 2, I observe that division of R&D into multiple units is associated with an increased likelihood of licensing but not of sourcing external inventions through alliances. Interestingly, I observe that R&D decentralization is associated with an increased propensity to source externally via acquisitions though the effect is much weaker than for licensing. However, undertaking separate individual logit regressions comparing the likelihood of sourcing via alliances, acquisitions and licensing relative to internal creation of inventions also suggests that division of R&D into multiple units is associated with an increased likelihood of sourcing via licensing, but not acquisitions and alliances. This is again consistent with Hypothesis 2.

Table 15: Robustness check. Logit regressions at drug-candidate level of analysis over the period 1996-2015 (using lagged independent variables)

DV = Is drug internal or external	**Model 1**	**Model 2**
R&D Decentralization	**0.185***	**0.191***
	(0.0937)	**(0.0897)**
Organization Design controls	Y	Y
Firm-level controls	Y	Y
Competition controls	Y	Y
Diversification controls	Y	Y
Portfolio controls	Y	Y
Year Fixed Effects	Y	Y
Therapeutic Area Fixed Effects	Y	Y
Clinical Phase Fixed Effects	Y	Y
Progression Controls	N	Y
Number of Observations	12016	12016
Pseudo-R^2	0.133	0.135
Log Likelihood	-7039.5	-7027.4

Standard errors in parentheses:$^{+}$ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$; Errors clustered at firm level

Table 16: Multinomial logit regression. Dependent Variable is categorical variable representing mode of sourcing invention

DV= Mode of Sourcing Base category = Internal	Model 9 Alliance	Model 10 License	Model 11 Acquisition
R&D Decentralization	**0.00376** **(0.0949)**	**0.317**** **(0.0749)**	**0.185**$^{+}$ **(0.0953)**
Organization Design controls	Y	Y	Y
Firm-level controls	Y	Y	Y
Competition controls	Y	Y	Y
Diversification controls	Y	Y	Y
Portfolio controls	Y	Y	Y
Year Fixed Effects	Y	Y	Y
Therapeutic Area FE	Y	Y	Y
Clinical Phase FE	Y	Y	Y
Progression Controls	Y	Y	Y
Number of Observations	12016	12016	12016
Pseudo-R^2	0.132	0.132	0.132
Log Likelihood	-11670.4	-11670.4	-11670.4

Standard errors in parentheses:$^{+}$ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$; Errors clustered at firm level

Supplemental analyses

In order to further examine the mechanisms through which firms' R&D organization structures are associated with the proportion of inventions sourced externally, I conduct three additional analyses. The first is focused on the novelty of inventions externally sourced. The second is focused on examining the impact a corporate business development group has on the proportion of inventions sourced externally by firms with centralized and decentralized R&D. The final analysis is focused on how the difference in the proportion of inventions sourced externally between firms with centralized and decentralized R&D varies across the various stages of the development pipeline.

First, both knowledge flow- and incentives-based arguments suggest that while decentralized R&D units are better aligned with business needs they may be limited in their ability to create more novel inventions. Using a knowledge-based argumentation, knowledge flows across decentralized R&D units will be lower than within centralized R&D groups limiting the rich recombination of different facets of a firms' knowledge for

two key reasons (e.g., Fleming, 2001; Fleming & Sorenson, 2004). First, leveraging the concept of stickiness of knowledge transfer, both the source and recipient of the knowledge may lack the motivation to transfer or utilize this knowledge or the organizational context may not be suitable (Szulanski, 1996). Second, Szulanski (1996) and Grant (1996) highlight that the highly tacit knowledge associated with the creation and refinement of inventions may require rich and frequent communications between the provider and recipient of the information. This necessitates a degree of "intimacy" between the recipient and source. If the recipient and source of the relevant knowledge are in separate organizational units, the more distant relationship between these units is likely to result in greater difficulties in the transfer of more tacit knowledge associated with the creation of inventions (Szulanski, 1996). Relatedly, managers within a unit may simply be unaware of the capabilities and knowledge existing in other units and thus may be less able to access them (e.g., O'dell & Grayson, 1998). Firms with decentralized R&D units are thus likely to draw on a narrower range of knowledge in developing their inventions which will result in a reduced supply of more novel inventions for firms with decentralized R&D.

Using an incentives-based argumentation, managers within decentralized R&D units are likely to have a lower demand for internally-created novel inventions. Managers within decentralized R&D units will be incentivized to focus their inventive efforts on more business-specific, incremental inventions that are more likely to make it through the development process (e.g., Arora et al., 2014; Bercovitz, de Figueiredo, & Teece, 1997). Such managers are more likely to source more novel inventions externally as such external sources can provide a source of "ready-made" proven novel inventions that can be subsequently developed. In contrast, R&D heads in centralized R&D units have the benefit of being able to create more novel inventions as they have a greater focus on capability development and can create inventions that may not be specific to a current part of the business thereby facilitating greater novelty (e.g., Argyres & Silverman, 2004).

For both high and low novelty drug candidates, no significant difference is observed in the proportion of drug-candidates sourced externally between firms with centralized and decentralized R&D (Table 17). However, a significant difference is observed for drug-candidates of intermediate novelty, with firms with decentralized R&D units externally

sourcing approximately ten percentage points more of such drug candidates externally. Comparing the coefficients for *R&D Decentralization* across models for the three dependent variables measuring the proportion of inventions sourced externally of different novelty levels, I find that the coefficient for medium novelty is significantly greater than that for low novelty (p=0.07), but it is not significantly greater than that for high novelty (partly due to the large standard error for the *R&D Decentralization* coefficient).

It appears that R&D decentralization is associated with sourcing a greater proportion of inventions of medium novelty externally than firms with centralized R&D as compared to low novelty inventions. However, when it comes to highly novel inventions both firms with centralized and decentralized R&D appear to externally source a similar proportion of external inventions. It may be the case that for highly novel inventions, firms with centralized R&D, despite having greater access to their overall knowledge base are less able to solve the more complex problems associated with more novel inventions internally. This is simply because they have little experience in dealing with such challenging technical problems internally and thus are as likely to need to resort to external sources of inventions as do firms with decentralized R&D. In contrast for medium novelty inventions, firms with centralized R&D appear to be more able to solve such problems through recombining existing knowledge across the organization. In this specific context, greater novelty is associated with a new mechanism of action and origin of material to the focal firm. Addressing both areas of novelty is likely to be highly challenging even for firms that recombine knowledge across the entire organization. However, if only one of these items is novel to the focal firm, it potentially makes creating such inventions more tractable and able to be solved using firms' existing knowledge base.

These observations were further supported through our discussions with R&D managers in centralized units:

> *"We also will use external candidates to add scientific expertise not already within our portfolio, example for us would be gene therapy"*
>
> *"Sourcing externally provides an ability to bring in ideas that are not strictly related to our technical areas of expertise"*

Table 17: Supplemental analysis. Fractional Logit and OLS regressions in which DVs are proportion of drug candidates of specific novelty class sourced externally

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9
	Low Novelty			Medium Novelty			High Novelty		
Type of Model	**FL**	**FL PSM**	**OLS CEM**	**FL**	**FL PSM**	**OLS CEM**	**FL**	**FL PSM**	**OLS CEM**
R&D Decentralization	**0.210**	**0.234**	**0.0654**	**0.289***	**0.540***	**0.0668***	**-0.211**	**0.162**	**-0.0410**
	(0.165)	**(0.260)**	**(0.0511)**	**(0.124)**	**(0.270)**	**(0.0309)**	**(0.261)**	**(0.893)**	**(0.0737)**
R&D Functional Differentiation	-0.0867	-0.180	0.0717	0.0945	-0.0437	0.0152	-0.0214	-1.771	0.104
	(0.140)	(0.496)	(0.0475)	(0.122)	(0.424)	(0.0375)	(0.251)	(1.845)	(0.0738)
Corporate Decentralization	0.510*	2.009**	0.132+	0.432*	0.525	0.150*	0.110	-1.112	0.165
	(0.243)	(0.664)	(0.0669)	(0.213)	(0.552)	(0.0598)	(0.457)	(1.943)	(0.129)
Business Development Role	-0.0645	-0.500	-0.0314	-0.172	0.0590	-0.0237	-0.178	0.669	-0.0182
	(0.124)	(0.332)	(0.0340)	(0.125)	(0.264)	(0.0278)	(0.229)	(0.902)	(0.0760)
Performance	-0.132	4.375	0.295	-1.008	3.794+	0.158	-1.996	-13.20	-0.139
	(1.196)	(3.148)	(0.309)	(0.923)	(2.022)	(0.255)	(1.324)	(11.43)	(0.494)
R&D Intensity	0.113	4.365**	0.157	-0.610*	4.278**	-0.0886	-0.439	-5.316	0.0776
	(0.495)	(1.475)	(0.124)	(0.287)	(1.193)	(0.0647)	(0.675)	(7.243)	(0.181)
SG&A	-0.200	0.388	-0.0177	-0.133	-0.361	-0.00168	-0.289	2.112	-0.0456
	(0.141)	(0.377)	(0.0472)	(0.110)	(0.316)	(0.0313)	(0.269)	(3.025)	(0.0784)
Size	0.293	0.291	0.0585	0.0656	0.505	-0.00590	0.438	-0.0544	0.152*
	(0.186)	(0.484)	(0.0493)	(0.115)	(0.406)	(0.0312)	(0.279)	(2.727)	(0.0748)
Slack	0.0994*	-0.259	0.0194	0.0449	0.0773	0.00970	0.0424	0.00504	0.0124
	(0.0492)	(0.160)	(0.0130)	(0.0464)	(0.0893)	(0.0119)	(0.0736)	(0.677)	(0.0216)
New CEO	-0.296+	0.350	-0.0294	-0.352**	-0.139	-0.0655+	-0.340	-5.018	-0.0255
	(0.159)	(0.448)	(0.0506)	(0.125)	(0.620)	(0.0330)	(0.317)	(3.384)	(0.117)
Total Patent Stock	0.0315	0.114	-0.0164	0.0140	-0.0515	0.00029	-0.212+	-0.634	-0.0449
	(0.0886)	(0.200)	(0.0265)	(0.0651)	(0.279)	(0.0192)	(0.111)	(0.653)	(0.0470)
Patent Family Count	-0.483	-0.992	-0.238	-0.00528	-0.413	-0.0555	0.371	3.212	-0.196
	(0.579)	(1.066)	(0.148)	(0.341)	(1.177)	(0.113)	(0.736)	(3.960)	(0.288)
Competition	-1.685	16.12	0.402	0.514	8.350	0.231	5.752	-41.61	2.286
	(3.736)	(25.70)	(2.590)	(4.204)	(15.78)	(1.602)	(4.250)	(56.15)	(3.861)
SBU	0.825*	0.327	24.23+	-0.0115	0.0281	-0.0383	-0.0181	-1.112	0.147
	(0.358)	(1.036)	(13.68)	(0.395)	(0.216)	(0.0966)	(0.513)	(1.741)	(0.203)
Technical Differentiation	-2.211	-24.89**	0.0811	0.203	-6.532**	-0.202	-1.034	1.097	-0.461
	(1.517)	(5.717)	(0.262)	(0.894)	(2.202)	(0.174)	(1.350)	(7.014)	(0.390)
Clinical Experience	0.393	2.589+	0.102	-0.121	-1.216	-0.121	0.698	1.340	0.677
	(0.468)	(1.518)	(0.197)	(0.445)	(1.489)	(0.158)	(1.174)	(4.207)	(0.430)
Internal Overall Portfolio	-0.011**	-0.0207	-0.0029*	-0.0074*	-0.00203	-0.00119	-0.00346	0.00510	-0.00183
	(0.0033)	(0.0150)	(0.0012)	(0.0032)	(0.0121)	(0.0009)	(0.0051)	(0.0221)	(0.0028)
External Overall Portfolio	0.00160	-0.0115	0.00063	0.0117*	0.0165	0.00351*	0.00157	-0.0730	-0.00263
	(0.0039)	(0.0148)	(0.0018)	(0.0047)	(0.0114)	(0.0015)	(0.0098)	(0.0522)	(0.0047)
Portfolio Novelty	-0.148	-0.485	0.0599	-1.058+	-1.782	-0.162	-0.384	3.392	-0.404
	(0.618)	(1.625)	(0.147)	(0.592)	(1.615)	(0.166)	(0.795)	(3.023)	(0.276)
Bio	-0.577	-11.37**	-0.0269	0.226	-6.456**	-0.0252	-0.0760	-14.04	-0.363
	(0.850)	(3.056)	(0.134)	(0.522)	(1.531)	(0.174)	(0.664)	(9.862)	(0.272)
Year Fixed Effects	Y	Y	Y	Y	Y	Y	Y	Y	Y
Business Category Fixed Effects	Y	Y	Y	Y	Y	Y	Y	Y	Y
Therapeutic Cat. Fixed Effects	Y	Y	Y	Y	Y	Y	Y	Y	Y
N	628	128	502	699	145	529	440	99	294
R^2	0.0605	0.233	0.199	0.0606	0.189	0.355	0.0918	0.386	0.291
Log Likelihood	-394.2	-70.81	-60.93	-454.2	-86.57	15.46	-270.7	-44.06	-107.4

Standard errors in parentheses:+ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$; Errors clustered at firm level
PSM – Propensity Score Matching, FL – Fractional Logit, CEM – Coarsened Exact Matching

In addition, firms may source novel inventions externally to complement the development of such inventions internally. A business development manager stated:

> *"Often early on we will get both internal and external candidates to look at the same issue and see which one works out, way of testing out alternatives and increasing the likelihood of success"*

As an alternative measure to *Novelty* I utilized new chemical entity status (NCE). I examine how the proportion of drug candidates sourced externally varied between NCE and non-NCE drugs for firms with centralized and decentralized R&D. As illustrated in Table 18, the proportion of non-NCE drugs externally sourced does not differ between firms with centralized and decentralized R&D. However, I observe a significant difference for the proportion of NCE drug-candidates sourced externally. The difference between the coefficients for *R&D Decentralization* for NCE and non-NCE is statistically significant ($p<0.08$) consistent with the results observed using the measure *Novelty*.

Table 18: Alternative measure of novelty analyses using proportion of new chemical entities (nce) that are externally sourced and proportion of non-nces that are externally sourced.

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Dependent Variable	**External non-NCE**			**External NCE**		
Type of Model	**FL**	**FL PSM**	**OLS CEM**	**FL**	**FL PSM**	**OLS CEM**
R&D Decentralization	**0.0680 (0.138)**	**0.0419 (0.199)**	**0.0549 (0.0523)**	**0.187 (0.142)**	**0.438* (0.189)**	**0.0733* (0.0357)**
Org. Design controls	Y	Y	Y	Y	Y	Y
Firm-level controls	Y	Y	Y	Y	Y	Y
Competition controls	Y	Y	Y	Y	Y	Y
Diversification controls	Y	Y	Y	Y	Y	Y
Portfolio controls	Y	Y	Y	Y	Y	Y
Year Fixed Effects	Y	Y	Y	Y	Y	Y
Business Category Fixed Effects	Y	Y	Y	Y	Y	Y
Therapeutic Category Fixed Eff.	Y	Y	Y	Y	Y	Y
N	702	224	332	658	209	304
R^2	0.051	0.094	0.467	0.078	0.139	0.441
Log Likelihood	-455.0	-138.2	4.491	-399.8	-120.4	18.80

Standard errors in parentheses: $^{+}$ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$; Errors clustered at firm level
PSM – Propensity Score Matching; FL – Fractional Logit, CEM – Coarsened Exact Matching
Observation counts vary due to missing data on NCE status for some firms' drug-candidates

Second, I examine how the presence of a corporate business development group (as reflected by the presence of such a unit whose lead reports directly to the CEO) can moderate the primary relationship between R&D design and the proportion of inventions sourced externally. Corporate business development groups can act as integrating structures across firms with decentralized R&D, thereby impacting firms' decisions to source inventions externally or create them internally (e.g., Lawrence & Lorsch, 1967) i.e. can make a decentralized firm more integrated.

However, as illustrated in Table 19, we observe no moderating impact of having a corporate Business Development Unit as illustrated by the non-significance of the coefficient *R&D Decentralization* x *Business Development Role* in models 1 and 2. I then examine how the presence of a corporate business development unit moderates the relationship between *R&D Decentralization* and the proportion of inventions sourced through acquisitions, alliances and licensing. I find that the presence of a business development group does negatively moderate the relationship between *Acquisition* and *R&D Decentralization* as illustrated in Models 3 and 4. This suggests that firms with decentralized R&D units and a corporate business development group tend to source fewer inventions through acquisitions than firms with decentralized R&D units and no corporate business development group (both relative to firms with centralized R&D units). This finding is consistent with the interviews with R&D and business development managers illustrated above in that business development groups may act as a "brake" on individual R&D units acquiring external inventions. Prior studies have highlighted the importance of such corporate groups in improving firms sourcing efforts (e.g., Kale et al., 2002).

In the interviews, there was a consistent theme that business development groups generally facilitate the decision to source drug-candidates externally. Business Development typically does this through highlighting potential external opportunities and enabling the execution of a specific deal rather than making the final decision to source drug-candidates. However, managers highlighted for larger deals, especially acquisitions, the corporate business development group became more involved and could veto such critical deals.

For example:

"There is a corporate BD group, they tend to manage large deals, multiple asset deals or company acquisitions/alliances, etc."

"If it is a big acquisition deal, then individual units cannot make a call, it goes to the executive committee and Corporate BD plays a key role"

Table 19: Supplemental analysis examining how corporate business development units could moderate the main relationships proposed by H1 and H2

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
Dependent Variable	**External**		**Acquisition**		**Alliance**		**License**	
Type of Model	**FL**	**FL PSM**	**FL**	**FL PSM**	**FL**	**FL PSM**	**FL**	**FL PSM**
R&D Decentralization	**0.212**$^{+}$ **(0.124)**	**0.387*** **(0.186)**	**0.257 (0.203)**	**1.250*** **(0.527)**	**-0.197 (0.199)**	**-0.421**$^{+}$ **(0.244)**	**0.282*** **(0.132)**	**0.246 (0.218)**
Business Development Role	**0.0518 (0.0814)**	**0.104 (0.208)**	**0.0694 (0.156)**	**1.231**** **(0.347)**	**-0.0798 (0.137)**	**-0.509 (0.349)**	**0.0838 (0.119)**	**-0.294 (0.297)**
R&D Decent. x BD Role	**-0.0975 (0.170)**	**-0.316 (0.288)**	**-0.872*** **(0.407)**	**-2.649**** **(0.634)**	**0.108 (0.271)**	**0.186 (0.415)**	**0.185 (0.222)**	**0.457 (0.350)**
Org Des. Controls	Y	Y	Y	Y	Y	Y	Y	Y
Firm-level controls	Y	Y	Y	Y	Y	Y	Y	Y
Competition ctrls	Y	Y	Y	Y	Y	Y	Y	Y
Diversification ctrls	Y	Y	Y	Y	Y	Y	Y	Y
Portfolio controls	Y	Y	Y	Y	Y	Y	Y	Y
Year Fixed Effects	Y	Y	Y	Y	Y	Y	Y	Y
Business Category Fixed Effects	Y	Y	Y	Y	Y	Y	Y	Y
Therapeutic Cat. Fixed Effects	Y	Y	Y	Y	Y	Y	Y	Y
N	769	165	769	172	769	172	769	172
R^2	0.0318	0.0782	0.0904	0.197	0.0739	0.156	0.0469	0.0963
Log Likelihood	-488.9	-109.6	-211.2	-52.39	-258.2	-56.29	-320.0	-80.29

Standard errors in parentheses:$^{+}$ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$; Errors clustered at firm level

I observe no moderating impact of a corporate business development group on sourcing via alliances or licensing. The licensing observation is consistent with the arguments made above which suggest that licensing is generally lower risk and commitment and can be delegated to individual R&D units. Alliances provide an interesting case in that these could potentially be major commitments, yet the results indicate that corporate business development groups do not to appear to influence the propensity to alliance for firms with either centralized or decentralized R&D.

Third, I examine how the primary relationship indicated by Hypothesis 1 changes by the stage of development or clinical phase in which an invention is sourced. In order to examine this, I undertake negative binomial regressions examining how the number of external drug-candidates externally sourced in each clinical phase is associated with *R&D Decentralization* using the same control variables and fixed effects as illustrated in Table 10. I undertake this analysis because there is a potential trade-off that firms face. Namely, sourcing more candidates at an earlier stage of development is higher risk but lower cost. As outlined in the theoretical argumentation, managers in decentralized R&D units face greater pressure to ensure a steady flow of new products. Sourcing later stage development inventions could be a way of alleviating this pressure.

As illustrated in Table 20, I observe that firms with decentralized R&D source more external drug candidates than those with centralized R&D in the pre-clinical (phase 0), phase1 and phase 2 stages of development. However, I observe less evidence of a difference in Phase 3. These results are consistent with the interviews with R&D personnel who highlighted that later stage assets due to their lower associated risk of failure tend to be more costly to source:

> *"The later the phase the more expensive an asset is, early stage millions, later stage billions"*
>
> *"If we source a phase 2 asset this can be done at the business unit level, any later and much broader involvement is required"*
>
> *"We are tending to source more pre-clinical drug-candidates recently as it gives more optionality and prices go up as for the later stages of the development process – prices recently have sky-rocketed for late-stage assets"*

These observations are consistent with the theoretical argumentation. Namely, those inventions that are more costly and likely to require cross-organizational buy-in to source are less likely to be sourced by firms with decentralized R&D thereby narrowing the gap of the proportion of inventions sourced externally between firms with centralized and decentralized R&D. Later stage drug-candidates represent such inventions and thus managers in decentralized R&D units are more likely to externally source earlier

development stage inventions which is what is observed in Table 20. Further, and also consistent with Hypothesis 2, I observe that firms with decentralized R&D source a significantly higher number of inventions through licensing across all these earlier phases than firms with centralized R&D, but observe limited differences for alliances and acquisitions. Further details on all the supplemental analyses described in this section are provided in Appendix 7.

Table 20: Supplemental analysis examining how the relationship between the number of externally-sourced drug-candidates and R&D Decentralization varies with the stage of clinical development.

DV= Number external drug-candidates	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**	**Model 7**	**Model 8**
Type of Model	**FL**	**FL PSM**	**FL**	**FL PSM**	**FL**	**FL PSM**	**FL**	**FL PSM**
Clinical Phase	**0**	**0**	**1**	**1**	**2**	**2**	**3**	**3**
R&D Decentralization	**0.200* (0.0800)**	**0.298** (0.115)**	**0.341* (0.165)**	**0.499** (0.173)**	**0.352^{+} (0.185)**	**0.355* (0.177)**	**0.256 (0.196)**	**0.373^{+} (0.224)**
Org Design Controls	Y	Y	Y	Y	Y	Y	Y	Y
Firm-level controls	Y	Y	Y	Y	Y	Y	Y	Y
Competition controls	Y	Y	Y	Y	Y	Y	Y	Y
Diversification controls	Y	Y	Y	Y	Y	Y	Y	Y
Portfolio controls	Y	Y	Y	Y	Y	Y	Y	Y
Year Fixed Effects	Y	Y	Y	Y	Y	Y	Y	Y
Business Category Fixed Effects	Y	Y	Y	Y	Y	Y	Y	Y
Therapeutic Category Fixed Effects	Y	Y	Y	Y	Y	Y	Y	Y
N	759	231	736	171	736	228	752	235
R^2	0.184	0.227	0.153	0.329	0.114	0.174	0.107	0.165
Log Likelihood	-1654.9	-509.4	-867.1	-182.2	-939.6	-305.1	-840.6	-267.3

Standard errors in parentheses:$^{+}$ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$; Errors clustered at firm level.
FL – Fractional Logit; PSM – Propensity Score Matching

Discussion and Conclusion

In order to ensure a continuous flow of inventions to market, firms need to constantly replenish their development pipelines as inventions reach the market or fall by the wayside. This replenishment could be done using internally created or externally sourced inventions. Existing theories examining firms' decisions to source inventions externally or create them internally have considered this decision to take place at the firm-level and the logic for decision-making at the transaction-level. As a result, prior studies have focused on isolated issues that pertain to an individual transaction (e.g., Pisano, 1990) or invention (e.g., Macher & Boerner, 2012) or assumed that firms are "black boxes" with pre-defined knowledge and capabilities accessible to the entire firm (e.g., Veugelers & Cassiman, 1999; West & Bogers, 2014).

In this study I integrate the incentive- and knowledge-based views of the firm to offer a novel theoretical explanation for this decision. Within my theory, I consider that firms may decentralize such decisions within specific units, and that the decision-making might operate at the pipeline-level rather than at the individual transaction-level. Firms that decentralize their pipeline management will engender greater incentives for managers to progress inventions to market at the cost of reduced capability development. This is because in decentralized R&D units managers are more beholden to their business units for resources in contrast to managers in centralized R&D organizations that are likely to receive resources at a corporate level rather than directly from business units. In addition, there is an increased likelihood of any individual decentralized R&D unit facing gaps in its pipeline as compared to centralized R&D that can pool all its inventions in one portfolio. In contrast, firms that centralize R&D and have a single pipeline of inventions will be associated with a greater focus on capability development. As a result, managers in firms with decentralized R&D units are more likely to externally source inventions they can then develop to replenish their pipelines than their equivalents in firms with centralized R&D. This is in order to avoid gaps in their pipelines and ensure a steady stream of new products to market. In support of these arguments, I find that decentralized organization designs with multiple R&D units are associated with a higher proportion of externally sourced

inventions, and this difference is primarily driven by licensing, and inventions of moderate levels of novelty.

This study provides three key contributions to the extant literature. First, this paper provides a theoretical contribution that enables a deeper understanding of what shapes firms' decisions to create inventions internally or source them externally. I highlight the intricate linkage between incentives associated with firms' design elements and firms' invention creation capabilities. Decentralized R&D unit managers face greater pressure from their commercial leads in business units and are more strongly incentivized to ensure a steady flow of new products to market and thus focus less on building internal invention creation capabilities. Managers within decentralized R&D units also face a greater likelihood of gaps within their invention development pipelines as they do not have as much risk pooling as otherwise equivalent firms that manage their inventions within a single portfolio. External inventions provide a ready route to fill these gaps. This highlights the importance of examining the make-buy decision in the context of pipeline management as opposed to individual transactions.

In addition reduced knowledge flows between R&D units are associated with the creation of less novel inventions, necessitating the external sourcing of more novel inventions. In contrast, firms with centralized R&D units can afford to build invention creation capabilities and undertake more innovation activities within the boundaries of the firm. Further, managers of R&D sub-units within the centralized model facing lower-powered incentives are more likely to share internally-created inventions across units than managers in decentralized R&D units facing higher powered incentives. These factors help to explain why firms with decentralized R&D source more inventions externally.

Thus it appears that decentralization of R&D and its associated higher powered incentives leads to a reduced focus on internal capability development and a greater external invention focus. Whereas centralization of R&D and its greater intra-organizational knowledge flows is associated with a stronger internal invention focus. However, for highly novel inventions, firms with centralized R&D reach the limits of their capabilities and equally resort to external sourcing of such inventions as firms with

decentralized R&D. This reiterates the importance of integrating knowledge- and incentives-based theories to understand the foundations for firms' capabilities (e.g., Argyres & Zenger, 2012).

Second, this study extends recent work examining how firms' internal design choices can shape their decisions to invent internally or externally (e.g., Arora et al., 2014; Grigoriou & Rothaermel, 2017; Leiponen & Helfat, 2011). Consistent with these prior studies I find that decentralizing R&D is associated with the sourcing of an increased proportion of external inventions, however I provide an alternative theoretical rational and illustrate that this difference is driven by licensing as opposed to alliances or acquisitions. Licensing provides a lower risk and up-front cost route to access new inventions that does not require cross-organizational buy-in and resources unlike, for example, acquisitions.

Supplemental analyses illustrate that for inventions in the later stages of development which are generally more costly, there is no difference in the proportion of inventions sourced externally between firms with centralized and decentralized R&D. Such late-stage assets may be beyond the resources of individual R&D units. We also observe that for firms with decentralized R&D units, the presence of a corporate business development unit is associated with reduced sourcing of inventions through acquisitions. The interviews highlight that such business development units play a significant role in larger scale acquisitions (as opposed to individual licensing of inventions). This suggests that business development units may rein in the acquisitions of individual units with an eye to optimizing acquisitions for the firm as a whole as opposed to a single unit.

Thus this study highlights that internal design can shape the mode through which managers source external inventions by influencing the resources to which they have access and their overall strategic priorities (i.e. building capabilities versus sourcing inventions). However, integrating units, such as business development, can further influence how managers within decentralized R&D units access external inventions by taking an organization-wide perspective and potentially limiting R&D units' utilization of more costly modes such as acquisitions.

Finally, this study indicates a potential association between firms' internal design

choices and the composition of markets for technologies. It is possible that the more liquid the market for technologies, firms may be more likely to decentralize R&D and focus on developing basic inventions in-house, externally sourcing more novel inventions for subsequent internal development. This would have to be investigated in a multi-industry study with industries that have different availabilities of technologies through open markets. Consistent with prior studies it is likely that as industries develop and markets for technologies emerge that firms will increasingly divide innovative labor between each other which has implications for how they are designed internally (e.g., Arora et al., 2016; Arora & Gambardella, 1994, 2010).

This study has a number of limitations that can provide avenues for future research. First, it may be that sources of unobserved heterogeneity associated with individual drug-candidates could influence the make versus buy decision. For example, a drug-candidate may involve a unique technology within a focal therapeutic class, and although the firm may have several internal drug-candidates within that category managers may still source externally to simply access this technology. It is likely to be the case that firms access such technologies prior to invention and use this knowledge to develop unique internal inventions. However in this study I do not observe firms' more upstream sourcing of knowledge. It would be valuable to compare firms' upstream sourcing of knowledge through, for example, research agreements with academic institutions and their sourcing of more downstream inventions under development and see if they are complementary. For example, upstream sourcing may be focused on supplementing internal knowledge that can provide firms the ability to develop novel, future inventions. Further downstream, sourcing may be more tactical focused on filling gaps in firms' portfolios.

Second, concerns regarding external validity may arise due to the focus on a single industry context. However, multiple industries follow a similar product development process to the pharmaceutical industry such as the aerospace, consumer goods and the chemicals industry (e.g., Barczak, Griffin, & Kahn, 2009; Griffin, 1997; Grönlund et al., 2010). Further, companies in other industries such as Procter & Gamble with its "Connect and Develop" model are increasingly externally sourcing the inventions that become their

ultimate products (e.g., Huston & Sakkab, 2006). It would be valuable to examine whether the results observed in this study hold in other industry environments.

Finally, there may be a distinction between how firms are structured internally and how they manage their portfolio of inventions. Specifically, firms may have decentralized R&D whereas firms may manage the portfolio of inventions as a single portfolio. This may be especially important for inventions later in development when the levels of investment associated with developing such inventions is much higher. I do find that that the results hold during the earlier stages of development including pre-clinical where I consistently heard in interviews the decision to source externally was generally made by the head of the relevant R&D unit. Relatedly, the measure for *R&D Decentralization* that I use may not fully capture the diversity of R&D structures such as hybrid models.

Despite these and other limitations, the study offers an important contribution to the extant literature on the management of innovation. This study illustrates that moving beyond a basic consideration of a specific transaction to considering the composition of a firm's pipeline of existing inventions as well as how a firm manages its invention pipeline can provide insight into what shapes the decision to source inventions externally or create them internally. It appears that design elements can shape both managerial incentives as well as firms' intra-organizational knowledge flows. External sourcing of inventions, especially through licensing, can make up for a lack of effective internal knowledge-flows as well as enable hard-pressed R&D managers in decentralized units to ensure a continuous flow of inventions to market thereby helping them to "mind the gaps" in their portfolios.

CHAPTER 4: STUCTURING TO SELL IDEAS: THE ROLE OF ORGANIZATION DESIGN IN THE COMMERCIALIZATION OF INVENTIONS

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Abstract

In this paper I examine the relationship between organization design and firms' commercialization of inventions. I argue that firms face a delicate balance. On the one hand, greater decentralization facilitates the more effective use of incentives which aids commercialization. On the other hand, greater centralization enables more effective allocation of complementary resources which also aids commercialization. Complementary resources such as sales and marketing are critical in enabling firms to sell new offers. I argue that this balance of the benefits and costs of decentralization shifts with the level of complementary resources available and the degree of concentration of sales of firms' existing products. Increasing levels of complementary resources are associated with increasingly inefficient allocation for more decentralized firms compared to more centralized firms resulting in a decreased proportion of sales of new products for decentralized firms compared to more centralized firms. Increasing dependence on a smaller proportion of existing products is associated with greater incentives for managers in decentralized units to allocate complementary resources away from new offers resulting in a decreased proportion of sales from new products for decentralized firms compared to more centralized firms. I find support for these arguments in the context of the pharmaceutical industry.

Introduction

> *"You don't want to be Tesla. He was one of the greatest inventors, but it's a sad, sad story. He couldn't commercialize anything, he could barely fund his own research. You'd want to be more like Edison. If you invent something, that doesn't necessarily help anybody. You've got to actually get it into the world; you've got to produce, make money doing it so you can fund it."* Larry Page (CEO Alphabet)

The successful commercialization of inventions is a key determinant of firms' ultimate performance (e.g., Nerkar & Shane, 2007; Rothaermel, 2001). However, as highlighted by the quote by Larry Page, impressive inventions can often fail to be successfully commercialized. For example, Xerox Corporations' history has been littered with several examples of significant inventions such as the graphical user interface or computer mouse that it failed to commercialize (Chesbrough & Rosenbloom, 2002). Scholars have highlighted that firms' organization designs can play a significant role in driving the success of their innovation activities (e.g., Argyres & Silverman, 2004; Eggers, 2016; Tushman et al., 2010). The canonical design solution to facilitate successful innovation has been to create dedicated units separate to the broader organization to focus on new offerings (e.g., Christensen & Bower, 1996; Lavie et al., 2010).

However, in understanding the relationship between organization design and innovation these studies have tended to focus on innovation as an outcome rather than a process (e.g., Garud et al., 2013). The same design element may have very different implications at different stages of the innovation process. For example, what may be effective for the creation of inventions may not be suitable for the effective commercialization and sales of fully developed inventions. Further, many studies have focused on firms creating highly novel inventions that may not align well with their existing business and the struggle firms face to get these inventions to market as opposed to examining value capture once an invention has been launched (e.g., Christensen, 2006; Nerkar & Shane, 2007). However, in order to maintain their on-going viability firms often manage pipelines of inventions that enable a steady flow of new offers to the market place from which they capture value in the form of new product sales (e.g., Chan et al., 2007; Klingebiel & Rammer, 2014). Thus, our understanding of how organization design can impact the

commercialization of firms' inventions in terms of the successful sales of these inventions on an on-going basis appears to be somewhat limited. This viewpoint is reinforced by recent studies that have highlighted that commercialization research is a relatively "*fragmented field of study*" (Kirkegaard Sløk-Madsen et al., 2017) and *"remains poorly understood"* (Datta et al., 2015).

In this paper, I examine the relationship between firms' organization designs and their on-going commercialization of new inventions emerging from their pipelines in terms of sales of new products. With respect to organization design, I focus on whether firms tend to centralize and align functionally or decentralize and align into a variety of different business units (e.g., Chandler, 1962). The degree of decentralization has implications for how firms manage their invention portfolios and allocate complementary resources to facilitate the market adoption of inventions (e.g., Argyres & Silverman, 2004; Bardolet et al., 2011; Teece, 1986). I argue that firms need to manage a challenging balance with respect to their designs. On the one hand, greater centralization facilitates functional excellence and the more effective allocation of resources. On the other hand, greater decentralization facilitates greater customer intimacy and knowledge and is associated with the more effective use of higher powered incentives which engenders greater managerial effort. Similar to Chapter 3, I extend the knowledge-incentive trade-off in Chapter 2 by considering the important topic of internal resource allocation. I argue that the relationship between organizational decentralization and the proportion of sales of new products is moderated by two factors that can influence this delicate balance through their impacts on resource allocation and managerial incentives. First, there is the quantity of complementary resources available for the sale of new and existing products which reduces the benefits of greater decentralization through magnifying the impact of ineffective resource allocation. Complementary resources such as sales and marketing are critical in enabling firms to sell new offers. Second, there is the concentration of sales of firms' existing products, namely reliance on the sales of a smaller number of existing products. This is also associated with lowering the benefits of greater decentralization as new products receive fewer resources.

I find support for these arguments in the context of the pharmaceutical industry over the period 1995 to 2015. As a baseline finding, I find that greater corporate

decentralization is associated with an increased percentage of revenues from new products launched in the current year. I also observe that this relationship is negatively moderated by the level of selling, general and administration (SG&A) spending. Further, I find that for firms that are more reliant on the sales of a smaller number of products there is a weaker relationship between corporate decentralization and the sales of new products. These observations are consistent with the less effective allocation of resources associated with greater decentralization as well as managerial incentives shaping resource allocation.

This study makes three primary contributions to the extant literature. First, this study theoretically contributes to the re-emergent organization design literature (Greenwood & Miller, 2010; Puranam et al., 2014; Van de Ven, Ganco, & Hinings, 2013) by illustrating a key balancing act firms need to manage when organizing to innovate. Namely, greater decentralization is associated with the more effective use of incentives and greater local market knowledge but comes at the cost of reduced functional scale and units competing for resources which can lead to inefficient resource allocation. Second, this study helps to extend our understanding of internal capital allocation within large, incumbent firms. I argue that greater decentralization comes at a cost in that business units increasingly compete for resources which may result in more powerful units accessing resources that could be more effectively utilized in other parts of the organization. Third, this study provides an interesting insight into the existing debate regarding organizational slack and firms' innovation efforts (e.g., Marlin & Geiger, 2015; Nohria & Gulati, 1996). Namely, the relationship between the level of resourcing and innovation performance is moderated by organization design. Greater decentralization may be more effective at lower resourcing levels as the more effective use of higher-powered incentives enables firms to get a "bigger bang" for their buck but this advantage diminishes as resource levels increase.

Theory and Hypotheses

Organization design and commercialization

Innovation can be viewed as a process consisting of three key stages (e.g., Garud

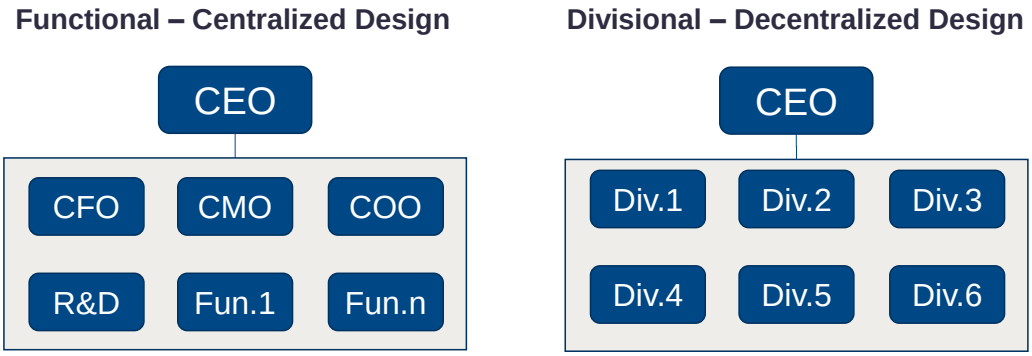
et al., 2013; Keum & See, 2017). First there is the act of invention that consists of the creation of novel ideas that in themselves are of limited economic value (e.g., Kapoor & Klueter, 2015; Schumpeter, 1939). Second, development is focused on converting an invention into a final product that can yield commercial value. Finally, there is commercialization which relates to firms' value appropriation from their developed inventions. With respect to commercialization, firms often manage a portfolio of products that they sell to end-customers (e.g., Day, 1977; Eggers, 2012). However, in order to ensure their sustainability firms need to continually renew their product portfolios through adding new inventions and removing products that are no longer delivering incremental value (Rothaermel, Hitt, & Jobe, 2006). This is because in competitive industries other firms will introduce new products which may make a focal firm's existing products obsolete (e.g., Bayus, Erickson, & Jacobson, 2003; Brown & Eisenhardt, 1997).

In this paper I build on the definition of commercialization by Datta et al. (2015). Namely commercialization of inventions relates to a firm's "*capacity to bring a technological innovation to market and reach some of the mainstream, beyond the initial adopters*." I specifically examine commercialization through *the proportion of sales from new products*. I use this lens rather than, for example, the proportion of new products in a firm's product portfolio because the focus of my theoretical development revolves around how effectively firms are able to reach customers which involves revenue capture as opposed to simply launching a product. The proportion of sales from new products is a well-established measure within the strategic management literature (e.g., Klingebiel & Rammer, 2014; Nerkar & Roberts, 2004).

Prior studies focusing on the latter stages of the innovation process have emphasized the important role of organization design in shaping firms' various innovation-related outcomes (e.g., Damanpour, 1991; Damanpour & Aravind, 2012). These studies have tended to illustrate the benefits of dedicated units for new offers separate to the core business (e.g., Christensen, 2006; Christensen & Bower, 1996; Tushman et al., 2010). Arguments to support this assertion relate to avoiding resource dependency on existing customers and organizational inertia. However, the focus of these studies has been on firms developing new offers that may conflict with a firm's current business. In this paper I focus

on how organization design can impact commercialization of firms' inventions within their on-going invention pipelines. In my empirical analyses I control for invention novelty but am neutral to novelty in my theoretical development focusing on firms' ongoing commercialization of new inventions that emerge successfully from their pipelines.[22]

Figure 8: Corporate Decentralization – examples of different design choices



- Manages single portfolio of inventions
- CEO reports incentivized by functional or overall business performance
- More challenging to link invention market performance to specific organizational unit e.g. was product good (i.e. R&D gets plaudits) or was marketing great for a mediocre product (e.g. marketing and sales gets plaudits)?
- Centralize capabilities to get commercial centers of excellence

- Multiple invention portfolios – one for each division
- CEO reports incentivized by division performance
- Easier to link invention market performance with specific organizational unit (e.g. if product X is successful unit X is rewarded accordingly)
- Capabilities in commercialization may be scattered across the organization

In this paper, the key organization design element focused upon is whether a firm is more centralized and functionally orientated or more decentralized and divisionally orientated. Namely the degree of *corporate decentralization* (e.g., Burton et al., 2011). The designs illustrated in Figure 8 portray the extremes of a highly centralized firm which is functionally aligned and has no business units and a highly decentralized firm which solely consists of a collection of independent business units. However, firms can have differing degrees of corporate decentralization with some functions being centralized at a corporate level and others being decentralized (e.g., Albert, 2018; Guadalupe et al., 2014). A pertinent difference is that centralized firms tend to manage a single portfolio of inventions,

[22] In this paper inventions represent products in the innovation process and new products or offers represent the outputs of the process.

in contrast in more decentralized models each division tends to manage its own portfolio of inventions.

With respect to the commercialization of firms' inventions emerging from their invention pipelines, firms face a delicate balancing act. Greater corporate centralization is associated with the development of greater functional expertise which will enable the more effective commercialization of new products (e.g., Burton et al., 2011). In addition, the commercialization of inventions requires firms to invest in complementary resources such as marketing campaigns, salesforces and manufacturing facilities. Without investing in these complementary resources firms can limit the sales of their new offers as, for example, customers are unaware of these new products, products may not be available in key distribution channels or sufficient quantities of the new product cannot be produced. Greater corporate centralization is associated with a broader more objective perspective when evaluating the merits of individual products requiring such complementary resources (Stein, 1997). This is because such resource allocation is likely to occur at the individual product level with each product assessed on its own merits as opposed to the business unit level in which the merits of individual business units are assessed (e.g., Bardolet et al., 2011; Bardolet et al., 2010). In more decentralized organizations, managers in business units will compete for complementary resources and potentially over-inflate the opportunities associated with their business units' portfolios of inventions that they wish to commercialize (Bardolet et al., 2010). These arguments suggest that allocation of complementary resources is likely to be more effective in more centralized organizations leading to the more effective commercialization of firms' inventions.

In contrast, greater corporate decentralization offers two key advantages. First, it facilitates the more effective usage of higher powered incentives as there is a clearer linkage between performance outcomes and managerial effort (e.g., Argyres, 1996; Zenger & Hesterly, 1997). This helps to engender greater effort of the managers commercializing new inventions which in turn can result in more effective sales of new products (e.g., Zenger, 1994). Further, the effectiveness of incentives is likely to increase from the highly uncertain stage of invention through to the more well-defined commercialization stage (e.g., Aghion & Tirole, 1994). Second, business units are also able to develop greater

knowledge of specific customer and market needs as these markets represent their primary focus as opposed to a more centralized, functional organization that disperses its focus across multiple customer groups and markets (e.g., Burton et al., 2011). This enables firms to more effectively drive sales of new products (e.g., Nerkar & Roberts, 2004). Intimate knowledge of the specific markets to which firms are selling their products such as appropriate distribution channels, suitable advertising media and relevant local competitors will facilitate sales of firms' products. This will be especially important following the initial launch of a new product where a product is seeking to penetrate a specific market and the marginal benefits of this specific local knowledge will be greater than for established products.

Although, the marginal benefits of effective resource allocation, functional expertise, incentives and local market knowledge will be greater for new as opposed to existing products (e.g., Angell, 2000; Bayus et al., 2003), *ex-ante* it is difficult to determine whether firms that are more or less decentralized will be associated with a greater proportion of sales from new products. As a result, I leave this as an open empirical question which I examine later in this paper. My theoretical focus revolves around examining the balance between greater decentralization facilitating the more effective usage of higher powered incentives and greater centralization enabling the more effective allocation of complementary resources. I examine two moderating factors that will influence the impact of resource allocation and the relevance of incentives. This enables me to develop clear theoretical predictions as to how corporate decentralization is associated with the commercialization of firms' inventions as measured through the proportion of sales of new products.

Moderating impact of quantity of complementary resources

The marginal benefits of complementary resources that facilitate the sale of new products are likely to decline as the quantity of these resources increases (e.g., Arrfelt, Wiseman, McNamara, & Hult, 2015; Nohria & Gulati, 1996). This is because the most favorable opportunities will tend to be taken at lower resource levels and generally be more

apparent to managers. As the quality of opportunities declines the level of managerial subjectivity is also likely to increase as relative quality will be more difficult to objectively determine. However, the decline in marginal benefits differs between firms that are more or less decentralized is likely to differ.

At lower quantities of complementary resources, the greater local market knowledge of more decentralized firms is likely to enable them to identify more effective complementary resources facilitating increased sales from their newly launched products as compared to more centralized firms (e.g., Argyres & Silverman, 2004). Further, managers in decentralized units are likely to engender more effort to drive sales of new products than managers in centralized units due to the greater effectiveness of higher powered incentives. At this lower quantity of complementary resources, only higher quality new product opportunities will tend to be supported effectively. As argued above, the marginal benefits of the complementary resources will be higher for these new products. Further there is a greater likelihood that each unit within a decentralized firm has at least a small set of good new product opportunities thereby helping to ensure complementary resources are used effectively. Thus I argue that at lower quantities of complementary resources, the benefits of the more effective use of incentives outweighs the costs of less effective resource allocation. Further, the marginal benefits of complementary resources will be greater for new as opposed to existing products as they are not already established in the market place. Thus the complementary resources can increase the sales of new products more effectively than existing products. Hence, these arguments suggest that at lower quantities of complementary resources, more decentralized firms will be associated with a higher proportion of sales from new products that more centralized firms.

However, as highlighted by the work of Bardolet et al. (2011), centralized firms tend to allocate investments in their portfolio of products at the individual product level, whereas for decentralized firms resources are allocated at the business unit level. With the tendency for business unit managers to battle for complementary resources to increase their own personal power there is a risk that firms invest in inferior new product opportunities as managers access resources which other parts of the organization could use more effectively (e.g., Birkinshaw & Lingblad, 2005; Ghoshal & Nohria, 1989; Rajan, Servaes,

& Zingales, 2000). As complementary resources increase managers in decentralized units will tend to over-state the opportunities they have available in order to increase their intra-organizational power (e.g., Rajan et al., 2000; Stein, 1997). For similarly sized business units, in order to overcome this struggle for resources, corporate managers may have a tendency to allocate resources equally across business units following the 1/n rule (Bardolet et al., 2010). This is not a major issue if new product opportunities are uniformly dispersed through the organization. However, this is unlikely to be the case with some business units having more attractive new product opportunities than other units. This will result in some high-value new product ideas not receiving sufficient complementary resources in decentralized firms as compared to centralized firms. Thus as the level of complementary resources increases this inefficient allocation of resources will eventually overcome the benefits of the increased effectiveness of incentives enabling more centralized firm to increase their proportion of sales of new products compared to more decentralized firms. This argumentation is best illustrated through a basic example.

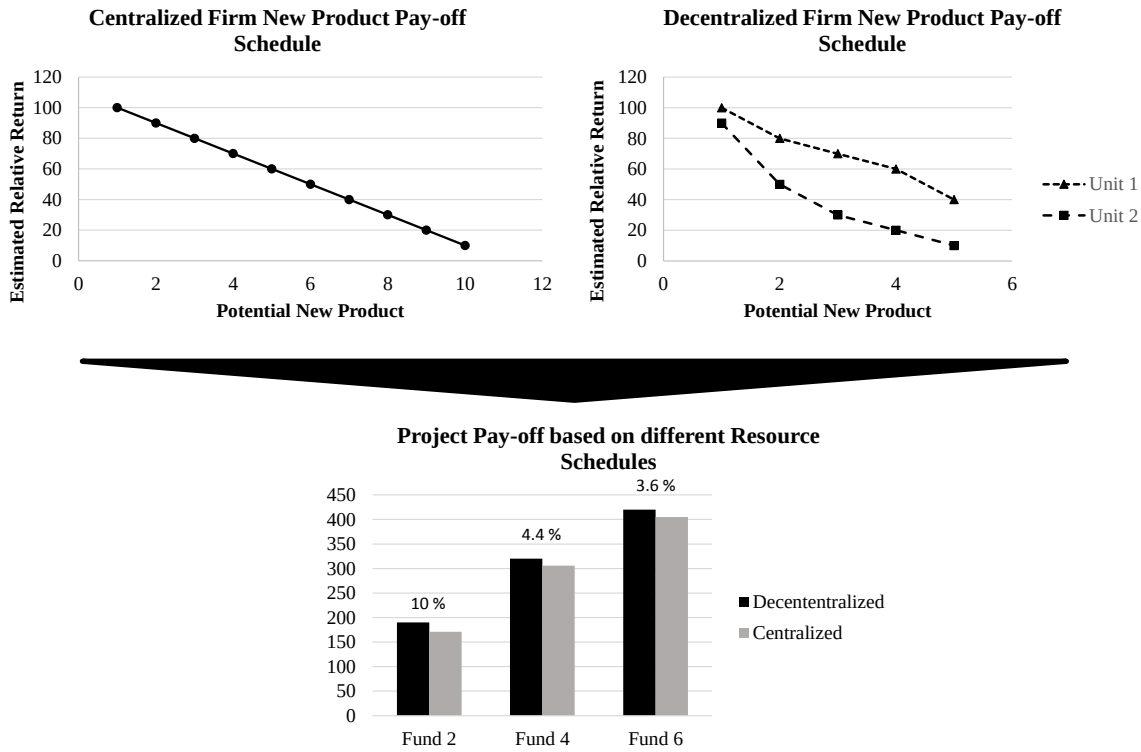
Consider two firms, one is centralized and the other is decentralized and has two business units. Across both firms they have the same set of ten new product opportunities with identical estimated pay-offs. However, in the decentralized firm, unit 1 has five of the better pay-off opportunities and unit 2 has five of the lower pay-off opportunities. These pay-off schedules are illustrated in the top of Figure 9. Most business units are likely to have one or two promising new product opportunities but there may be a much steeper decline in the quality of new product opportunities for decentralized business units as compared to centralized firms which have a much deeper set of potential new product opportunities due to pooling across the entire firm.

Managers in decentralized units should be able to exploit their new product opportunities more effectively than managers in centralized firms due to the greater effectiveness of incentives. This suggests that decentralized firms can capture a greater proportion of the pay-off associated with each new product opportunity than centralized firms. By combining these pay-off schedules in the top of Figure 9 and the fact that decentralized firms can capture a greater proportion of these pay-offs, the pay-offs associated with different levels of funding can be estimated. For illustrative purposes, it is

assumed that centralized firms are able to capture 90 % of the pay-offs that decentralized firms are able to.

In this example, based on the quantity of complementary resources, firms can fund two, four or six new products. In the decentralized firm case, the best one, two or three projects in terms of pay-offs are supported in each business unit. In the centralized case, the best two, four and six products for the firm as a whole are supported. The allocation of complementary resources to more promising new products in centralized firms will start to overcome the impact of reduced incentives as the quantity of complementary resources increases and more new products are funded. This results in more centralized firms increasing their pay-offs of new products relative to the pay-offs of more decentralized firms as the level of complementary resources increases. This can be seen in the bottom of Figure 9 with the percentages representing the differences in pay-offs between the firms.

Figure 9: Illustrative example of centralized and decentralized firms new product pay-off schedules and pay-offs based on different resourcing levels



New products are more dependent on the quantity of complementary resources as they are not already established in the market place. Thus, the proportion of sales from new products for more centralized firms will increase relative to the proportion of sales from new products for more decentralized firms as the quantity of supporting resources increases. Thus, this line of argumentation suggests that:

> *H1: The quantity of complementary resources negatively moderates the relationship between corporate decentralization and the proportion of sales from new products such that firms with higher quantities of complementary resources will be associated with an increased proportion of sales from new products for more centralized firms compared to more decentralized firms.*

Moderating impact of concentration of sales of existing product base

So far I have been largely silent with respect to firms' portfolios of existing products. I will now specifically focus upon the concentration of sales of a firm's existing product portfolio. Namely, is a firm dependent on the sale of a few high ticket items or does it have its sales more equally dispersed across a wide variety of products? I examine this parameter as it is likely to influence both the allocation of resources to new products as well as managerial incentives which in turn will influence the balance of the benefits and costs associated with more or less decentralization.

For more decentralized firms that have a higher concentration of sales from their highest selling products, those business units with the highest selling products will tend to yield greater influence (e.g., Watson & Wooldridge, 2005). This will result in a greater proportion of complementary resources shifting to units that have the more prominent products which will limit access to complementary resources by other units with new products. Further, within a specific business unit with a smaller portfolio of products for which there are a small number of existing products driving sales, managers will tend to allocate more supporting resources to those prominent existing products to limit the risk of diminishing sales at the business unit level. This will again potentially limit access to suitable quantities of complementary resources for the units' new products.

Although centralized firms may be reliant on the sales of a few products, managing

a single portfolio of new and existing products means that managers have more scope to divert resources to new products even if the firm is reliant on the sale of a small number of existing products. This is because of the risk mitigation effect of pooling all products into one portfolio such that if sales of an existing product are impacted by reduced resourcing, other products are there to make up for this shortfall.

Thus, as the concentration of firms' portfolios of existing products increases, new offers in decentralized firms are likely to receive increasingly lower levels of supporting resources compared to the equivalent new products in centralized firms. This is because managers in decentralized units will tend to focus complementary resources on existing rather than new products as they are less able to afford failures from more uncertain new product offerings. Thus, although managers in decentralized units may face higher powered incentives thereby engendering more effort, they may be also incentivized to allocate fewer complementary resources to these new products thereby limiting the impact of these additional efforts. Ultimately, as a result of the decreasing level of complementary resources allocated to new products for more decentralized firms as compared to more centralized firms, I argue that the proportion of sales of new products will decrease for more decentralized firms as compared to more centralized firms. Thus I hypothesize:

> *H2: The concentration of sales of a firm's existing product portfolio negatively moderates the relationship between corporate decentralization and the proportion of sales from new products such that firms whose sales are more concentrated on a few products will be associated with an increased proportion of sales from new products for more centralized firms compared to more decentralized firms.*

Methods

Research Context

The context for this study is the pharmaceutical industry over the 20-year period 1995 to 2015. This industry has a well-established product development process consisting of a sequence of *in-vitro* discovery activities and *in-vitro* as well as *in-vivo* development tasks that involve multiple phases of clinical trials (e.g., Kapoor & Klueter, 2015; Petrova, 2014). During the development process drug-candidates are both tested for safety and

efficacy and further developed through, for example, evaluation of their mechanisms of action and optimizing their delivery to target areas of patients' bodies. Drug-candidates are largely patented (e.g., Dushnitsky & Shaver, 2009; Gunther McGrath & Nerkar, 2004) and represent a potential new offering. In this study new drugs launched into the market place following approval by the FDA (Food and Drug Administration) represent the new products created by firms.

This context provides a rich domain for testing the hypotheses described above for three key reasons. First, the conversion of drug-candidates into final marketed products forms the lifeblood of large global pharmaceutical companies ensuring that senior managers pay close attention to their innovation pipelines. This focus on new product development is illustrated by the large proportion of revenues that are dedicated to funding research and development compared to other industries (Strategy &, 2016). Second, firms vary in their organization design driven by factors such as geographical location, history of mergers, acquisitions and divestments as well as managerial changes (e.g., Pisano, 2006). These variations in design within firms and over time facilitate an evaluation of how such design elements are associated with the ability of firms to refresh their product portfolios. Third, with only a limited period of exclusivity afforded by patent protection, these firms are looking to capture as much value from their inventions as possible in the limited period of time they have before competitors can replicate their technology in the form of generic products. Thus, effective commercialization of inventions is critical for firms' on-going viability as the large investment made in R&D needs to be recovered as well as generating a return for shareholders.

Data and Sample

The sample consists of 48 leading pharmaceutical firms over the period 1995 to 2015. The sample is developed using 2004-6 annual prescription drug sales as defined by the Pharmaceutical Executive magazine's Top 50 Pharmaceutical companies (e.g., Klueter et al., 2017). Over this period, 64 firms appear in the Top 50 list. The 16 excluded firms are either private firms or do not provide sufficient information on key variables in their

public filings. These excluded firms are in the lower half (26-50 ranking in terms of pharmaceutical sales) in one or more of the three years in the 2004-6 period. Using the mid-point of the sample enables the examination of firms that have at least 10 years of history within the sample time-frame prior to any significant M&A event. 33 out of the 48 sample firms are still in the top 50 pharmaceutical firms in 2015, 12 firms had been acquired by other firms in the sample and 3 firms had divested their pharmaceutical businesses. Upon acquisition or divestment of their pharmaceutical business these 15 firms dropped out of the sample.

The primary dataset consists of an unbalanced panel of 396 firm-year observations with an average of 8 observations per firm ranging from 1 to 18 observations over the 20 year period. This heterogeneity in coverage is driven by the dependent variable (proportion of sales from products launched in the focal year) which is sourced from the Evaluate Pharma database. Data on firms' portfolio of inventions under development is sourced from the Pharmaprojects clinical trial database (e.g., Chandy et al., 2006; Kapoor & Klueter, 2015). This data is supplemented with patent data from the European Patent Office Patstat database (e.g., Conti et al., 2013), company annual reports/financial filings and financial data from Compustat. I supplement this archival, quantitative data with 61 interviews with managers from 28 of the sample firms. This enables me to validate my organization design measures. See Appendix 3 for further details on interviews.

Measures

Dependent Variable: The dependent variable pertaining to each of the two hypotheses is measured using the proportion of sales from new products launched in the current year *(1-yr New Sales Proportion)*. Various scholars have highlighted that the initial sales level is indicative of the success of firms' commercialization of their inventions as value needs to be captured rapidly in order to recoup sunk investments in, for example, R&D (Gatignon, Weitz, & Bansal, 1990; Nerkar & Roberts, 2004). This data is obtained from the EvaluatePharma database. Due to the difficulty in collecting such specific information on firms' portfolio of new products the coverage is better for larger US firms

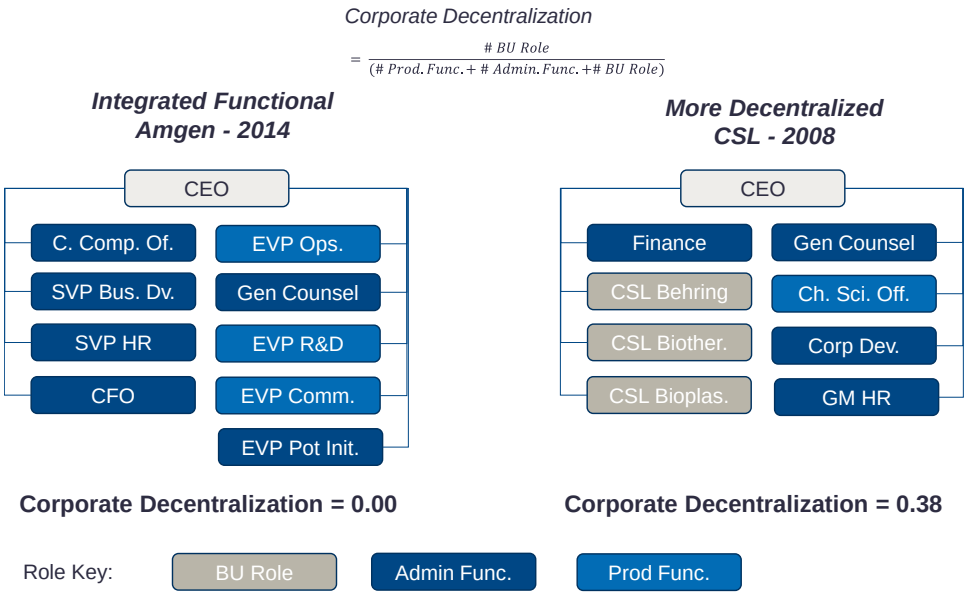
over more recent years in my sample and more sporadic for smaller and non-US firms as well as earlier years in the sample. Comparing the mean values for key co-variates between the sample of 396 firm-years and the overall number of firm year for which other co-variate data is available (n = 803) indicates that the sample firm years are larger in terms of the firm size variables, such as annual revenues, SGA, patent stock, development portfolio size, number of drugs progressing through development portfolio, the number of new drug applications and diversity of portfolio. However, the samples are not statistically different in terms of key design variables (e.g. *corporate decentralization*), performance, R&D intensity, slack or number of reporting segments. This is consistent with the fact that EvaluatePharma has poorer coverage of annual drug sales for smaller firms. Thus, in interpreting the results presented below with respect to external validity it is important to recognize that the findings pertain to larger pharmaceutical firms.

Independent Variables: To test the hypotheses, three key independent variables are used. First, in order to develop a measure of the degree of *corporate decentralization* top management team data available from company 10-K/20-F/DEF 14A SEC filings and Annual Reports is utilized. The use of top management team data to develop high-level organizational structural measures is well-established in the strategic management literature (e.g., Albert, 2018; Girod & Whittington, 2015; Guadalupe et al., 2014). A database of 15,129 executive and extended executive team roles for the sample of firms over the period 1995-2015 is developed using these sources. This results in a total of 898 firm-years of data and an average of 16.8 executive and extended executive roles per firm-year (standard deviation = 11.1).

Coding of roles and various facets of organizational decentralization and differentiation are undertaken through careful review of the management roles in each organization and further validated through review of organizational descriptions from companies' various filings (e.g. as described in the CEO's letter to shareholders). For those firms where top management team (TMT) roles come from multiple sources (e.g. 10-K and Annual report) all roles are captured and then allocated to the executive team or extended

team based on designations provided in either document. For 28 out of the 48 firms, interviews with strategy and R&D managers were conducted to confirm whether the measures provided an accurate reflection of their firms' structures. Due to the limitations of access to detailed structural data, the focus is on higher level measures of decentralization. The managers within the sample firms interviewed confirmed that the structure of the top management team (TMT) provides an accurate reflection of their firms' structures. See Appendix 2 for further details and Figure 10 for an example.

Figure 10: Illustration of *Corporate Decentralization* measure



In order to develop a measure of *Corporate Decentralization*, TMT members are categorized as general managers, functional administrative managers or product administrative managers using the approach developed by Guadalupe et al. (2014). The independent variable *Corporate Decentralization* is therefore determined as a proportion, namely the number of general manager (or business unit) roles in a top management team divided by the total size of the TMT excluding the CEO (Albert, 2018). These roles relate to managers who are responsible for the performance of a defined sub-section of the business which may be a geographical area or a specific product area and have defined profit & loss responsibilities. To account for firms operating in non-pharmaceutical

domains such as bulk chemicals, business unit leads in these areas are excluded. The higher the value of this variable, the more decentralized a firm is. If there are no business unit roles the firm is defined as having a value equal to zero. Figure 10 illustrates how this approach is used to measure *Corporate Decentralization* for two different firms in the sample. This variable is lagged one year relative to the dependent variable as prior decisions shaped by firms' design choices will often take time to shape external market outcomes.

In order to measure firms' level of spend on complementary resources, the natural log of firms' selling, general and administrative expenses is utilized to create the variable *SG&A* (e.g., Shin, Kraemer, & Dedrick, 2009). These expenses represent both the direct and indirect costs associated with the sale of firms' existing and new products (Lévesque, Joglekar, & Davies, 2012). This variable is lagged one year relative to the dependent variable to reflect that investments in supporting resources precede value capture from firms' new products. In using *SG&A* to estimate the quantity of complementary resources for the sale of firms' portfolio of products, the pharmaceutical industry provides a good context as marketing and sales of products represent more than 80 % of *SG&A* (IHSP, 2016). Note that in the theoretical development I do not distinguish between resources for sale of new and existing products as I argue that an increased level of overall supporting resources will disproportionately impact the sale of new products over existing products.

The concentration of sales of firms' existing products is based on the percentage of sales from the top 5 products (*Top 5 Products*). This measure is obtained from the Evaluate Pharma database. As a robustness check, I conduct the same analyses using the percentage of sales from the top product and top 3 products.

Control Variables: Six sets of control variables are used in the regression analyses. First, additional structural design controls are used at the firm-year level such as whether or not R&D is centralized. Second, a variety of firm-specific controls such as R&D intensity and the stock of patents are utilized. Third, the degree of market competition firms' face in their respective therapeutic areas of focus is also controlled for. Fourth,

controls are used pertaining to the degree of diversification of the firm such as the operating segments in which it operates. Fifth, the number of successful new drug applications prior to the focal year is included as more successful applications will be associated with a higher proportion of sales from new products as opposed to existing products. Finally, a series of controls are used relating to the properties of firms' drug-candidate pipelines under development. These control variables are summarized in Table 21.

Table 21: Summary of control variables used in this study

Variable	Description	Rationale
1. Organizational Design controls (lagged one year)		
R&D Decentralization	This variable represents whether firms' R&D is centralized into a single unit or decentralized into multiple units covering different domains such as product, scientific area etc. This is developed using companies' TMT composition and set to 0 if R&D is centralized under a single Head or 1 if it is decentralized into separate R&D units addressing different technical or product domains. It is akin to horizontal integration of R&D.	Firms with centralized R&D units may develop different inventions to those with decentralized R&D. Further firms that differ in the degree of centralization of R&D may also differ on their dependency on external inventions.
R&D Functional Differentiation	This variable represents whether firms' research and development units are integrated across both functions -research and development or are separated into individual research and development units. This is developed using companies' TMT composition and set to 0 if R&D is functionally integrated under a single Head or 1 if R&D is functionally disintegrated into separate research and development units with separate heads in the top management team. It is akin to vertical integration of R&D.	Firms with separate research and development units may differ in the speed of development of new inventions and the quality of inventions progressed thereby potentially influencing subsequent value capture.
2. Firm-level controls (lagged one year)		
Performance	The annual return on assets of the firm (Richard et al., 2009)	Higher performing firms may potentially develop a higher volume of higher quality new products
R&D Intensity	The annual spend on R&D by a firm as a proportion of annual revenues	Firms that spend a higher proportion of their sales on R&D may potentially see higher inventive and innovative output (e.g., Mairesse & Mohnen, 2005).
Sales	Natural log of Annual Rx and OTC drug sales in focal year (not lagged)	Controls for annual sales of drugs as firms that have higher sales may find it more challenging to sell a higher proportion of new products. Also controls for the size of the firm.
CEO	A dummy variable set to 1 if a new CEO was appointed in a specific firm-year	May be the catalyst for a reorganization or uptick in performance through, for example, increased sales of new products.
Patent Stock	Discounted total quantity of patent families granted by focal firm (Arora et al., 2014). A 15 % discount	Controls for firms' existing knowledge collected over a period of time which will

Variable	Description	Rationale
	rate is used. Similar "stock" measures of a firm's experience in a specific knowledge domain have been used in prior studies (e.g., Henderson & Cockburn, 1994; Hoang & Rothaermel, 2010). Measured in 000s.	impact whether firms decide to make or buy a specific invention. Also helps to control for firms' internal inventive capability.
3. Number of new products approved (lagged one year)		
New Approved	Number of new molecular entities (NME) approved by focal firm in year prior to dependent variable (percentage of sales from products launched in year).	More NMEs approved will result in a higher proportion of revenues from new products.
4. Competition controls (lagged one year)		
Competition	Measure of competition firms face across their development portfolios. Sum of market shares (by drug-candidate count) of drug-candidates within all development phases per therapeutic class squared weighted by contribution to portfolio (i.e. proportion of firms' portfolio a therapeutic class represents across all phases) subtracted from 1. Higher value signifies firms operate in more competitive therapeutic classes	Controls for the degree of competition firms face across their portfolio of drug-candidates. Firms in more competitive markets may find it more challenging to sell their new products.
5. Diversification Controls		
Technical Diversification	Measure of technological diversity of firms' R&D efforts. This is estimated using the sum of the squared proportions of drug candidates in each therapeutic class in a firm's development portfolio within a focal year and subtracted from 1. The larger the value the more diversified a firm's portfolio is across therapeutic classes in a specific year.	Controls for the level of technological diversity of a firm's portfolio. Firms undertaking a broader array of technological activities may develop more novel inventions which may result in increased new product sales.
Category Dummy Fixed Effects	Series of dummy variables representing whether a firm has operating segments in categories beyond pharmaceuticals. Specifically: consumer goods, medical devices, animal medication, bulk chemicals, nutrition. Also have dummy if firm has a generics business. These can vary by firm-year as firm acquires or divests specific businesses.	Control for diversification of firms' businesses beyond pharmaceuticals. For example, firms in a more diverse array of businesses may focus less effort on the sales of new products in the core pharmaceutical business.
6. Development Portfolio level controls (lagged one year)		
Portfolio	Total number of development projects firm has from pre-clinical to phase 3. Numbers in 100s	Controls for the size of the existing portfolio and the number of future new product opportunities firms' have. Larger development portfolios may be associated with reduced investment in current suite of new products.
Progress	Count of drug candidates that progressed to next stage of clinical trials in a focal year.	Provides an indication of the flow of inventions through firms' pipelines. The more candidates flowing through a firm's pipeline the more potential future opportunities potentially reducing investment in current products.
External	Proportion of externally-sourced drugs in portfolio across development portfolio	Externally-sourced drug-candidates may be more difficult to commercialize due to issues such as not invented here syndrome (Katz & Allen, 1982).
NCE	Proportion of portfolio at specific stage of clinical development that are new chemical entities (NCE)	Indication of degree of novelty of portfolio. NCEs include no component that has been previously approved by the FDA. NCE designation from the US Food and Drug Administration (FDA)

Variable	Description	Rationale
		provides firms with five years of marketing exclusivity.[23]
Bio	Proportion of firms' portfolio that are biotechnology candidates.	Firms focusing on biotechnology products may allocate more resources to R&D as opposed to current products.
Portfolio Novelty	The average novelty of a firm's portfolio of drug candidates under development in a specific year based on a 0 to 2 scale based on whether, in a specific therapeutic class, the mechanism of action and source of material are new to the focal firm.	Firms with more novel portfolios of products may dedicate more investment to R&D rather than capturing value from newly launched products.
7. Other Controls		
Year fixed effects	Series of dummies for each year in sample	
Firm fixed effects	Series of dummies for each firm in sample	

Methodology

As the dependent variable is a proportion and bounded between 0 and 1, the fractional logit analytical approach is used to test both hypotheses (Papke & Wooldridge, 1996; Papke & Wooldridge, 2008). The majority of co-variates are lagged one-year with respect to the dependent variable. To control for unobserved heterogeneity a variety of fixed effects are used such as business category, therapeutic category year, and firm-fixed effects.

To further control for omitted variable bias, propensity score matching models (PSM) are used (e.g., Caliendo & Kopeinig, 2008). In order to undertake this matching analysis the variable *Corporate Decentralization* is dichotomized around the median, with the value being set to 0 for highly centralized firms and 1 for decentralized firms. All covariates in Table 21 are used to match firms that are more or less decentralized. A variety of cut-points for *Corporate Decentralization* are used in creating the dichotomous variable and similar results are obtained. Appendix 5 provides further details on the propensity score matching process that I utilize in this dissertation chapter and includes details of the first stage regression model used in the matching process.

[23] https://www.fda.gov/downloads/drugs/guidancecomplianceregulatoryinformation/guidances/ucm386685.pdf

Regression analyses are then conducted using matched observations. Standard errors are clustered at the firm-level (Petersen, 2009). This helps to reduce the possibility that the results are driven by the inherent differences between less and more decentralized firms as regular regressions are estimated only on observably equivalent groups.

Results

Descriptive statistics

Table 22 illustrates the key summary statistics for the sample used in this study. On average 2.2 % of revenues come from new products launched in the past year. As illustrated in Figure 11 there has been a decline in the proportion of revenues generated by new products over the period 1995 to 2015. This is consistent with previous work indicating declining productivity in pharmaceutical R&D (e.g., Scannell, Blanckley, Boldon, & Warrington, 2012).

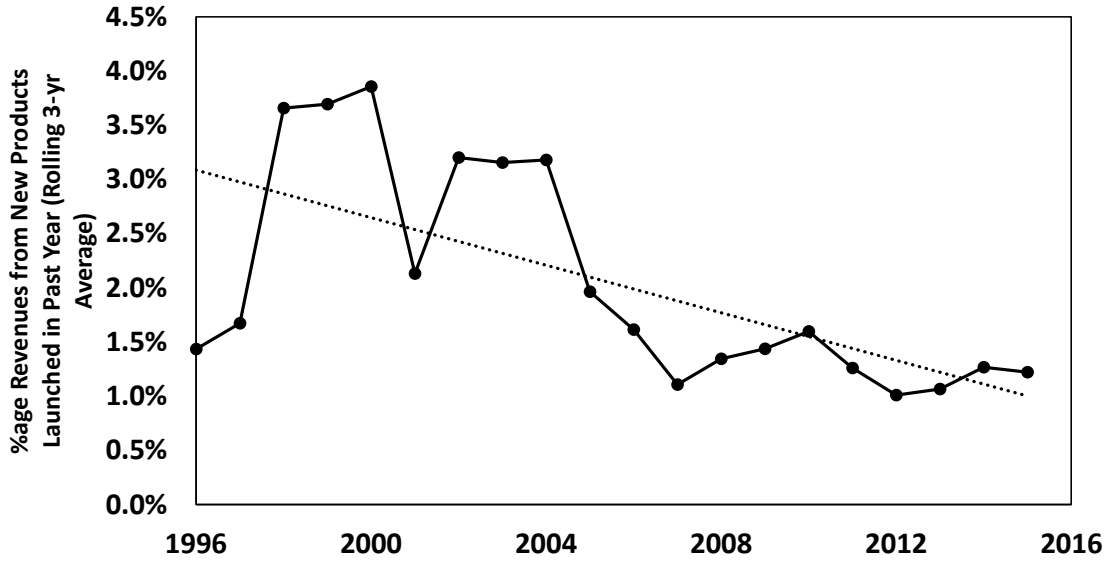
Across the sample of firm-years 28 % of top management team roles (excluding CEO) within the pharmaceutical business of each firm are business unit roles. *1-yr New Sales Proportion* is strongly correlated (>0.4) with R&D intensity and negatively correlated with annual drug sales. These results are not entirely surprising as greater R&D investment is likely to lead in the creation of more new products and firms that have greater sales of drugs will find it more challenging to have a higher proportion of sales of new products as the sales threshold for new products increases.

Further details on the variation of *Corporate Decentralization* over time are also provided in Appendix 4, alongside details on how the other (control) structural variables change over time.

Table 22: Descriptive statistics for variables used in this study (n = 396 firm-years)

Variable	Mean	SD	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1. 1-yr New Sales Proportion	0.022	0.061	1.00																			
2. Corporate Decentralization	0.283	0.239	-0.07	1.00																		
3. SG&A	8.177	1.338	-0.32	0.08	1.00																	
4. Top 5 products	0.529	0.221	0.06	-0.26	-0.17	1.00																
5. R&D Decentralization	0.134	0.341	0.16	0.06	0.10	-0.06	1.00															
6. R&D Functional Differentiation	0.205	0.404	-0.08	-0.14	-0.01	0.06	-0.10	1.00														
7. Performance	0.086	0.086	-0.28	-0.01	0.22	0.11	0.02	0.04	1.00													
8. R&D Intensity	0.169	0.169	0.49	-0.12	-0.08	0.33	0.05	0.03	-0.53	1.00												
9. Sales	8.754	1.405	-0.49	0.13	0.92	-0.25	0.05	-0.00	0.34	-0.28	1.00											
10. CEO	0.106	0.308	-0.02	-0.02	0.06	-0.08	0.05	0.02	-0.06	-0.03	0.07	1.00										
11. Patent Stock	1.458	1.429	-0.20	0.09	0.76	-0.29	0.08	-0.01	0.14	-0.06	0.72	0.05	1.00									
12. New Approved	1.611	1.860	-0.08	0.12	0.45	-0.14	0.08	-0.04	0.19	-0.01	0.45	0.01	0.44	1.00								
13. Competition	0.954	0.030	0.18	-0.11	-0.65	0.19	-0.11	0.05	-0.17	0.02	-0.61	-0.02	-0.67	-0.51	1.00							
14. Technical Diversification	0.783	0.155	-0.23	0.18	0.45	-0.07	0.06	0.09	0.03	0.06	0.40	0.01	0.38	0.31	-0.41	1.00						
15. Portfolio	0.807	0.684	-0.20	0.16	0.75	-0.25	0.13	-0.02	0.19	-0.04	0.72	0.07	0.77	0.59	-0.83	0.46	1.00					
16. Progress	11.513	10.811	-0.19	0.17	0.67	-0.20	0.05	-0.04	0.19	-0.03	0.64	0.07	0.70	0.52	-0.69	0.42	0.88	1.00				
17. External	0.514	0.192	0.10	-0.03	-0.28	0.06	0.02	-0.11	-0.05	-0.07	-0.22	-0.06	-0.28	-0.24	0.30	-0.30	-0.32	-0.26	1.00			
18. NCE	0.540	0.192	-0.19	0.05	0.20	0.05	0.02	0.12	0.04	0.07	0.17	0.03	0.20	0.18	-0.22	0.55	0.27	0.25	-0.27	1.00		
19. Bio	0.227	0.162	-0.05	-0.04	0.13	0.09	-0.07	0.01	0.00	-0.06	0.17	0.01	-0.01	-0.06	0.08	-0.26	-0.04	-0.07	0.15	-0.60	1.00	
20. Portfolio Novelty	0.978	0.240	0.19	-0.09	-0.74	0.06	-0.10	-0.04	-0.09	-0.02	-0.69	-0.04	-0.63	-0.41	0.63	-0.50	-0.66	-0.57	0.34	-0.23	-0.06	1.00

Figure 11: Variation in proportion of revenues generated from new products launched in the past year



Main analysis

Table 23 and Table 24 illustrate the results of the key analyses used to test Hypotheses 1 and 2. Models 1-5 (Table 23) are for unmatched firm-year observations with respect to corporate decentralization and Models 6-10 (Table 24) illustrate the same analyses using propensity score matched samples (the co-variate balance table is illustrated in Table 25). I also tested for multicollinearity between variables. Variance inflation factors (VIFs) for each of the key variables were below 6.3, with the overall VIF of 2.7, which is substantially below the guideline threshold of 10 (Hair, Anderson, Tatham, & Black, 1998). Across the majority of models, as would be expected a higher number of newly approved drug candidates in the prior year is associated with a higher proportion of revenues from new products in the following year as illustrated by the statistically significant positive coefficient for *New Approved*.

Interestingly in all models (1 – 10) the coefficient for *Corporate Decentralization* is positive and statistically significant (at the 95 % confidence level or above). It appears that firms which are more decentralized tend to be associated with a higher proportion of

revenues from new products. A one standard deviation increase (0.28) in corporate decentralization (using Model 5) is associated with a 0.7 percentage point higher proportion of sales from new products launched in the current year (note sample mean is 2.2 %). As highlighted in the theory section of this paper, due to arguments in both directions the relationship between *Corporate Decentralization* and the proportion of sales of new products is an empirical question. It appears that, on average, greater corporate decentralization is associated with more effective commercialization of products' inventions suggesting that the greater effectiveness of higher powered incentives and greater local market knowledge overcome less effective resource allocation and decreased functional expertise.

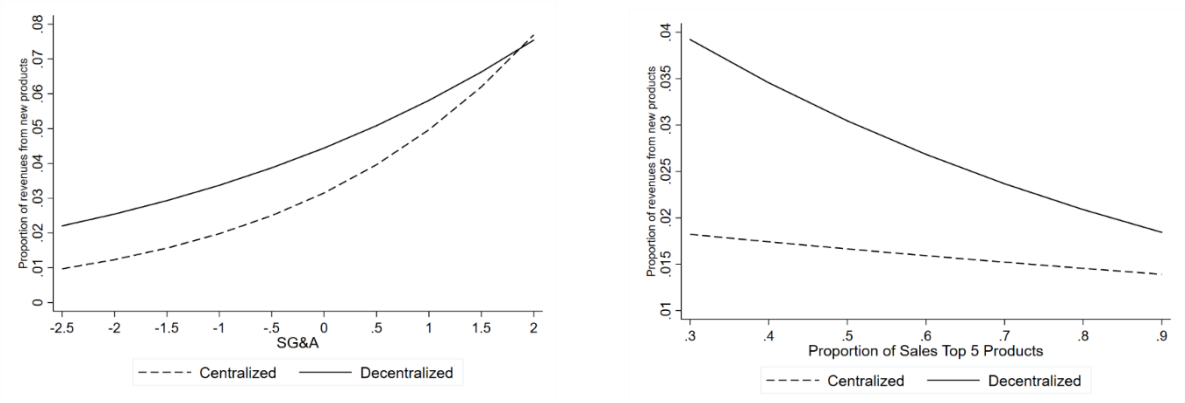
Hypothesis 1 is supported in models 3 and 5 (non-matched sample) as well as 8 and 10 (matched sample) through the statistically significant (at the 90 % confidence level or above) negative interaction term between *SG&A* and *Corporate Decentralization*. Thus, the difference between more centralized and less decentralized firms in terms of the proportion of sales that they are able to capture from their recently launched products declines at higher levels of *SG&A*. In terms of the magnitude of the impact, for firms at the 10^{th} percentile of *SG&A* a one standard deviation increase in *Corporate Decentralization* is associated with a 0.7 % point higher proportion of sales from new products. However, at the 90^{th} percentile of *SG&A* a one standard deviation increase in *Corporate Decentralization* has no statistically significant association with the proportion of sales from new products. Namely, at higher levels of *SG&A* the proportion of sales from new products for more centralized firms increases relative to that for more decentralized firms consistent with Hypothesis 1. Figure 12a graphically illustrates the interaction between *Corporate Decentralization* and *SG&A*.

Hypothesis 2 is supported in models 4 and 5 (non-matched sample) as well as 9 and 10 (matched sample) through the statistically significant (at the 90 % confidence level or above) negative interaction term between *Corporate Decentralization* and *Top 5 Products*. Thus, the difference between more centralized and less decentralized firms in terms of the proportion of sales that they are able to capture from their recently launched products declines at higher product concentration levels. In terms of the magnitude of the

impact, for firms at the 10th percentile of *Top 5 Products* a one standard deviation increase in *Corporate Decentralization* is associated with a 1.1 % point higher proportion of sales from new products. However, at the 90th percentile of *Top 5 Products* a one standard deviation increase in *Corporate Decentralization* has no statistically significant association with the proportion of sales from new products. Namely, at higher levels of *Top 5 Products* the proportion of sales from new products for more centralized firms increases relative to that for more decentralized firms consistent with Hypothesis 2. Figure 12b graphically illustrates the interaction between *Corporate Decentralization* and *Top 5 Products*.

Figure 12: Chart illustrating the interaction between *Corporate Decentralization* and (a) *SG&A* (mean centered) (b) *Top 5 Products*. Corporate decentralization is set to 25th percentile for *Centralized* and 75th percentile for *Decentralized.*

(a) **(b)**



Similar results are obtained for the propensity score matching models using different values of *Corporate Decentralization* to dichotomize this variable (0.08 – 0.40) as well as different caliper matching radii. This provides some additional confidence in the validity of the results presented in this section.

Table 23: Main analysis. Fractional logit unmatched models

DV= 1-yr New Sales Proportion	Model 1	Model 2	Model 3	Model 4	Model 5
Corporate Decentralization		**1.398****	**0.981****	**2.468****	**2.099****
		(0.325)	**(0.363)**	**(0.618)**	**(0.659)**
H1: Corporate Decentralization x SG&A			**-0.497***		**-0.507***
			(0.238)		**(0.242)**
H2: Corporate Decentralization x Top 5 Products				**-2.044***	**-2.149**$^{+}$
				(1.035)	**(1.119)**
SG&A	0.425^{+}	0.451*	0.452*	0.495*	0.498*
	(0.242)	(0.225)	(0.207)	(0.223)	(0.206)
Top 5 Products	-1.078	-1.550*	-1.314^{+}	-1.467*	-1.215^{+}
	(0.781)	(0.712)	(0.708)	(0.695)	(0.699)
R&D Decentralization	-0.078	-0.047	-0.169	-0.038	-0.164
	(0.234)	(0.246)	(0.225)	(0.245)	(0.221)
R&D Functional Differentiation	0.423	0.550	0.584^{+}	0.571	0.608^{+}
	(0.347)	(0.342)	(0.347)	(0.348)	(0.353)
Performance	-0.328	-0.320	-0.221	-0.374	-0.265
	(0.976)	(1.012)	(0.945)	(0.990)	(0.932)
R&D Intensity	-0.470	-0.511	-0.421	-0.585	-0.488
	(0.651)	(0.649)	(0.655)	(0.629)	(0.636)
Sales	-0.77**	-0.76**	-0.76**	-0.75**	-0.75**
	(0.246)	(0.253)	(0.245)	(0.244)	(0.235)
CEO	0.177	0.287	0.290	0.290	0.293
	(0.244)	(0.226)	(0.214)	(0.215)	(0.202)
Patent Stock	-0.52**	-0.47**	-0.49**	-0.46*	-0.48**
	(0.188)	(0.176)	(0.183)	(0.177)	(0.182)
New Approved	0.130*	0.131*	0.136**	0.129*	0.134**
	(0.054)	(0.053)	(0.051)	(0.053)	(0.051)
Competition	0.0254	-1.073	-1.710	-0.595	-1.186
	(4.200)	(4.151)	(4.402)	(4.299)	(4.579)
Technical Diversification	0.0367	0.190	0.144	0.298	0.258
	(0.497)	(0.463)	(0.463)	(0.459)	(0.463)
Portfolio	-0.020	0.069	-0.035	0.135	0.0329
	(0.384)	(0.442)	(0.454)	(0.443)	(0.454)
Progress	0.038*	0.040*	0.040*	0.040*	0.041*
	(0.016)	(0.016)	(0.017)	(0.017)	(0.017)
External	0.092	-0.008	-0.126	-0.016	-0.130
	(0.674)	(0.622)	(0.566)	(0.626)	(0.572)
NCE	0.621	0.306	0.255	0.159	0.105
	(0.686)	(0.643)	(0.622)	(0.675)	(0.668)
Bio	-0.512	-0.501	-0.413	-0.632	-0.551
	(0.674)	(0.651)	(0.595)	(0.686)	(0.645)
Portfolio Novelty	1.326	1.671	1.853	1.649	1.831
	(1.241)	(1.244)	(1.217)	(1.223)	(1.189)
Year Fixed Effects	Y	Y	Y	Y	Y
Category Fixed Effects	Y	Y	Y	Y	Y
Firm Fixed Effects	Y	Y	Y	Y	Y
Matching	N	N	N	N	N
N	396	396	396	396	396
Log Likelihood	-32.38	-32.26	-32.23	-32.25	-32.22

Standard errors in parentheses:$^{+}$ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$; Errors clustered at firm level

Table 24: Main Analysis. Fractional logit propensity score matched (PSM) samples (caliper=0.00085). *Corporate Decentralization* is dichotomized around median for matching

DV= 1-yr New Sales Proportion	Model 6	Model 6	Model 8	Model 9	Model 10
Corporate Decentralization		**0.581***	**0.505***	**2.641****	**2.268***
		(0.284)	**(0.247)**	**(1.025)**	**(1.028)**
H1: Corporate Decentralization x SG&A			**-0.392+**		**-0.330+**
			(0.201)		**(0.198)**
H2: Corporate Decentralization x Top 5 Products				**-4.628***	**-3.925+**
				(2.186)	**(2.221)**
SG&A	0.997	0.364	0.334	1.175	0.987
	(0.694)	(0.805)	(0.806)	(0.904)	(0.892)
Top 5 Products	0.840	0.697	0.907	5.957	5.407
	(1.781)	(2.160)	(1.991)	(3.710)	(3.421)
R&D Decentralization	-2.25**	-2.03**	-2.00**	-1.74*	-1.76*
	(0.853)	(0.780)	(0.743)	(0.800)	(0.769)
R&D Functional Differentiation	0.419	0.357	0.700	1.227+	1.375*
	(0.608)	(0.605)	(0.607)	(0.700)	(0.634)
Performance	-4.22	-6.06*	-7.75**	-5.95*	-7.44**
	(3.325)	(2.498)	(2.223)	(2.338)	(2.235)
R&D Intensity	-7.84**	-8.75**	-9.77**	-7.81**	-8.78**
	(2.066)	(1.819)	(2.131)	(1.866)	(2.217)
Sales	-0.478	0.215	0.262	-0.575	-0.380
	(0.596)	(0.717)	(0.724)	(0.811)	(0.812)
CEO	0.255	0.463	0.239	0.205	0.0562
	(0.457)	(0.445)	(0.337)	(0.382)	(0.297)
Patent Stock	0.127	0.171	0.0646	0.204	0.124
	(0.322)	(0.346)	(0.341)	(0.356)	(0.344)
New Approved	0.223**	0.170**	0.133*	0.118+	0.0939
	(0.075)	(0.058)	(0.052)	(0.068)	(0.063)
Competition	-13.38	-16.25+	-15.40+	-21.64*	-20.17*
	(9.561)	(9.047)	(8.596)	(8.837)	(7.884)
Technical Diversification	0.127	-0.017	0.122	1.234	1.171
	(0.991)	(1.065)	(1.020)	(1.446)	(1.425)
Portfolio	1.720**	1.895**	1.651*	1.531**	1.385*
	(0.661)	(0.588)	(0.687)	(0.558)	(0.620)
Progress	-0.036	-0.033	-0.009	-0.012	0.005
	(0.037)	(0.031)	(0.035)	(0.030)	(0.030)
External	7.197**	7.174**	7.868**	7.522**	8.014**
	(1.793)	(1.702)	(2.292)	(1.589)	(2.093)
NCE	4.754	3.768	3.989+	5.833*	5.733*
	(2.951)	(2.716)	(2.360)	(2.686)	(2.662)
Bio	6.221*	5.156*	5.000*	6.508*	6.177*
	(2.561)	(2.485)	(2.328)	(2.614)	(2.631)
Portfolio Novelty	8.629**	10.52**	10.15**	9.746**	9.572**
	(1.944)	(1.994)	(1.950)	(2.039)	(2.022)
Year Fixed Effects	Y	Y	Y	Y	Y
Category Fixed Effects	Y	Y	Y	Y	Y
Firm Fixed Effects	Y	Y	Y	Y	Y
Matching	PSM	PSM	PSM	PSM	PSM
N	129	129	129	129	129
Log Likelihood	-10.00	-9.992	-9.982	-9.982	-9.975

Standard errors in parentheses:+ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$; Errors clustered at firm level

Table 25: H1-2 balance tests for propensity score matching model (Caliper=0.00085). The variable *Corporate Decentralization* is dichotomized around the mean value. Year grouping variable is used as another covariate with observation years being grouped into four 5-year periods.

Variable	Mean		p>|t|
	Corporate Decentralization ≥ Mean Value	Corporate Decentralization < Mean Value	
SG&A	8.39	8.25	0.543
Top 5 Products	0.47	0.46	0.55
R&D Decentralization	0.06	0.11	0.231
R&D Functional Differentiation	0.22	0.29	0.344
Performance	0.09	0.07	0.051
R&D Intensity	0.16	0.14	0.232
Sales	8.98	8.77	0.339
CEO	0.11	0.07	0.387
Patent Stock	1.67	1.71	0.871
New Approved	1.44	1.14	0.238
Competition	0.95	0.95	0.77
Technical Diversification	0.80	0.80	0.867
Portfolio	0.86	0.79	0.483
Progress	11.8	10.5	0.41
External	0.53	0.53	0.954
NCE	0.55	0.53	0.436
Bio	0.25	0.22	0.298
Portfolio Novelty	0.97	0.97	0.854
Year	2.67	2.65	0.938

Supplemental analyses

Three supplemental analyses are conducted (also see Appendix 6 and 7). Two of these supplemental analyses are focused on testing the robustness of the main results. The other analysis examines the mechanisms outlined in the theory section of this paper through evaluating how product functional units (Guadalupe et al., 2014) that have the impact of centralizing more decentralized firms influence my main results.

First, in the main analyses a lag of one year is used between the measure of *Corporate Decentralization* and *New Sales Proportion*. However, the degree of *Corporate Decentralization* both prior and concurrent with the first year of sales of a new product may be linked to the outcome of the proportion of sales from new products launched in the focal year. Namely, effort undertaken prior to the launch of the product and concurrently

with the first year of sales of the new product could drive the proportion of sales from new products. As a result, two and three year rolling averages of *Corporate Decentralization, SG&A* and *Top 5 Products* are developed based on the values of these variables in the same year as the first year of sales of new products and the prior one or two years. Models 11 and 12 use the 2-year and 3-year rolling averages for these variables (Table 26). It can be seen that all three hypotheses continue to be supported, though for the 2-year rolling averages Hypothesis 3 is only directionally supported (p=0.25). Thus it appears that my theoretical arguments also apply for firms' structures, levels of supporting resources and product concentrations averaged over multiple observation windows.

Table 26: Supplemental analyses. Models 11 and 12 examine 2- and 3-year rolling averages of *Corporate Decentralization, SG&A* and *Top 5 Products*. Models 13 and 14 focus on different measures for product portfolio concentration i.e. percentage of sales from Top 1 or 3 products.

DV= 1-yr New Sales Proportion	Model 11 2-year roll avg.	Model 12 3-yr roll avg.	Model 13 Top 1 Product	Model 14 Top 3 Products
Corporate Decentralization	7.736**	10.01**	1.579**	1.552**
	(2.598)	(3.343)	(0.477)	(0.591)
Corporate Decentralization x SG&A	-0.719**	-0.906**	-0.508*	-0.437*
	(0.274)	(0.326)	(0.246)	(0.220)
Corporate Decentralization	-2.138	-4.390+	-2.949+	-1.177
x Top 5 (Models 11/12), 3 (13) or 1 (14) Products	(1.862)	(2.618)	(1.750)	(1.200)
Controls (Table 21)	Y	Y	Y	Y
Year Fixed Effects	Y	Y	Y	Y
Category Fixed Effects	Y	Y	Y	Y
Firm Fixed Effects	Y	Y	Y	Y
N	386	367	396	396
Log Likelihood	-30.09	-27.23	-32.23	-32.20

Standard errors in parentheses: + $p < 0.1$, * $p < 0.05$, ** $p < 0.01$; Errors clustered at firm level

Second, I examine how the main results are dependent on the measure of concentration of firms' product portfolios beyond the percentage of sales associated with the top 5 products. I evaluate how the main results change with the proportion of sales from the top selling one and three products. These results are outlined in Models 13 and 14 (Table 26). The main results are broadly supported, however the coefficient for *Corporate Decentralization* x *Top 3 Products* is negative but not statistically significant. Thus, I

continue to broadly find support for my hypotheses.

Finally, as described by Guadalupe et al. (2014), top management team roles can fall into three categories, product functional (e.g. sales and marketing, R&D), administrative functional (e.g. finance, IT) and business unit roles. While the measure used to capture decentralization examines the proportion of business unit roles it assumes product and administrative functional roles play a similar role (e.g., Albert, 2018). However, product functional units can have the impact of more strongly centralizing certain elements of business units' activities associated with the commercialization of their new products. For example, firms may have a corporate sales and marketing group that support the activities of business units. However, this takes away some of the discretion that business units have in undertaking their commercialization strategies. As a result of this reduced business unit discretion, the impact of corporate decentralization on the proportion of sales from new products launched in the focal year is likely to decrease. Thus, based on the empirical observation above the negative relationship between *Corporate Decentralization* and the proportion of sales of new products should become weaker with a higher number of product functional roles/units.

In order to evaluate the impact of an increased proportion of product functional units, I examine Model 2 in Table 23 for the bottom 20 % of firm-years with respect to the proportion of functional roles with the remaining sample (other 80 % of observations) as illustrated in Models 15 and 16 in Table 27. The coefficient for *R&D Decentralization* is higher in the low product administrative role sample than in the remaining sub-sample. Comparing the coefficients for *Corporate Decentralization* across Models 15 and 16 using a Wald test, the coefficient for *Corporate Decentralization* in Model 15 is significantly greater than that in Model 16 at the 90 % confidence level consistent with the line of argumentation above. Namely, it appears that for a lower proportion of product functional roles/units that business units have greater discretion as to the actions that they can take to commercialize their inventions and as a result we see a stronger impact of decentralization on the proportion of sales from new products. Effectively, a higher proportion of more product functional roles reduces the differences between firms that are more or less decentralized.

Table 27: Supplemental analyses. Models 15 and 16 represent sub-samples of firm-years. The analysis compares those observations with the lowest proportion of product functional roles (top 20 %) with the remainder of the sample.

DV= 1-yr New Sales Proportion	Model 15 Bottom 20 %	Model 16 Remainder
Corporate Decentralization	**0.0432**** **(0.00481)**	**0.0228**$^{+}$ **(0.0123)**
SG&A	0.0805** (0.00524)	0.0487** (0.0160)
Top 5 Products	-0.265** (0.0172)	-0.0443 (0.0271)
R&D Decentralization	0.0139* (0.00604)	0.00902 (0.00834)
R&D Functional Differentiation	-0.0391** (0.00535)	0.00422 (0.00933)
Performance	0.226** (0.0362)	0.0935^{+} (0.0472)
R&D Intensity	0.216** (0.0483)	0.103* (0.0458)
Sales	-0.0168 (0.00999)	-0.0577** (0.0167)
CEO	0.0168** (0.00567)	0.00363 (0.00524)
Patent Stock	0.00415 (0.00393)	-0.00279 (0.00665)
New Approved	0.00102 (0.00134)	0.00177 (0.00148)
Competition	1.890** (0.275)	0.0855 (0.139)
Technical Diversification	-0.00367 (0.0171)	0.0160 (0.0221)
Portfolio	0.0816** (0.00987)	0.00882 (0.00793)
Progress	0.000140 (0.000322)	0.000268 (0.000336)
External	-0.112** (0.0107)	-0.0417 (0.0333)
NCE	-0.148** (0.0332)	-0.0159 (0.0298)
Bio	-0.368** (0.0770)	-0.0310 (0.0336)
Portfolio Novelty	-0.0141 (0.0150)	0.0707 (0.0451)
Year Fixed Effects	Y	Y
Category Fixed Effects	Y	Y
Firm Fixed Effects	Y	Y
N	79	317
R^2	0.992	0.594

Standard errors in parentheses: $^{+}$ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$; Errors clustered at firm level.
OLS fixed-effects regression

Discussion and Conclusion

Scholars have illustrated how firms' organization designs can influence their innovation outcomes (e.g., Argyres & Silverman, 2004; Arora et al., 2014; Tushman et al., 2010). However, these prior studies have tended to examine innovation as an outcome rather than a process not highlighting the differences in activities associated with the various stages of the innovation process (e.g., Keum & See, 2017). With respect to the latter stages of the innovation process, scholars have highlighted the benefits of stand-alone units for nurturing new inventions (e.g., Christensen & Bower, 1996; Tushman et al., 2010). However, these studies have focused on inventions that represent a significant departure from firms' existing businesses. In contrast firms often manage a pipeline of inventions that enables them to deliver a steady stream of new products to market (e.g., Klingebiel & Rammer, 2014).

In this study, I argue that firms face a challenging balancing act with respect to the relationship between their organization design and their innovation outcomes. On the one hand, greater decentralization (more divisonalized as opposed to functionally aligned) is associated with the more effective use of incentives and greater local market knowledge but comes at the cost of the less effective allocation of complementary resources and reduced functional expertise. Empirically, I find that firms that are more decentralized are associated with the sale of a higher proportion of new products launched in the current year. I theoretically argue that this primary relationship between decentralization and the proportion of sales from new products is moderated by two factors that can influence the allocation of complementary resources (SG&A) that facilitates the sales of new and existing products as well as managerial incentives.

First, SG&A moderates the primary relationship because as the level of supporting resources increases, business units increasingly compete for more available resources. This results in less effective allocation of resources to the sales of new and existing products with a greater impact on new products which are more dependent on these resources. Thus the balance shifts towards decentralization being less advantageous. Second, the concentration of sales of products moderates the primary relationship. In this case, business units with the more prominent products may starve units with new products of sufficient

resources impacting the proportion of sales from new products, again making decentralization less advantageous. Thus, both factors in turn reduce the difference between more and less decentralized firms in terms of their proportion of sales from new products.

This paper makes three key contributions. First, this study contributes theoretically to the re-emergent organization design literature (e.g., Greenwood & Miller, 2010; Puranam et al., 2014) by illustrating a key trade-off firms face when organizing to innovate. Namely, greater decentralization is associated with the more effective use of incentives and greater local market knowledge but comes at the cost of reduced functional scale and units competing for resources which can lead to inefficient resource allocation. This balance can be shifted under circumstances under which resource allocation is likely to be less effective or incentives are more prominent. Such circumstances include when greater levels of resources are available or there is a power imbalance between business units. Under these circumstances, business units may hoard resources that they do not need or units which have the products that are responsible for the majority of sales may capture the majority of resources. Further, the presence of corporate product functional roles such as Sales and Marketing, tend to have a centralizing impact on more decentralized firms lowering the effectiveness of incentives and relevance of local knowledge. These insights suggest that counter to the prevailing wisdom of the "ambidextrous" firm, creating dedicated units for new products may involve significant risk as bigger existing units may compete resources away from them limiting the ability of a firm to sell its new products.

Second, this study helps to extend our understanding of internal capital allocation within large, incumbent firms. I highlight that increasing competition between business units may have unintended consequences in that although these highly incentivized units may exert more effort to sell their new products they are likely to compete intensively with other units for resources to facilitate the sales of new products. This can lead to empire-building and resource accumulation in units that do not have the best use for these resources. In contrast, in more centralized organizations in which resources are allocated at an individual product level, resources can be allocated based on the merits of each product rather than the business unit. This does not rule out that even in more centralized

firms that managers associated with individual products may lobby for more complementary resources than they actually can use effectively but the impact is likely to be lower. Thus this study helps to illustrate that beyond inventing and developing inventions, successful innovation, which involves firms capturing value from new offers, requires effective allocation of complementary resources. However, managers face a challenging environment within firms. They have to meet the needs of various parties such as managers within business units or balancing the needs of existing and new products.

Finally, this study provides an interesting insight into the existing debate regarding organizational slack and firms' innovation efforts (e.g., Marlin & Geiger, 2015; Nohria & Gulati, 1996). Namely, organization design can strongly influence how resources are allocated and some units within a firm which have greater bargaining power (i.e. those that are responsible for a greater proportion of revenues or profitability) may sequester greater levels of resources than smaller, less powerful units. Hence different units within the same firm may vary as to the level of slack that they face. Thus the relationship between resourcing and innovation performance appears to be moderated by organization design. Namely how firms are designed can influence how effectively resources are allocated thereby impacting subsequent performance. Further, these results suggest that the most effective organization structure is contingent on the level of resources available (Lawrence & Lorsch, 1967). Namely, greater decentralization may be more effective at lower resourcing levels as the more effective use of higher-powered incentives enables firms to get a "bigger bang" for their buck from their limited resources but this advantage diminishes as the level of resources available increases.

This study has a number of limitations that can provide avenues for future research. First, this study is conducted in a single industry context which raises external validity concerns. Comparing the results of this study with those in other industries will provide keen insights into the boundary conditions of the findings associated with this study. Second, despite multiple approaches used to control for the endogeneity of a firm's organization design such as the use of multiple control variables and various matching strategies, there is still the concern of omitted variable bias. Ideally some form of natural experiment can be conducted such that organization design is varied through an exogenous

shock such as an external legislative change. Third, the dependent variable used in this study, which pertains to the proportion of sales from new products, may not fully capture firms' success in commercializing their new products. New product sales may come at a significant cost meaning that the focal firm may be capturing little value from their new products and all their surplus is being captured by, for example, suppliers, vendors or end customers. Future studies could examine measures of profitability associated with sale of firms' new products.

Despite these and other limitations, this study can help to further our understanding of the relationship between organization design and the commercialization of firms' inventions. Ultimately, firms face a key trade-off when organizing to effectively commercialize their inventions. On the one hand, greater decentralization facilitates the more effective use of incentives and is associated with more intimate local market knowledge. On the other hand, greater centralization enables greater functional scale and expertise and can result in the more effective allocation of resources as they are allocated at the product rather than business unit level. My analysis suggests that the benefits of decentralization outweigh its disadvantages resulting in an increased proportion of sales from new products. However, as the level of investment in supporting resources increases or for firms who are more dependent on the sales of a small number of products, the benefits of decentralization decrease as resources may not be effectively allocated to new products.

CHAPTER 5: CONCLUSIONS

> *"The outcome of any serious research can only be to make two questions grow where only one grew before,"* Thomas Veblen (US Social Scientist 1857-1929)

What we have Learned from the Work in this Dissertation

Innovation is a key driver of a firm's overall performance. Within an organization, innovation involves multiple actors transforming a firm's knowledge into a final market offering. How an organization is designed can shape this transformation by influencing actors' behaviors and interactions. As a result, understanding the relationship between organization design and innovation is an area of significant concern to both managers and scholars. However, despite its importance the study of organization design waned between the late 1980s and 2000s (Greenwood & Miller, 2010). Recently scholars have shifted their attention back to this important topic. Yet, despite this resurgence our understanding of the relationship between organization design and innovation is somewhat limited.

This dissertation aims to improve our understanding and examines the relationship between various facets of organization design and both how firms innovate as well as their innovation outcomes. Ultimately, I sought to answer the following research question:

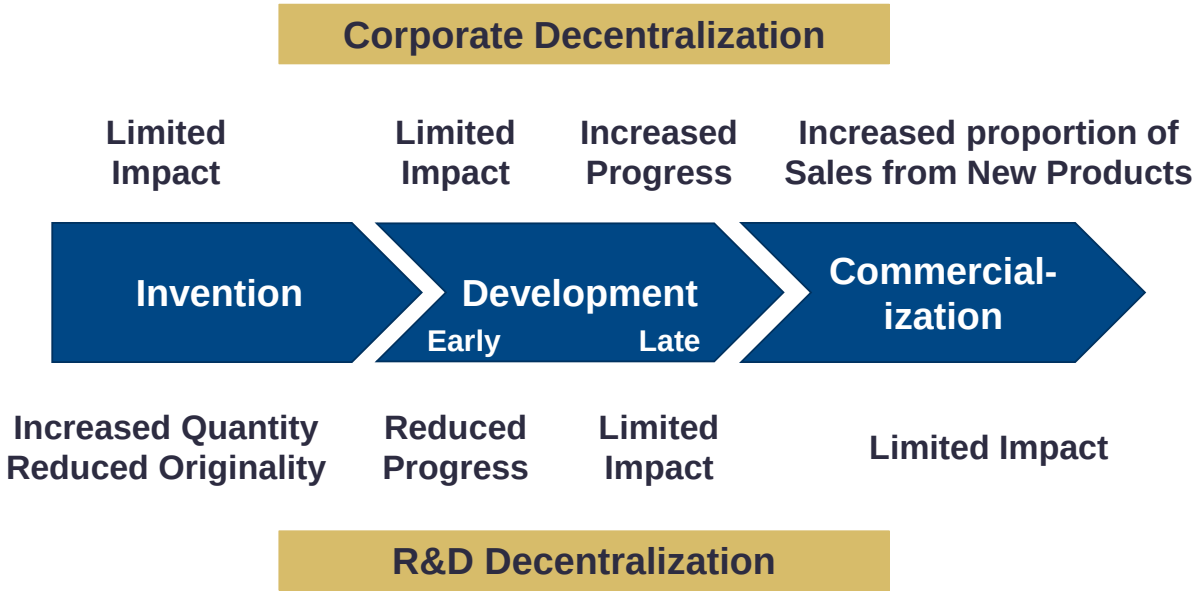
> *How are different facets of organizational decentralization (e.g. R&D, overall organization) associated with how firms innovate as well as their innovation outcomes across the innovation process spanning invention to ultimate commercialization?*

The key findings with respect to firms' innovation outcomes are highlighted in Figure 13. I suggest that the commercialization of knowledge occurs through a three stage process. This process may not necessarily be linear and firms may iterate between steps or even skip steps such as selling raw inventions for commercial gain rather than going to the effort of their commercialization as in the case of small, biotech firms or universities. Rather, the objective of this framework is to provide a systematic way of unpacking the creation and commercialization of firms' knowledge as encapsulated in their inventions.

I find that decentralization of R&D into multiple separate units with different

reporting lines to the CEO is associated with less original inventions on average but more of them, with fewer progressing through the early stages of the development process. Decentralization of R&D has a limited impact in the later stages of development and commercialization. The result that R&D decentralization is associated with less original inventions is consistent with the findings of Argyres and Silverman (2004). However in this dissertation I argue that this is as a result of greater knowledge flows in more centralized organizations rather than reduced transaction costs. The knowledge flows mechanism is supported by supplementary analyses that highlight the benefits of centralization are enhanced for firms with a broader array of knowledge. The observation that R&D decentralization has a limited impact on firms' innovation outcomes later in development and during commercialization is unsurprising as the role of R&D diminishes through the development process as more technical issues get addressed and the focus is on manufacturing the product at scale and getting the product to market effectively.

Figure 13: Summary of key findings relating to my first research question



The degree of corporate decentralization does not have an impact on invention and

early development outcomes. Again, certainly within the empirical context investigated, more commercial functions do not tend to get involved in these earlier stages of the innovation process so this result is not surprising. However, greater organizational decentralization is associated with the progression of more inventions through the later stages of development and a greater proportion of sales from new products launched in the current year. I argue that these outcomes result from the more effective usage of incentives as business units are responsible for their own sub-portfolios of inventions and there is a clearer linkage between managerial effort and individual product success. For the later stages of development this will translate into more managerial effort enabling more products to progress through the later stages of development. With respect to commercialization, the impact of organization design on incentives and knowledge flows can also influence internal resource allocation. Decentralized designs are associated with resources being allocated at the unit level as opposed to the individual innovation project level. This can result in less effective resource allocation which is accentuated at higher resource levels as increasingly vocal business units receive more resources starving resources from more promising projects in other business units. Resource allocation is important and can influence firms' innovation outcomes. As a result, at higher resourcing levels, the difference in new product commercial performance between more and less decentralized firms declines.

These results are consistent with those of the ambidexterity and disruptive innovation literatures (e.g., Christensen & Bower, 1996; Tushman et al., 2010). Namely, autonomous business units appear to be more able to translate new technologies into the market place. The theoretical rationale in both literatures is similar to an incentives-based argumentation in that resource dependency on existing customers can limit the core business from innovating new offers that may differ significantly from their existing offers. However, the work in this dissertation makes no assumptions about the type of technology being developed and commercialized. This work illustrates that more decentralized firms will have units that are dependent on their own sub-portfolio of inventions to ensure their on-going success as compared to more centralized firms that can pool risk across their entire portfolio of inventions under development or on the market. Due to this form of

"resource dependency", I argue that managers in decentralized units will be more incentivized to ensure the success of individual inventions as compared to managers that are responsible for the entire portfolio of products where failures in one area can be countered by successes elsewhere. Further, with a clearer linkage between managerial effort and outcomes, decentralization can engender even greater effort through the more effective usage of higher powered incentives. As a result of this greater effort, greater decentralization is associated with stronger outcomes related to the latter stages of the innovation process where effort plays a greater role as compared to invention and early development.

These results highlight two major trade-offs firms face at different stages of the innovation process outlined in Figure 13. First, during the invention and development stages firms face a knowledge-incentive trade-off. Namely, greater decentralization is associated with reduced knowledge flows but the more effective usage of incentives. This means centralization can facilitate the creation and early development of more novel inventions, whereas decentralization facilitates the creation of more inventions as well as their later development. Second, in the commercialization stage firms face a resource allocation-incentive trade-off. Namely, greater decentralization is associated with less effective resource allocation across new products but enables the more effective usage of incentives. This means that at low resource levels, decentralization enables the greater sale of new products but at higher resourcing levels, centralization may be more effective.

With respect to how firms innovate, I find that decentralization of R&D is associated with sourcing a greater proportion of inventions externally that are subsequently developed internally. I argue that this is because decentralized R&D units are more incentivized to progress inventions through to fruition rather than build internal capabilities to create inventions internally. Decentralized R&D units will suffer from reduced intra-organizational knowledge flows such that less original inventions will be created necessitating them to rely more on external sources for such inventions. I also find that this greater proportion of externally sourced inventions primarily comes from licensing which is generally under the control of individual business units as a mode of sourcing inventions externally as it is relatively low cost and risk. In contrast sourcing via alliances or

acquisitions generally incurs greater additional cost (this can be in terms of time and money) and is higher risk thereby generally requiring approval at levels above the business unit at a more corporate level.

Further, consistent with the fact that decentralized R&D units are less able to create more original inventions internally, the difference in the proportion of externally sourced inventions is primarily driven by more novel inventions. However, for highly novel inventions there is no difference in the proportion of inventions sourced externally between firms with centralized and decentralized R&D. This suggests that even firms with centralized R&D and more effective access to a firm's broader knowledge base may not have access to the relevant knowledge internally to create highly novel inventions meaning that they have to be sourced externally. Thus, internal R&D design through its influence on incentives and knowledge flows can shape whether invention resources are allocated within the focal firm or externally. This serves to illustrate that internal design and firm boundary choices are closely related and cannot be seen as being independent strategic choices that managers make.

Primary Contributions to the Extant Literature

The work in this dissertation makes five primary contributions to the strategic management literature. First, by breaking down the innovation process into more granular stages (e.g., Kapoor & Klueter, 2015; Keum & See, 2017) this dissertation helps to integrate the organization design and innovation literatures more closely. Much prior work in the innovation domain has tended to conflate the various stages of the innovation process (e.g., Garud et al., 2013). Using this approach helps to highlight that the same organization design choice (i.e. increased decentralization) may have different outcomes depending on whether it pertains to firms' invention or development activities. This has broader implications for future studies relating to organization design in that the relevant design choice must be closely mapped to the specific activities being undertaken. Broad measures of design may not be able to capture how such choices can impact a targeted set of organizational outcomes, leading to misleading or null inferences. This dissertation

therefore highlights an important additional contingency beyond, for example, the type of innovation, when investigating the relationship between firms' design parameters and their innovation outcomes, namely the innovation process stage. Thus, it is important to understand where (in organization e.g. R&D) and when (in the relevant process e.g. invention stage) design choices are made. This may help to reconcile the varied findings within the extant literature pertaining to how firms' design elements can impact their innovation outcomes as these studies focus on different aspects of "where" and "when".

Second, this dissertation provides a theoretical contribution in that it extends recent work combining both knowledge-based and organizational economics-based theories (e.g., Argyres, 2011; Argyres et al., 2012; Argyres & Zenger, 2012; Kapoor & Lim, 2007). Whereas previous studies combining both theoretical lenses have focused on the boundaries of the firm, this dissertation uses their integration to examine how internal design parameters can impact various organizational outcomes.

Third, this dissertation also contributes to the literature on the capability-based view of the firm (e.g., Barney, 1991). I argue that firms' design features, such as the extent to which they decentralize certain parts of their organization, can strongly influence firms' access to their broader knowledge base. Thus, internal design parameters can shape firms' innovation capabilities and influence whether firms undertake these activities in-house or externally. This dissertation can therefore provide some insight into the foundations of firms' capabilities (e.g., Helfat & Peteraf, 2015; Teece, 2007).

Fourth, this dissertation extends recent work investigating how firms' internal design elements can shape their decision to innovate internally or externally (e.g., Arora et al., 2014; Grigoriou & Rothaermel, 2017). This work has primarily examined the sourcing of knowledge in the form of patents as opposed to more fully refined inventions which forms the focus of this dissertation. Further, this work has not examined the type of knowledge sourced or the sourcing mode. Such an analysis provides insights into what shapes firms' integration of external inventions addressing a key gap in the open innovation literature as there has been "*a relative dearth of research related to integrating* [External Inventions]" (West & Bogers, 2014).

Finally, this dissertation highlights the important relationship between firms'

organization design, resource allocation and commercialization of their inventions. Consistent with prior studies, greater decentralization can adversely impact how firms allocate their resources (e.g., Bardolet et al., 2011; Bardolet et al., 2010; Stein, 1997). It appears that greater decentralization and its associated higher powered incentives can result in business units competing intensively for resources to support the sales of their new products. This, in turn, can result in the less effective allocation of resources for more decentralized firms which can lead to reduced sales of new products. This suggests that there is a "dark side" associated with the creation of autonomous units to facilitate the sale of new offers (e.g., Christensen & Bower, 1996; Tushman et al., 2010). Namely, despite their creation they may not garner sufficient resources to aid effective commercialization of new products. Sometimes keeping new products closer to the core business may be a good strategy.

Limitations

As with any research effort, the work described in this dissertation proposal suffers from multiple limitations that can form the focus of future research endeavors. First, a common issue that plagues any research involving firms' endogenous, strategic choices is that of omitted variable bias and concerns with effective identification. This issue affects all three of my dissertation chapters. The presence of natural experiments in which an exogenous shock results in firms altering some aspect of their organization design or a specific strategic choice appear to be limited and difficult to come by. A more promising route is to instrument for key strategic choices and undertake two-stage least squares regression analyses (e.g., Angrist & Pischke, 2008). However my several attempts at finding a suitable instrument for the design parameters on which I focus were unsuccessful and fell prey to violating one or both of the key assumptions required for the identification of a suitable instrument i.e. relevance and exclusion. A potential alternative avenue is to examine some form of laboratory experiment where more or less decentralized teams that are randomly allocated are tasked to perform specific innovation tasks. This experimental approach is starting to gain some traction within the organization design domain (e.g.,

Keum & See, 2017).

Second, these studies have been conducted in a single industry context which potentially limits the external validity of my findings. Further I have focused on a product based industry that is highly regulated and firms live or die through their innovation pipelines. My findings may be very different in more service-focused or asset light industries with faster commercialization lifecycles and no hard line between research and development. For example, the development of phone apps is likely to follow a different innovation pathway to pharmaceuticals meaning that the impact of various organization design features could be very different in this industry to the observations I make in this dissertation. Studying similar phenomena in very different industries may provide some unique insights.

Third, the internal organization design measures I use in this dissertation are still relatively crude. There is some merit to undertaking single company studies in which more granular and specific organization design measures can be developed and their impact on innovation outcomes evaluated. Focusing on a single company and undertaking an in-depth study of their organization design attributes opens the exciting opportunity of undertaking field experiments in which specific design features are randomly allocated to different parts of their organization and their impact on particular innovation outcomes evaluated.

Fourth, although I examine the mechanisms which I argue link organization design to firms' innovation outcomes, there is an opportunity to more precisely understand how design can impact these innovation outcomes. For example, there is an opportunity to understand how knowledge flows through organizations at a more micro-level through individual interactions between scientists. Through then examining how different design features impact these individual level interactions a richer picture of how design can impact innovation can be delivered. It may be the case that highly incentivized managers of scientists in more decentralized units frown upon interactions with scientists in other units and encourage them to focus on their own research projects thereby limiting knowledge flows. Similarly, examining how greater incentives can engender greater managerial efforts at different stages in the innovation process would further help to better our understanding

of how design can impact innovation. For example, do managers in decentralized units seek ways to streamline the later stages of development to ensure a speedier progression?

Future Research Opportunities

Future research associated with this dissertation falls into three categories, short term enhancement of the three papers in this dissertation in preparation for submission to leading management journals (1 year time-frame), medium term projects building on the work in this dissertation (3 year time frame) and longer term research themes that will help shape my ultimate research identity (greater than 3 years).

Short-term (<1 year) focus

In the short-term my focus will be on Chapters 3 and 4. In Chapter 3, I can further control for the portfolio of firms' innovation projects and existing products by including controls for the demography of firms' exiting product patent portfolio. It may be the case that firms with a larger proportion of products whose patents are about to expire may place a greater emphasis on the sourcing of new inventions externally. Potentially, the industry level of external sourcing of inventions could be used to instrument external sourcing of individual firms.

In Chapter 4, additional work will be focused on two primary areas. First, I will explore the potential to measure the distribution of new products across different business units within decentralized firms. This will help to provide greater confidence as to the theoretical arguments provided in this chapter. I will be able to observe if new and existing products are uniformly or unevenly present across a firm's business units. This can help to provide some evidence to suggest that larger business units divert resources from smaller business units with new product opportunities. Second, I will conduct additional interviews with managers within select centralized and more decentralized firms in my sample to garner more qualitative insights into the resource allocation process.

Medium-term (1-3 year) opportunities

In the medium term, there are two primary areas which are likely to form the focus of my on-going research program. First, the work that I describe in this dissertation is focused on understanding the relationship between various elements of organization design and firms' innovation outcomes, however firms will often change their structures which can have an impact on their innovation outcomes (e.g., Karim & Kaul, 2015). One corporate strategy that firms may undertake that changes their internal organization design involves the divestiture of business units. However, few studies have examined the impact of divestitures of elements of firms' businesses on the innovation performance of firms (e.g., Datta, 2003; Moschieri & Mair, 2011).

When examining how a divestiture could impact the innovation output of a firm it is unclear whether the impact will be harmful or beneficial. A common rationale for firms divesting businesses is that it enables them to focus on their core business. For example, Merck & Co. divested its consumer business in 2014 based on the rationale:

> *"the Company* [Merck & Co.] *divested its Consumer Care ("MCC") business to Bayer, which provided capital to the Company to better resource its core areas of focus", 2014 10-K Merck & Co.*

This greater focus can manifest itself in multiple ways such as channeling more resources into the core business (e.g., Helfat & Eisenhardt, 2004), increased managerial attention (e.g., Ocasio, 1997) or the ability to manage a smaller portfolio of activities more effectively (Klingebiel & Rammer, 2014). Ultimately, with increased managerial attention and greater resources at hand, firms should be more able to innovate more successfully.

However, divestitures can result in the loss of important knowledge and capabilities that were of importance to the business in its innovation efforts. This knowledge may be highly tacit (e.g., Grant, 1996) making it more challenging to access it through the open market potentially limiting the innovative capacity of a firm to address more challenging problems (e.g., Macher & Boerner, 2012). Further, organizational routines may be disrupted that could impact innovation activities in the core business especially if the

divested business is in a related industry (e.g., Feldman, 2013). Such factors may result in divestitures of businesses adversely affecting the innovation outcomes of the focal firm.

This balance of reallocation of resources and knowledge loss will be dependent upon whether the business divested is a core or non-core business. In contrast to the case of a core business, a non-core business unit divestiture will be associated with a limited loss of key tacit knowledge but enables the reallocation of resources to the core business. In undertaking this work it is important to make this distinction between core and non-core businesses as the knowledge-loss/resource reallocation balance will shift significantly.

The impact of these mechanisms (reduced firm knowledge and resource reallocation) on firms' invention outcomes is also influenced by firms' internal organization designs. Work in this dissertation and prior studies have highlighted that organization design can shape how resources are allocated (e.g., Birkinshaw & Lingblad, 2005; Ghoshal & Nohria, 1989; Rajan et al., 2000). For example, resources may be allocated at the business unit or individual project level depending on design (Bardolet et al., 2010). Further, design can shape how knowledge is accessed and recombined within an organization through, for example, influencing knowledge flows or internal transaction costs (e.g., Argyres & Silverman, 2004). Thus, organization design can shape the impact of divestiture on invention through influencing the relative benefits of resource reallocation and costs of lost knowledge.

I will utilize the pharmaceutical industry dataset developed in this dissertation to examine this phenomenon, supplementing it with a set of divestitures of core and non-core businesses obtained from the SDC Platinum dataset. This work will enable me to further integrate the corporate strategy and organization design literatures as I will evaluate how internal design can shape the performance consequences of firms' divestitures.

Second, in the classic Chandlerian sense strategy and structure are intricately related (Chandler, 1962). Firms undertake a variety of very different strategies which implies that very different structures will be utilized. However, scholars have highlighted that it is challenging to fully define a firm's strategy as there is no defined lexicon to describe a firm's specific strategy (Nag, Hambrick, & Chen, 2007). In a parallel stream of

work with Mike Mannor, we have developed a text analysis tool that enables the quantification of the degree to which firms focus their attention on different strategies. The tool consists of 13 strategy categories ranging from areas such as new product development to mergers and acquisitions. Through examining the regular communications of organizations such as their quarterly analyst calls or letters to shareholders, this tool will enable me to start to quantify the strategies to which managers in different firms pay attention. I can then examine the structures that firms utilize through evaluating the composition of the top management teams akin to the approach that I used in this dissertation.

Such an analysis of both firms' articulated strategies and their expressed structures can enable me to evaluate how different strategies tend to be associated with specific structures. For example, firms that over-emphasize new product development may tend to have centralized R&D in which the Head of R&D has a greater relative power within the top management team as compared to other parts of the organization such as marketing or manufacturing. Alternatively, for low cost and efficiency strategies firms may tend to centralize and limit the power of individual business units so that greater economies of scale can be realized. The challenge in this form of analysis will be illustrating causality but even illustrating the association of different unique strategies with specific organization designs could provide some distinctive insights. Theoretically this work could enhance our understanding of how structure can enable firms to develop unique capabilities that can provide sustainable competitive advantage.

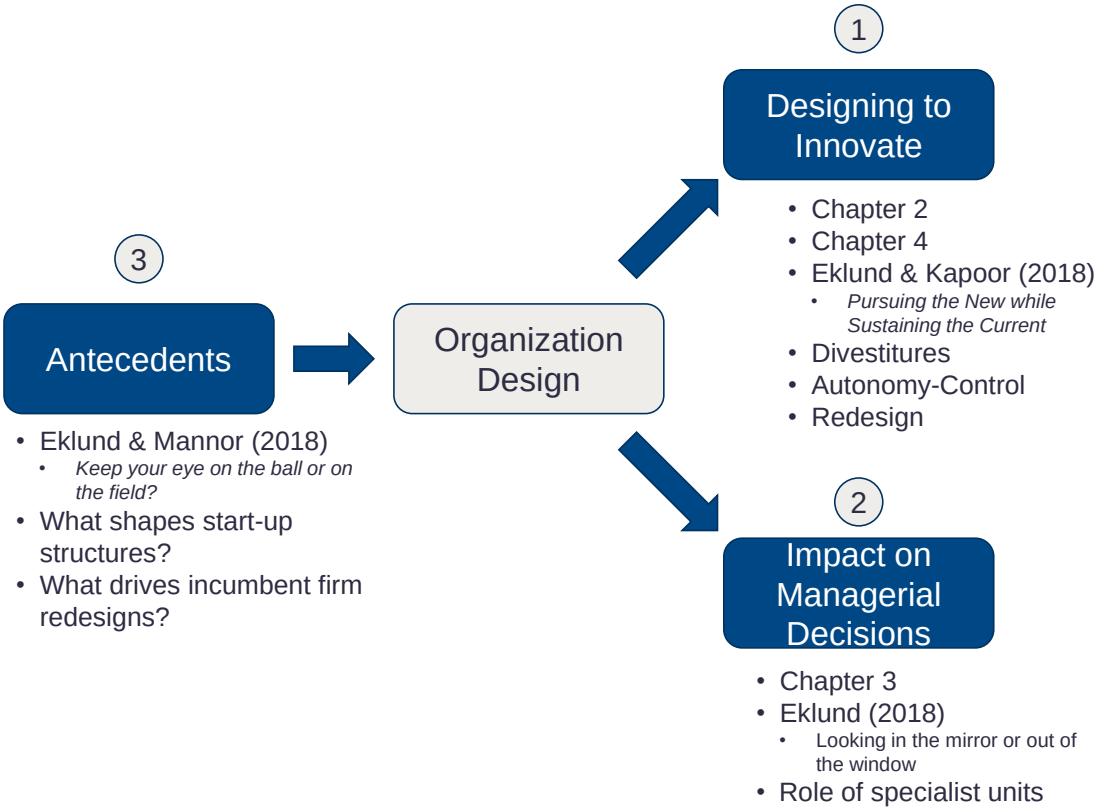
Longer term (>3 years) research agenda

As my research progresses, I see my research agenda falling into three key themes all focused around different facets of organization design. These three themes are illustrated in Figure 14.

The first theme extends the work in this dissertation and focuses around understanding the relationship between organization design and innovation. Chapters 2 and 4 of this dissertation and other recent work (Eklund & Kapoor, 2019) fall squarely in this

stream of work. There are two major questions that I encountered in my management interviews that the extant literature does not appear to address adequately.

Figure 14: Long-term research agenda. Example existing and future projects under each theme.



First, the popular belief within the extant literature is that inventors free of significant hierarchical control are able to create more novel inventions (e.g., Kay, 1988). However, as described in this dissertation, innovation is a process and needs to be managed to ensure ultimate offerings can be launched into the market place. This tension poses an interesting organization-design question: how can organization design facilitate sufficient autonomy for inventors to create novel inventions but ensure such inventors are held accountable such that they provide tangible outputs for the business? Organization design can play a major role in shaping this tension as it influences allocation of decision rights and incentives to conform to organizational goals. Recent studies have highlighted the

concept of micro-divisionalization which managers perceive helps to address this issue (Meyer, Lu, Peng, & Tsui, 2017). However, simply splitting the organization into highly autonomous units with decision rights pushed down to more junior managers that are highly incentivized may apply to the sales of existing products but is not likely to do so for the complex process of innovation that pulls on resources from across an organization.

Second, organization redesign has been illustrated to impact firms' innovation outcomes (Karim & Kaul, 2015). However, this prior work has tended to focus upon recombination of business units that facilitates increased intra-organizational knowledge flows that, in turn, enables unique pieces of knowledge to be recombined to create new inventions. However, often firms go beyond simply repackaging units but undertake more radical or more nuanced redesigns. More radically, firms may move from a technology discipline division of labor to a product-based division of labor or vice-versa. A good example of this is the move of Microsoft from a divisional organization to a function one under Steve Ballmer. At a more nuanced level, firms may maintain existing units but allocate greater responsibility across more stages of the innovation process to these units. For example, pharmaceutical firms have experimented with the concept of innovation centers that are generally quite autonomous and have responsibility for broad swathes of the innovation process. Thus, there is an opportunity to examine a broader variety of reorganizations upon firms' innovation outcomes.

In examining the autonomy-control balance and different forms of organizational redesign, multiple empirical methods will need to be employed. Beyond archival analysis, alternative methods could include detailed qualitative analysis or laboratory experiments. Through, for example, detailed case studies and further managerial interviews I may be able to start to identify different forms of organizational redesign firms have utilized in the past. Laboratory experiments provide a greater degree of control with respect to internal validity as treatment can be randomly allocated. For example, I may be able to exert different levels of autonomy and control using varying team designs and see their impact on innovation outputs in a laboratory setting.

The second theme focuses upon how firms' organization designs can impact managerial decision making. For example, a highly decentralized structure with high

powered incentives may result in managers making very different decisions to those in highly centralized firms where the adverse consequences of ineffective decisions are much lower. Chapter 3 falls into this domain as I examine how firms' internal organization designs can influence firms' capabilities and the key managerial decision of whether to create new inventions internally or source them externally. I have also undertaken some recent related work that examines how organizations' capabilities can shape managerial decisions (Eklund, 2017).

The extant literature on managerial decision-making has tended to focus on the biases that managers may have (e.g., Bingham & Eisenhardt, 2011; Kahneman & Klein, 2009), managerial characteristics (e.g., Hambrick & Mason, 1984) or managerial self-interest (Eisenhardt, 1989a). However, managers operate in a highly complex organizational environment and this is likely to shape their specific decisions. One such organizational factor is how the organization is structured. As indicated in the work in this dissertation, different structures can be associated with access to different organizational information and incentives schemes. This sets up some interesting tensions managers may face when making decisions that are shaped by firms' organization designs. For example, highly decentralized firms with strongly incentivized managers may be designed with the intent for autonomous managers to make riskier decisions free from the glare of the parent organization. However, such managers may play it safe to avoid downsides and capture some of the value associated with their higher powered incentives. In contrast, managers in centralized units with lower powered incentives may have less to lose and take on greater risks. This is consistent with the concept of "loss aversion" highlighted by scholars such as Kahneman and Tversky (1979).

In a similar vein, certain organizational units may provide managers access to new information that may not be accessible through alternative designs thereby differentially shaping managerial decisions. For example, how does having a corporate development group shape managerial decisions with respect to the scope of the firm? Do such units encourage managers to expand the scope of the firm by illustrating attractive opportunities for inorganic growth, or do they hold back managerial decisions with respect to scope through highlighting the potential downsides of specific scope expansion opportunities?

Further, business development units may facilitate managers in business units to make more considered decisions with respect to acquisitions or alliances. This can be achieved through providing additional information or insight that can facilitate more considered decision-making. This is akin to a shift from Type 1 to Type 2 decision-making (Kahneman & Tversky, 1979).

The third theme pertains to the antecedents of organization design. Although scholars have developed a good understanding of the different forms of organization design that can be selected by firms (Burton et al., 2011), it is less apparent how firms' designs emerge over time starting from their founding. Why do start-ups select the structures that they ultimately utilize? Similar firms may follow very different paths in terms of how they structure themselves, yet we are unclear as to what these trajectories look like and what drives them. As highlighted by Dierickx and Cool (1989), there is a strong path dependency that shapes ultimate firm performance, it is likely to be the case that part of what drives this is the selections of structures that firms make as they grow into large, incumbent firms. Such evaluation of firms' structures from their inception is challenging to undertake as limited data is available. Recently, scholars have highlighted that firms may be strongly influenced in their designs by their origins or can radically shift as they grow (DeSantola & Gulati, 2017). However, we have little understanding of the contingencies shaping whether firms "stick or twist" with respect to their designs.

One route would be to either undertake survey-based analyses of a random sample of firms that have grown and been founded in the past 10-years (to ensure founders still can recollect why certain structures were selected) or in depth case-study analyses of firms that have grown. Such approaches would enable me to develop a richness of understanding pertaining to how firms' structures evolve over time. Is it a case that initial focus is on functional division of responsibilities and units, which then shifts to a divisional focus and then progresses into a more complex matrix form? Through the comparison of the different structural paths that firms pursue we may also be able to start to understand another route which leads to the heterogeneity in performance of firms – a central strategic management question.

Further, large incumbent firms restructure on a regular basis. It is often challenging to determine what the main rationale for these changes is. CEOs often highlight reasons such as changes in strategy or poor performance. It would be of value to understand what can influence managerial attention upon organization redesign activities in the first place as often there is a significant gap between a structural change and when managers decide that a restructure is required. Using text-based analysis tools to examine the different strategies to which managers within firms pay attention can enable me to evaluate what can shape management attention to an organizational restructuring (Eklund & Mannor, 2018). In this approach I could analyze the text of firms' quarterly analyst calls and look for signs of managers describing issues pertaining to organization design that they are considering. Then I can examine what is strongly associated with this attention. Is it primarily driven by firm characteristics such as organizational performance, industry characteristics such as munificence, or managerial characteristics such as tenure? This could enable me to develop a rich theoretical and empirical analysis of the antecedents of the changes in large, incumbent firms' organization designs. Thus, by investigating how firms develop their structures in the first place and what shapes how these structures change, this can help me to provide a more joined-up perspective of the antecedents of firms' organization designs.

In conclusion, my future research agenda will revolve around the important topic of organization design. I hope to contribute to the re-emerging scholastic discussion on organization design through building our understanding of the antecedents of organization designs and the impact of design on firms' innovation activities and their broader managerial decision making.

APPENDICES

Appendix 1: Summary of Hypotheses

The eight hypotheses outlined and tested in this dissertation are:

Chapter 2: Invention

H1: Firms with decentralized R&D are associated with the generation of inventions that are less original than those of firms with centralized R&D.

H2: Firms with decentralized R&D are associated with the generation of more inventions than firms with centralized R&D.

Chapter 2: Development

H3: Firms with decentralized R&D are associated with the progression of fewer inventions through the earlier stages of development than firms with centralized R&D.

H4: Greater corporate decentralization is associated with the progression of more inventions through the later stages of development.

Chapter 3: Development

H1: Firms with decentralized R&D will source a higher proportion of inventions externally than firms with centralized R&D.

H2: The difference in the proportion of inventions sourced externally between firms with decentralized R&D and centralized R&D will be greater for licensing as compared to acquisitions or alliances.

Chapter 4: Commercialization

H1: The quantity of complementary resources negatively moderates the relationship between corporate decentralization and the proportion of sales from new products such that firms with higher quantities of complementary resources will be associated with an increased proportion of sales from new products for more centralized firms compared to more decentralized firms.

H2: The concentration of sales of a firm's existing product portfolio negatively moderates the relationship between corporate decentralization and the proportion of sales from new products such that firms whose sales are more concentrated on a few products will be associated with an increased proportion of sales from new products for more centralized firms compared to more decentralized firms.

Appendix 2: Additional Methodological Details

Determining patent assignees for patent-based measures

Two separate approaches are used to define the assignees of patents pertaining to firms in the study sample. First, the limited number of firms in the sample enables the manual matching of patent assignees (as defined by DOC_STD_NAME in the Patstat parent database) to sample firms. Using the Bureau van Dijk "Orbis" database, a list of subsidiaries for each sample firm is developed. Any Patstat assignee that contains a focal firm's subsidiary or parent name text string (and multiple variants of this text string) is captured. This subset of patent assignments per focal firm is then manually checked for each of the 49 firms in the sample to arrive at an intermediate set of Patstat assignees. As the Orbis database provides a snapshot of ownership at a specific point in time (2015), assignees that were subsidiaries of parent companies had to be checked to ensure whether they should be allocated to the parent company or whether when the patent was filed, the subsidiary was an independent company. Using the Zephyr database from Bureau Van Dijk, merger and acquisition (M&A) activity in the industry is controlled for by ensuring assignees represent the original corporate entity filing a patent rather than the parent owner in 2015 provided by the Orbis database. As a result, prior to the specific M&A event, patents are retrospectively assigned to the acquired firm from the acquiring firm.

Second, following the process of Arora et al. (2014) patent assignees were matched against firm and subsidiary names obtained from Bureau Van Djik's "Icarus" database following cleaning of names using a standardized name-cleaning algorithm. This was an iterative process involving the adjustment of matching rules and manual checking. Again, using a similar process to that described above, the Zephyr database was used to control for M&A activity and retrospectively reassign patents to acquired firms from the acquiring firm prior to the M&A event.

Both approaches used to develop standardized names provided similar results with 99.7 % of assignees being the same for each sample patent. Those patents that did not have the same assignees from both methods were manually checked and reassigned appropriately.

Development based measures - allocating drug candidates to parent firms

To ensure that a drug candidate in the clinical development process is allocated to the appropriate firm using Pharmaprojects data, two key steps are followed. First, transactions are examined using the Recap database and the "Overview" section of the Pharmaprojects database to ensure that the firm assigned to a drug in the Pharmaprojects database is the actual firm managing the development of that drug candidate. These transactions include deals in which a selection of drug-candidates are sold from one company to another, a complete firm is acquired or merges with another and strategic alliances between firms in which an invention may be created through an alliance and then subsequently pursued through clinical trials by another firm. If a transaction is observed in Recap, the firm managing the development of that drug is adjusted accordingly in the second step.

Second, prior to 2012 Pharmaprojects retrospectively assigns a drug candidate to an acquiring firm following acquisition of another firm. As a result even prior to the acquisition year that drug candidate will be assigned to the acquiring firm rather than the acquired firm which was at that time an independent entity. Adjustment of these assignments requires a careful assessment of the "Overview" section of the Pharmaprojects record of a drug which indicates which firm was initially responsible for a drug-candidate prior to the respective deal. For M&A activity post 2012, Pharmaprojects correctly allocates the firm responsible for the original development of a drug candidate. For M&A activity post 2012, drug-candidates were reassigned to the acquiring firm the year after the acquisition. Merger and acquisition data from Recap and the Zephyr database from Bureau Van Dijk were used to reassign drug candidates following post-2012 M&A activity. Further, it is noted whether a drug-candidate was developed internally, acquired via an M&A deal, acquired from another firm or was originally created through an alliance.

In the absence of any transaction in Recap or additional information on a drug-candidate provided in the Pharmaprojects "Overview" section, the original firm assignment in the Pharmaprojects database is utilized.

Organization design measures

Obtaining data on a commercial firms' internal organization structures has been highlighted as a significant challenge for the management scholar (e.g., Greenwood & Miller, 2010; Sathe, 1978; Walton, 1981). A review of the management literature highlights three methods by which internal organization structures are inferred.

First, scholars use publicly available firm administrative records such as high level organizational charts and company annual reports to directly infer organization structures (e.g., Albert, 2018; Girod & Whittington, 2015; Guadalupe et al., 2014). Although this data is readily accessible it is limited in its coverage and can result in an incomplete picture of a firm's organization structure being derived. For example, public administrative record information is often limited to the senior most levels of the organization and focuses on direct reports to the CEO – the executive team. As a result, it is challenging to accurately infer organization structure lower down the organization.

Second, indirect proxies are used to determine structure using publicly available information. For example, Arora et al. (2014) use patent assignee data to define the level of centralization of a firm's R&D function based on whether patents are assigned to the parent company or a subsidiary. Other studies also focusing on the R&D function examine the number of employees in corporate and divisional laboratories (Argyres & Silverman, 2004). Using the ratio of employees in both types of laboratory a degree of centralization percentage can be estimated. This approach requires careful consideration of construct validity as the indirect measure may not correlate perfectly with organization structure.

Finally, the most common tool used in organization structure research is survey analysis in which firms are questioned directly about their organization structure in a standardized manner (e.g., Hill, Hitt, & Hoskisson, 1992; Markides & Williamson, 1996; Turner & Makhija, 2012). This enables scholars to tailor questions to better capture the information that they need, and helps them to observe organization structure at a greater level of depth. Survey studies generally use multiple questions to measure a variety of specific organizational constructs. For example, Russell and Russell (1992) use surveys to measure structural components such as the degree of centralization, integration and breadth

of control. Turner and Makhija (2012) measure whether firms are organic (more decentralized and less bureaucratic) or mechanistic (more centralized and process focused). The survey approach is limited by the usual factors associated with any form of survey research e.g. accessing the right survey respondents, and the extended period of time required to conduct survey.

In this dissertation a combination of the first and third methods are used to develop three organization structural measures: *R&D Decentralization, R&D Functional Differentiation* and *Corporate Decentralization*. First, company administrative records such as annual reports can be used to identify the executive level of management of each pharmaceutical firm. Each executive level management team role corresponds to a structural element (e.g. R&D, manufacturing) and these can be coded systematically to enable an estimate of the structural parameters described above. Second, survey-type interviews are conducted with sample firms to validate and expand upon the measures captured from archival sources.

Appendix 3: Managerial Interviews

Methodological description

To enrich the archival data analysis multiple managers within 28 firms from the sample of 49 firms (see Table 28 for further details of firms interviewed) and five industry experts were interviewed. In total 61 interviews were conducted. The managers interviewed were senior level R&D and strategy managers who had a good understanding of the structure of both R&D and their organization as a whole. The interviews were conducted between 2015 and 2018. The interviews were undertaken via teleconference and each interview typically lasted between 30 and 90 minutes with outline questions distributed to the respondent in advance to enable suitable preparation and follow-up clarification questions being conducted post-interview through email. Detailed notes were collected during each interview. Notes from all 61 interviews were reviewed to determine key issues pertaining to three areas.

First, interviews were used to validate the relevant structural measures that were developed through coding of firms' top management team structures using publicly available data sources (*R&D Decentralization*, *Corporate Decentralization* and *R&D Functional Differentiation*). Second, the mechanisms through which managers perceive firms' organization design choices impact their innovation outcomes were also examined. The focus of these interview questions related to the incentives- and knowledge-based mechanisms through which decentralization could impact innovation. Third, a sequence of questions was asked relating to the product development decision-making process in these pharmaceutical companies and which parts of the organization are involved at different stages of the drug development process.

I supplement the data collected from these interviews through review of the more qualitative aspects of firms' annual reports and 10-K filings. A research assistant (RA) reviewed the letter to shareholders, business description, operational review and R&D overview of firms' annual financial filings for each year in the period 1995-2015. The text extraction was focused on descriptions of organization design and references to incentives and knowledge-flows.

Table 28: Study sample firms and firms interviewed in this study

#	Firm	GVKEY	Interviewed
1	Abbott Laboratories	001078	Yes
2	Actavis	027845	Yes
3	Akzo Nobel	015334	
4	Allergan	015708	Yes
5	Altana	100004	
6	Amgen	001602	Yes
7	Ares-Serono	102045	
8	Astra Zeneca	028272	Yes
9	Aventis	013467	
10	Baxter International	002086	Yes
11	Bayer	100080	Yes
12	Biogen Idec	024468	Yes
13	Bristol-Myers Squibb	002403	Yes
14	Cephalon	023945	
15	Chugai Pharma.	100441	
16	CSL	223003	Yes
17	Daiichi Sankyo	100336	Yes
18	Eisai	100418	Yes
19	Eli Lilly	006730	Yes
20	Forest Labs	004843	
21	Genentech	005020	
22	Genzyme	012233	
23	Gilead Sciences	024856	Yes
24	GlaxoSmithKline	005180	Yes
25	Johnson & Johnson	006266	Yes
26	King	112033	
27	Kyowa Hakko Kirin	100516	
28	Lundbeck	232106	
29	Medlmmune	024008	
30	Merck & Co	007257	Yes
31	Merck KGaA	220301	
32	Mylan	007637	Yes
33	Novartis	101310	Yes
34	Novo Nordisk	008020	Yes
35	Pfizer	008530	Yes
36	Roche	025648	Yes
37	Sanofi	101204	Yes
38	Schering AG	101076	
39	Schering-Plough	009459	
40	Schwarz Pharma	108182	
41	Shire	212340	Yes
42	Solvay	101394	
43	STADA Arz.	214700	
44	Takeda	100718	Yes
45	Tanabe	100021	
46	Teva	014538	Yes
47	UCB	100751	Yes
48	Valeant Pharma. Int.	009340	Yes
49	Wyeth	001478	

I follow a two-step process to validate the structural measures using companies' financial filings. First, any evidence pertaining to the R&D or the overall organization structure of each firm was captured. This data was again used to validate the various organization design measures developed. Further, any evidence in the managerial discussion pertaining to how organization design choices could impact incentives and knowledge flows was also captured.

In the second phase of work these data extracts were further examined and common, major themes that are used to inform the qualitative commentary were captured. These insights were complemented with relevant findings from the interviews with strategy and R&D managers. It should be emphasized that this analysis is not intended to be a rigorous case-based form of qualitative analysis (e.g., Eisenhardt, 1989b). It is simply designed to add greater insight into and confidence in the main quantitative archival analysis.

Supporting interview results

Table 29 illustrates the key descriptive statistics for the 28 firms interviewed. Although questions were asked about how the firms' structure changed over time, the data in this table pertains to their structures in the final year of the sample period (2015). It can be seen that, consistent with the overall sample, approximately 11 % of firms had decentralized R&D structures. Interestingly, the key way in which R&D was sub-divided was by functional area (68 % of firms interviewed had some form of functional sub-division in R&D). In a centralized R&D structure this will facilitate knowledge flows across therapeutic areas potentially facilitating invention and development outcomes. For those firms which had business units and were not functionally aligned, these business units were primarily organized along therapeutic area lines as opposed to geographies (83 % versus 17 %). Interestingly, these results highlight that R&D tends to be sub-divided by function (e.g. science area or stage of R&D) whereas the more commercial aspects tend to be more therapeutic area aligned.

Table 29: Key descriptive statistics for sample firms interviewed (n=28 firms and 61 interviews)

Interview Item	N	%
Decentralized R&D		
Centralized R&D	25	89
Decentralized R&D	3	11
Total	*28*	*100*
R&D Sub-division		
Functional	14	50
Mixed	5	18
Therapeutic	9	32
Total	*28*	*100*
Corporate Decentralization		
Divisional	18	64
Functional	10	36
Total	*28*	*100*
Business unit categories		
Therapeutic Area	15	83
Geography	3	17
Total	*18*	*100*
Respondents mentioning specific mechanism (unprompted)		
Knowledge Flows	18	64
Incentives	12	43

The majority of managers interviewed outlined in some form or other the importance of ensuring good cross-organizational knowledge flows to aid effective innovation (64 % as illustrated in Table 29). Greater organizational integration such as the creation of a more centralized R&D unit was one way of achieving this, but managers described other routes this could be achieved such as cross-organizational research forums and the use of various online knowledge management tools. Ensuring good knowledge flows was seen as especially important for ensuring the development of novel inventions and for facilitating their development into final products.

> *"Organizing to ensure greater integration across therapeutic areas is important as an idea in one area may be able to be translated into another therapeutic area. Quite often an indication may be unsuccessful in one therapeutic domain but have legs in another, however with the wrong structure scientists may not be able to take advantage of this"*

> *"It is important to get the viewpoint of multiple functions during clinical development and even earlier in the discovery phase"*

Managers frequently referred to the creation of organizational siloes with more decentralized structures that can result in poor knowledge flows and potential repetition of effort.

> *"Avoiding silos is an issue – we need to force people to collaborate with each other. Ultimately some technology will be replicated across the organization and this is ok if the cost of transporting a molecule is prohibitive, but the firm could improve in not replicating activities across labs in our more decentralized R&D organization"*

> *"It can always be difficult to get different teams collaborating as people fixate on the specific unit of the organization in which they are located"*

These poorer knowledge flows between business units could ultimately lead to inferior innovation outcomes.

> *"Drugs make great business units but business units do not make great drugs"*

Less attention was paid to incentives in firms' annual reports but interviews with R&D managers highlight that incentives could influence innovation outcomes and are related to a firm's organization design attributes. 43 % of managers interviewed mentioned the importance of incentives and how these could shape R&D behavior (Table 29). The key theme that emerged was that R&D managers tended to be incentivized by the volume of inventions and ensuring that they progress through the innovation process rather than by the quality of the inventions being progressed. Greater centralization was seen as being associated with lower powered incentives which some managers perceived could hinder innovation performance:

> *"The issue with incentives in a corporate (more centralized) setting is they are generally quite poor and under-reward good performance and over-reward poor performance i.e. people don't get fired"*

However, managers did highlight using higher powered incentives are not a panacea and could come at a cost:

"Ultimately there is a trade-off of getting ambitious performance and ensuring a good work environment and collaborative atmosphere"

"Incentivizing people by counting compounds is not a way of incentivizing good science"

Finally, many managers highlighted the organizational challenge firms' face in deciding the degree of organizational decentralization:

"*You need to put in swing lanes to provide some discipline, the problem is that you make the swing lanes too narrow and people focus too narrowly and can be restricted in what they can do and may not collaborate effectively with individuals in other swing lanes"*

"Balance between being smaller more decentralized units and being agile like a biotech and being able to leverage scale of a larger organization"

In summary, it appears that organization design attributes can impact innovation outcomes through both knowledge flows and provision of incentives. Managers in pharmaceutical firms do discuss both mechanisms and how design can emphasize one over the other and some even highlight the trade-offs firms' face when deciding to integrate more tightly or decentralize. However, no real mention was made as to the boundary conditions in which greater decentralization may be more appropriate.

Appendix 4: Additional Descriptive Results

Structural variables

Figure 15, Figure 16, and Figure 17 illustrate the sample mean variation across firms of each of the three key structural variables in this study over the period 1995-2015. From Figure 15, it can be seen that *R&D Decentralization* increases from 1998 to 2001 as more firms decentralized their R&D units. Then it drops in 2002 and remains relatively flat to 2008. R&D decentralization increases from 2009 to 2012 and then remains flat. Figure 16 illustrates that *R&D Functional Differentiation* fluctuates over time peaking in 2004 and then dropping to a relatively steady value between 2005 and 2015. In contrast, *Corporate Decentralization* has been relatively steady over the study period (Figure 17). These results illustrate that design choices can be cyclical influenced by events such as merger and acquisition activity or, potentially, firms attempting to replicate the structures of other firms. This viewpoint was referred to multiple times in managerial interviews:

> *"Organizational design changes seem to go in waves across the industry, at one stage centralization is in, then it is all about being decentralized and nimble"*[24]

Interestingly, firms with decentralized R&D tend to be more geographically dispersed than firms with centralized R&D as measured by the average number of countries from which inventors on a firm's patents are originated. Firms with decentralized R&D on average have inventors in 19.1 countries versus 15.7 countries for firms with centralized R&D. This difference is statistically significant (p=0.004). There is a risk that this variable of the number of countries in which firms invent is a "bad control" (Angrist & Pischke, 2008) as R&D decentralization could result in greater geographic spread and is thus only used in robustness tests and not the main analyses. However, this difference in the number of geographies from which firms' inventors originate provides some confidence in the measure of R&D decentralization used in this study.

[24] Due to confidentiality associated with the study interviews, I cannot ascribe the comments to any specific firm or individual

Figure 15: Sample variation of R&D Decentralization over time. Each point is mean across firms in sample in that year

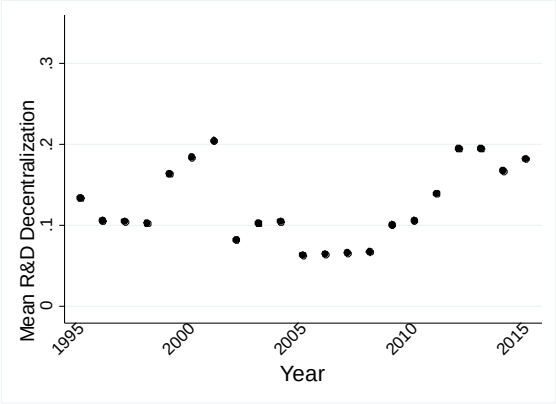


Figure 16: Sample variation of *R&D Functional Differentiation* over time. Each point is mean across firms in sample in that year

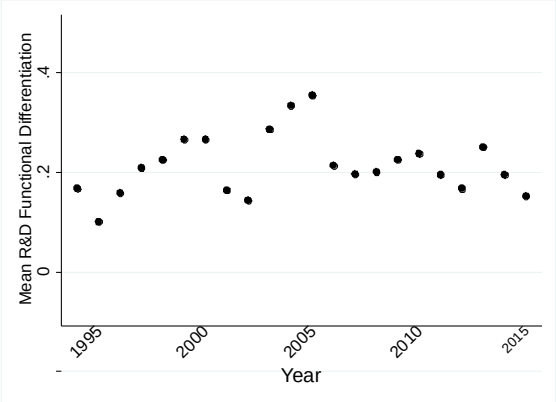
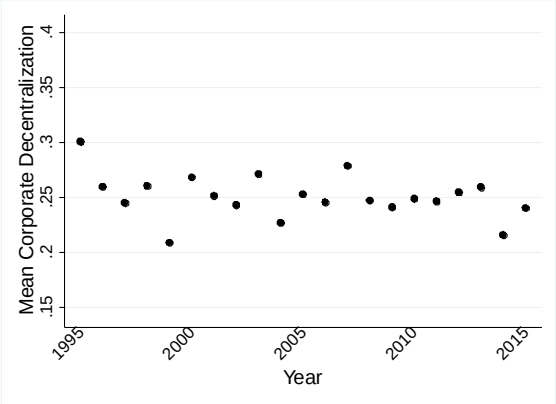


Figure 17: Sample variation of *Corporate Decentralization* over time. Each point is mean across firms in sample in that year



Dependent variables

In chapter 2, for the two invention hypotheses I examine the variables *Quantity* and *Originality*. Figure 18 illustrates the variation of these two variables at a firm-year level averaged across all firms in the sample. Interestingly, *Quantity* appears to rise over the study time period and *Originality* declines over the same time period. The two development variables *prog0* and *prog2* that represent the progression of drug-candidates from phase 0 to 1 and phase 2 to 3 respectively are the outcomes associated with the two development hypotheses in Chapter 2. From Figure 19 it appears that *prog0* peaks in 2008 whereas *prog2* remains relatively flat over the study time period.

In chapter 3, in Hypothesis 1 I examine the proportion of externally sourced inventions. For the study sample the temporal variation of this variable (*external)* is illustrated in Figure 7 in chapter 3. It can be seen that the proportion of externally sourced inventions has increased over the period 1995 to 2015.

For Hypothesis 2, I examine the proportion of inventions sourced via different modes: licensing, acquisitions and alliances. Figure 20 illustrates how the proportion of drug-candidates sourced via each of these different modes varies over time. It can be seen that the proportion of drug-candidates sourced via alliances has declined over the study period, in contrast the proportion of drug-candidates sourced via licenses has increased. The proportion of drug-candidates sourced via acquisitions has remained relatively flat.

In supplementary analyses, I examine how the proportion of low, medium and high novelty inventions is associated with R&D Decentralization. Figure 21 illustrates the variation of these proportions over time. It appears to be that these proportions remain relatively flat across the sample of firms over the study time-period, with a greater proportion of highly novel inventions sourced externally consistent with the findings of Chapter 3.

In Chapter 4, the key dependent variable is the proportion of new drug sales from drugs launched in the focal year. It can be seen from Figure 11 in Chapter 4 that this proportion has declined over the study time-period consistent with prior observations of Scannell et al. (2012).

Figure 18: Sample variation of (a) Quantity and (b) Originality (Chapter 2) over time. Each point is mean across firms in sample in that year

(a) **(b)**

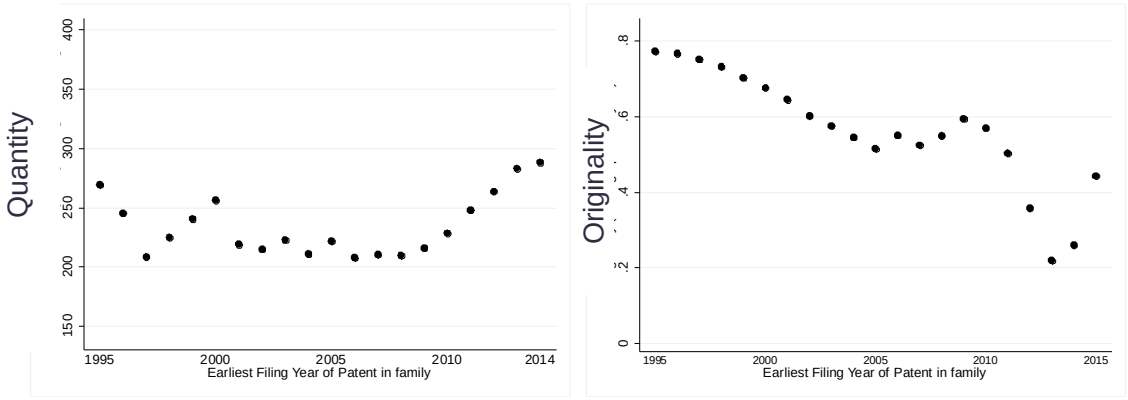


Figure 19: Sample variation of (a) *prog0* and (b) *prog2* (Chapter 2) over time. Each point is mean across firms in sample in that year

(a) **(b)**

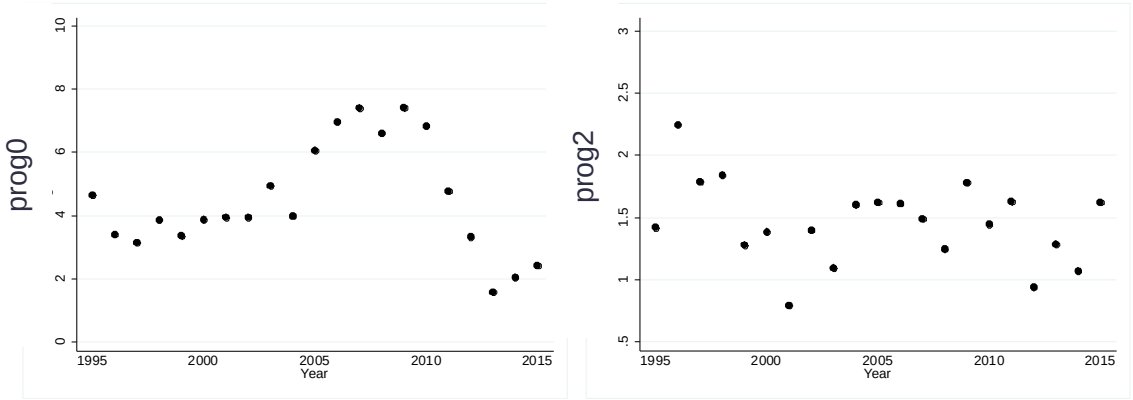


Figure 20: Sample variation of proportion of drug-candidates sourced externally via (a) alliances, (b) licensing and (c) acquisitions over time (Chapter 3). Each point is mean across firms in sample in that year

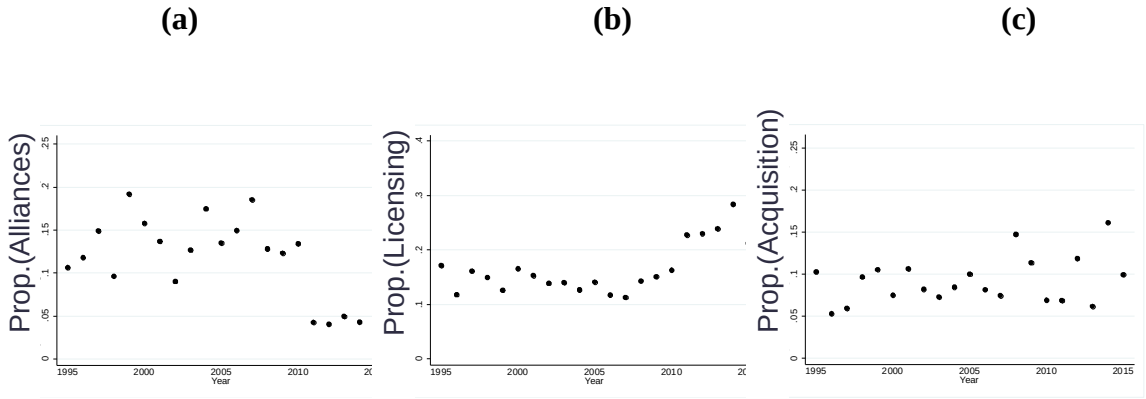
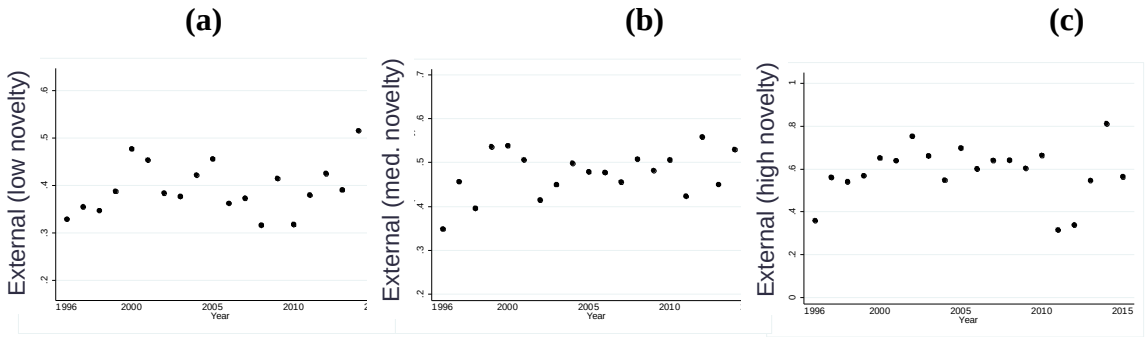


Figure 21: Sample variation of proportion of (a) low, (b) medium and (c) high novelty drug-candidates sourced externally over time (Chapter 3). Each point is mean across firms in sample in that year



Appendix 5: Additional Main Analysis Results

Propensity score matching - first stage regression & balance checks

Propensity score matching (PSM) models are used to generate matched samples of more decentralized and less decentralized firms in all three chapters of this dissertation. In the first step, a logit regression is used to predict the likelihood that a firm will have the relevant decentralization dimension based on a set of observable variables. Second, a standard regression of the pertinent innovation outcome against the appropriate structural variables using controls and fixed effects is undertaken for the matched sample identified using the first-stage logit regression. Matching is undertaken either using nearest neighbor (i.e. matching untreated and treated observations that have closest propensity scores) or caliper (i.e. setting a maximum propensity score difference between observations that are treated and untreated) methods (Caliendo & Kopeinig, 2008). Similar results are obtained using either approach. The focus of this analysis is to limit the possibility that firms' innovation outcomes result from inherent differences between firms which are more or less decentralized. This may result in regular regression analyses on the full sample being extrapolated to areas where there is no data on firms which are either centralized or decentralized limiting the effectiveness of any comparison.

In Chapter 2, for H1 and H2, the relationship between *R&D Decentralization* and two different invention outcomes (originality of inventions, quantity of inventions) are examined. The first stage logit regression is highlighted in Table 30 and Table 31 presents the balance test across all the covariates in the first-stage regression.

For H3, the relationship between *R&D Decentralization* and progression of inventions through the early development process is investigated and the match is based on the dichotomous variable *R&D Decentralization*. For H4, the variable *corporate decentralization* is related to the progression of inventions through the later stages of the development process. As *corporate decentralization* is a continuous variable, this variable is dichotomized around the median and matching is undertaken using this variable. Several cut-points between 0.2 and 0.6 are used to dichotomize *corporate decentralization,* similar results are obtained for each cut-point. In the analysis of mechanisms, the variable *R&D*

functional differentiation is related to the progression of inventions through the earlier stages of the development process and the match is based around this dichotomous variable.

Table 30: Chapter 2: Hypothesis 1-2 propensity score matching analyses. First stage logit regression

Dependent Variable	R&D Decentralization
R&D Functional Differentiation	-1.530**
	(0.410)
Corporate Decentralization	0.523
	(0.487)
performance	-1.435
	(1.711)
R&D Intensity	2.051**
	(0.773)
SG&A	-0.493+
	(0.287)
Size	0.752**
	(0.291)
slack	0.0968
	(0.0847)
CEO	-0.307
	(0.378)
SBU	-0.164
	(0.108)
tech. diversity	-1.238
	(1.119)
patent stock	0.0710
	(0.133)
competition	-0.900
	(4.730)
Year grouping	Y
N	803
Pseudo-R^2	0.0652
Log Likelihood	-280.3

Standard errors in parentheses: + $p < 0.1$, * $p < 0.05$, ** $p < 0.01$; Standard Errors clustered at firm level

Table 31: Chapter 2: Hypothesis 1-2 balance tests for propensity score matching model (Caliper=0.00035)

Variable	Mean		p>|t|
	R&D Decentralization =1	R&D Decentralization =0	
R&D Functional Differentiation	0.093	0.093	1.000
Corporate Decentralization	0.296	0.309	0.735
performance	0.074	0.093	0.115
R&D Intensity	0.156	0.144	0.454
SG&A	7.865	7.990	0.578
Size	8.782	8.904	0.575
Slack	2.472	2.330	0.608
CEO	0.107	0.107	1.000
SBU	2.467	2.467	1.000
tech. diversity	0.771	0.763	0.633
patent stock	1.085	1.171	0.689
competition	0.961	0.957	0.455
Year grouping variable	2.693	2.560	0.448

Table 32 illustrates the first stage logit regression results and Table 33 highlights the accompanying balance tests of the resulting matched samples which are used for subsequent analyses to test H3 and H4 as well as to examine the mechanistic analyses associated with the variable *R&D Functional Differentiation*.

As can be seen from Table 31 and Table 33, the balance tests indicate that for the majority of covariates the samples achieve balance. However, for H3, the decentralized sample is moderately smaller and has a smaller patent stock. For H4, the decentralized sample faces a moderately more competitive environment.

Table 32: Chapter 2: Hypothesis 3-4 Propensity score matching analyses. First stage logit regressions

Hypothesis	3	4	Mechanism
Dependent Variable	**R&D Decentralization**	**Corporate Decentralization (dichotomized)**	**R&D Functional Differentiation**
Table/Model	**Table 6 Model 3**	**Table 7 Model 4/5**	**Table 6 Model 6**
Phase	**Phase 0 to 1**	**Phase 2 to 3**	**Phase 1 to 2**
R&D Decentralization		0.485^{+}	-1.215**
		(0.253)	(0.399)
R&D fnl. differentiation	-1.195**	-0.350^{+}	
	(0.391)	(0.200)	
Corporate Decentralizn.	0.574		-0.872*
	(0.499)		(0.437)
performance	-0.540	-1.109	0.705
	(1.711)	(1.299)	(1.376)
R&D Intensity	2.224**	-3.192**	1.377*
	(0.803)	(1.132)	(0.662)
SG&A	-0.394	0.191	-0.339
	(0.325)	(0.213)	(0.261)
size	0.695*	-0.378^{+}	0.257
	(0.323)	(0.215)	(0.257)
slack	0.0467	-0.0865	0.240**
	(0.0886)	(0.0682)	(0.0694)
CEO	-0.426	-0.238	-0.141
	(0.399)	(0.244)	(0.307)
SBU	-0.129	0.366**	-0.130
	(0.111)	(0.0752)	(0.0884)
patent stock	-0.0318	-0.0974	0.327**
	(0.135)	(0.111)	(0.124)
portfolio	0.00435	0.0112	-0.0527**
	(0.00642)	(0.0108)	(0.0158)
external	0.852	-0.375	-0.410
	(0.564)	(0.353)	(0.375)
NCE	-0.301	0.774^{+}	2.156**
	(0.674)	(0.443)	(0.562)
bio	-1.340^{+}	0.962^{+}	3.067**
	(0.766)	(0.520)	(0.652)
tech. diversity	0.0846	1.749**	2.006**
	(0.705)	(0.477)	(0.548)
competition	1.768	-6.932^{+}	0.298
	(5.755)	(4.205)	(5.700)
Year grouping variable	Y	Y	Y
Firm Fixed Effects	N	N	N
Bus. Seg. Fixed Effects	Y	Y	Y
N	787	762	764
Pseudo-R^2	0.071	0.119	0.137
Log Likelihood	-273.1	-464.7	-357.8

Standard errors in parentheses:$^{+}$ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$; Standard errors clustered at firm level.

Table 33: Chapter 2: Hypothesis 3-4 balance tests for propensity score matching model

Hypothesis	H3: Means Post Balance			H4: Means Post Balance			Mechanism: Means Post Balance		
PSM Model	Table 6 Model 3 Nearest Neighbor (3)			Table 7 Models 4/5 Caliper (0.0002)			Table 6 Model 6 Caliper (0.008)		
Treatment Variable	R&D Decent.=1	R&D Decent.=0	p>|t|	Corporate Decent. =0	Corporate Decent.=1	p>|t|	R&D FD=1	R&D FD=0	p>|t|
R&D Decentralization				0.113	0.081	0.547	0.052	0.065	0.733
R&D functional differentiation	0.085	0.099	0.738	0.242	0.210	0.671			
Corporate Decentralization	0.303	0.312	0.802				0.204	0.206	0.949
performance	0.089	0.073	0.224	0.092	0.088	0.783	0.081	0.077	0.612
size	9.177	8.746	0.042	9.228	9.175	0.805	8.756	8.544	0.153
SG&A	8.256	7.887	0.068	8.402	8.298	0.645	7.940	7.723	0.121
slack	2.223	2.538	0.188	2.098	1.907	0.260	2.532	2.822	0.105
R&D Intensity	0.151	0.199	0.134	0.164	0.140	0.189	0.183	0.195	0.622
patent stock	1.450	1.103	0.068	1.440	1.355	0.720	1.264	1.135	0.364
CEO	0.085	0.099	0.738	0.097	0.145	0.413	0.103	0.071	0.315
competition	0.952	0.957	0.230	0.950	0.959	0.053	0.960	0.965	0.104
SBU	2.404	2.323	0.629	2.403	2.645	0.225	2.368	2.348	0.894
portfolio	36.89	30.74	0.202	20.27	18.82	0.624	11.31	9.284	0.057
external	0.504	0.516	0.745	0.514	0.560	0.200	0.479	0.476	0.912
NCE	0.554	0.534	0.583	0.554	0.528	0.531	0.542	0.563	0.545
bio	0.215	0.201	0.640	0.244	0.268	0.485	0.305	0.247	0.060
tech diversity	0.726	0.678	0.186	0.762	0.724	0.159	0.618	0.606	0.648
Year grouping variable	2.585	2.447	0.412	2.565	2.452	0.545	2.477	2.452	0.825

Table 34: Chapter 3: Hypothesis 1-3 propensity score matching analyses. First stage logit regression

Dependent Variable	R&D Decentralization
R&D Functional Differentiation	-0.994*
	(0.388)
Corporate Decentralization	0.631
	(0.561)
Business Development Role	0.682**
	(0.259)
Performance	0.357
	(1.827)
R&D Intensity	2.555**
	(0.898)
SG&A	-0.293
	(0.330)
Size	0.786*
	(0.340)
Slack	0.0972
	(0.0891)
New CEO	-0.319
	(0.401)
Total Patent Stock	-0.596**
	(0.200)
Patent Family Count	2.542**
	(0.944)
Competition	5.285
	(7.724)
SBU	-0.0739
	(0.117)
Technical Differentiation	-1.495
	(1.047)
Clinical Experience	3.333*
	(1.347)
Internal Overall Portfolio	-0.00447
	(0.00716)
External Overall Portfolio	-0.0177+
	(0.00975)
Portfolio Novelty	-0.459
	(0.866)
Bio	-4.775**
	(1.025)
Year grouping	Y
N	769
Pseudo-R^2	0.143
Log Likelihood	-251.44

Standard errors in parentheses $^{+}$ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$; Standard errors clustered at firm-level

In Chapter 3, for both hypotheses the key independent variable is *R&D Decentralization*. Thus, the propensity score matching is undertaken for firms that have centralized and decentralized R&D. The first stage model is illustrated in Table 34. Again balance in key co-variates is obtained for firms that have centralized and decentralized R&D as illustrated in Table 31.

Table 35: Chapter 3: Hypothesis 1-2 balance tests for propensity score matching model (Caliper=0.008)

Variable	Mean		p>|t|
	R&D Decentralization =1	R&D Decentralization =0	
R&D Functional Differentiation	0.086	0.151	0.175
Corporate Decentralization	0.305	0.267	0.266
Business Development Role	0.409	0.344	0.367
Performance	0.089	0.080	0.524
R&D Intensity	0.152	0.199	0.047
SG&A	8.279	8.248	0.872
Size	9.190	9.087	0.599
Slack	2.250	2.272	0.913
New CEO	0.086	0.075	0.789
Total Patent Stock	1.847	1.850	0.989
Patent Family Count	0.313	0.319	0.886
Competition	0.952	0.956	0.257
SBU	2.398	2.290	0.528
Technical Differentiation	0.780	0.763	0.487
Clinical Experience	0.433	0.406	0.607
Internal Overall Portfolio	44.473	39.301	0.370
External Overall Portfolio	38.473	37.172	0.783
Portfolio Novelty	0.955	0.957	0.931
Bio	0.206	0.214	0.748
Year grouping variable	2.581	2.763	0.237

In Chapter 4, for both hypotheses a key independent variable is *Corporate Decentralization*. As in Chapter 2, this variable is dichotomized around the median and matching is undertaken using this variable. Several cut-points were used to dichotomize *corporate decentralization*, similar results were obtained for each cut-point. The first stage matching model is illustrated in Table 36 and the table illustrating the balance in co-variate values between centralized and decentralized firms is illustrated in Chapter 4, Table 25.

Table 36: Chapter 4: Hypothesis 1-2 propensity score matching analyses. First stage logit regression

Dependent Variable	R&D Decentralization
SGA	-0.626*
	(0.290)
R&D Decentralization	0.400
	(0.336)
R&D Functional Differentiation	-0.215
	(0.271)
Performance	-4.725**
	(1.718)
R&D Intensity	-3.617**
	(1.272)
Sales	0.469
	(0.293)
CEO	-0.334
	(0.358)
Patent Stock	-0.0935
	(0.136)
New Approved	0.0777
	(0.0787)
Competition	-1.408
	(6.649)
Technical Diversification	2.315*
	(1.095)
Portfolio	-0.218
	(0.499)
Progress	0.0503*
	(0.0230)
External	-0.352
	(0.674)
NCE	-0.163
	(0.900)
Bio	1.103
	(0.986)
Portfolio Novelty	-0.340
	(0.811)
Year grouping	Y
N	390
Pseudo-R^2	0.076
Log Likelihood	-249.5

Standard errors in parentheses: $^{+}$ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$. ; Standard Errors clustered at firm level

Appendix 6: Additional Robustness Test Results

Chapter 2 robustness tests

The robustness tests undertaken in Chapter 2 are outlined fully in Table 37 (H1/H2), Table 38 (H3/4) and Table 39 (alternative patent quality measures for Hypothesis 1). With respect to the alternative measures for originality (Table 39) as described in footnote 13 in the Chapter 2, I find that R&D decentralization is associated with less radical patents. *"Radicalness of a patent is measured as a time invariant count of the number of IPC technology classes in which the patents cited by the given patent are, but in which the patent itself is not classified.*" (Squicciarini et al., 2013). Unsurprisingly, radicalness is strongly correlated with originality (pairwise correlation > 0.6). Consistent with Argyres and Silverman (2004) I observe that R&D decentralization is associated with less general patents. However, the effect size is lower than for originality as *R&D decentralization* is associated with patents that are 0.02 lower (0.13 standard deviations) in generality. Further, I observe that *R&D decentralization* is not associated with fewer breakthrough patents (i.e. top 1 % of highly cited patents 5 years after publication). These results are consistent with the theoretical argumentation provided in the main paper that R&D decentralization is associated with reduced intra-organizational knowledge flows which results in inventions drawing on a narrower knowledge base (i.e. less original and radical patents).

Further, for a small sub-sample of drug-candidates for which patent data can be matched, I conduct discrete-time event model analyses using logit regression models with a linear time function (Allison, 1982). The dependent variable in these models is a binary variable indicating whether a drug-candidate moves from one phase to the next in a specific year. Controlling for drug-level attributes such as therapeutic class, standard firm, and portfolio- level attributes and year fixed-effects, I find that drug-candidates associated with more radical patents are less likely to progress from pre-clinical to phase 1. However I see no impact of patent radicalness for progression through the later stages of development. This suggests that the impact of drug radicalness making development most challenging tends to occur in the earlier stages of development. This is consistent with the importance of knowledge flows being greater in the earlier stages of development in order to address the more complex technical problems associated with more radical drug-candidates.

Table 37: Chapter 2: summary of additional robustness tests – Hypotheses 1 and 2

	1. Coarsened Exact Matching (CEM)		2. Alternate Specification		5. Geographic Control Using PSM		6a. Lagged IV		6b. Rolling Average IV	
DV	**Originality**	**Quantity**	**Originality (OLS)**	**Log (Quantity)**	**Originality**	**Quantity**	**Originality**	**Quantity**	**Originality**	**Quantity**
R&D Decentralization	**-0.190***	**0.279****	**-0.0372****	**0.246+**	**-0.208***	**0.184***	**-0.162***	**0.186**	**-0.161***	**0.224**
	(0.0753)	**(0.0686)**	**(0.0132)**	**(0.147)**	**(0.0824)**	**(0.0929)**	**(0.0716)**	**(0.136)**	**(0.0705)**	**(0.158)**
R&D Func. Differentiation	-0.0450	0.132+	0.00868	0.164	0.00354	0.267	0.0374	0.0934	0.0121	0.125
	(0.0835)	(0.0742)	(0.0141)	(0.103)	(0.279)	(0.192)	(0.0605)	(0.0971)	(0.0603)	(0.0975)
Corporate Decentralization	-0.118	0.0863	0.0271	-0.0137	0.0344	0.0757	0.126	-0.0457	0.107	-0.0363
	(0.165)	(0.133)	(0.0270)	(0.189)	(0.201)	(0.256)	(0.121)	(0.153)	(0.123)	(0.180)
performance	-1.614*	-0.737	-0.0895	0.256	-2.127*	0.817	-0.460	0.268	-0.423	0.197
	(0.743)	(0.571)	(0.0769)	(0.668)	(0.940)	(0.787)	(0.352)	(0.638)	(0.346)	(0.620)
R&D Intensity	-0.138	0.0796	0.00248	0.346	0.157	0.113	-0.0154	0.199	0.0169	0.175
	(0.139)	(0.161)	(0.0293)	(0.288)	(0.492)	(0.291)	(0.185)	(0.309)	(0.138)	(0.270)
size	0.0836	0.348**	0.000748	0.346**	0.0480	0.0975	0.000568	0.287**	0.00144	0.313**
	(0.0588)	(0.0572)	(0.0102)	(0.0649)	(0.125)	(0.0843)	(0.0478)	(0.0634)	(0.0452)	(0.0610)
slack	0.0657*	-0.0477*	0.00144	-0.0118	-0.0256	-0.0183	0.00639	-0.00562	0.00767	-0.00391
	(0.0316)	(0.0222)	(0.00452)	(0.0332)	(0.0770)	(0.0445)	(0.0224)	(0.0333)	(0.0196)	(0.0299)
CEO	-0.120	-0.0292	-0.0149	0.0162	-0.446**	-0.0463	-0.0739	0.0346	-0.0744	0.0306
	(0.0863)	(0.0886)	(0.0125)	(0.0708)	(0.139)	(0.0959)	(0.0563)	(0.0600)	(0.0543)	(0.0595)
tech. diversity	-0.0876	1.571*	0.202*	2.893**	1.826*	2.095+	0.946**	2.051**	0.878**	1.842**
	(0.816)	(0.615)	(0.0769)	(0.561)	(0.894)	(1.147)	(0.351)	(0.646)	(0.341)	(0.646)
patent stock	-0.00867	0.499**	-0.00230	0.481**	-0.152	0.314**	-0.0131	0.478**	-0.0116	0.461**
	(0.0562)	(0.0503)	(0.00908)	(0.0675)	(0.123)	(0.0788)	(0.0418)	(0.0673)	(0.0398)	(0.0664)
competition	-1.140	-3.627+	-0.534*	-3.210	-3.613	-2.654	-2.447+	-2.988+	-2.484*	-3.238+
	(1.638)	(1.945)	(0.251)	(2.026)	(3.233)	(1.633)	(1.249)	(1.766)	(1.162)	(1.696)
R&D Geographical Cover					0.0168+	0.0488**				
					(0.00868)	(0.0102)				
Year Fixed Effects	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Bus. Seg. Fixed Effects	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Matching	CEM	CEM	N	N	PSM	PSM	N	N	N	N
N	329	329	803	803	176	186	773	773	803	803
R^2	0.0639	0.161	0.541	0.620	0.0990	0.167	0.061	0.134	0.0631	0.132
Log Likelihood	-208.2	-1815.9	487.8	-758.6	-115.3	-1018.4	-496.7	-4319.0	-513.0	-4480.0

Standard errors in parentheses: + $p < 0.1$, * $p < 0.05$, ** $p < 0.01$ Standard errors clustered at firm level. Originality regressions are Fractional Logit Regressions; Quantity regressions are Negative Binomial Regressions; PSM = Propensity Score Matching; CEM = Coarsened Exact Matching

Table 38: Chapter 2: summary of additional robustness tests – Hypotheses 3 and 4

Dependent variable	**Number of inventions progressing to next phase (prog)**					**Invention progress in focal year**		**Number of inventions progressing to next phase (prog)**					
Unit of analysis	**Firm-year**					**Invention-year**		**Firm-year**					
Robustness test	**1. CEM**			**2. Alternate Spec.**		**3. Individual Inv.**		**4. Novelty Measure**		**6a. Lagged IV**		**6b. Rolling Avg. IV**	
Hypothesis	**H3**	**H4**	**H4**	**H3**	**H4**	**H3**	**H4**	**H3**	**H4**	**H3**	**H4**	**H3**	**H4**
R&D Decentralization	**-0.216***	-0.0826	-0.214	**-0.150***	-0.201^{+}	**-0.263****	-0.158	**-0.213***	-0.171	**-0.133**	-0.282**	**-0.237***	-0.283*
	(0.0919)	(0.145)	(0.174)	**(0.0707)**	(0.105)	**(0.0965)**	(0.117)	**(0.103)**	(0.104)	**(0.0984)**	(0.100)	**(0.114)**	(0.114)
R&D Functional Decentralization	0.304**	0.0394	-0.159	-0.125^{+}	-0.0864	-0.0103	-0.179^{+}	-0.0435	-0.0653	-0.112	-0.152^{+}	-0.124	0.00547
	(0.109)	(0.124)	(0.156)	(0.0665)	(0.0907)	(0.0746)	(0.101)	(0.0792)	(0.0872)	(0.0770)	(0.0883)	(0.0888)	(0.0893)
Corporate Decentralization	0.209	**0.216***	**0.223**$^{+}$	0.0790	**0.328***	0.144	**0.259**$^{+}$	0.0886	**0.299**$^{+}$	0.0617	**0.144**	0.124	**0.0732**
	(0.188)	**(0.0962)**	**(0.129)**	(0.133)	**(0.165)**	(0.155)	**(0.150)**	(0.120)	**(0.165)**	(0.130)	**(0.186)**	(0.130)	**(0.174)**
performance	-2.456**	-0.278	-0.0293	-0.375	0.445	-0.441	0.709	0.00416	0.527	0.209	0.637	0.0542	0.371
	(0.891)	(0.859)	(1.104)	(0.407)	(0.419)	(0.444)	(0.519)	(0.343)	(0.404)	(0.402)	(0.401)	(0.409)	(0.433)
R&D Intensity	-0.0991	0.829	1.366	-0.00748	0.273	-0.0577	0.816*	0.616**	0.314	0.768**	0.703**	0.613**	0.340
	(0.933)	(0.762)	(0.982)	(0.209)	(0.328)	(0.239)	(0.399)	(0.179)	(0.309)	(0.188)	(0.242)	(0.195)	(0.244)
size	0.338**	0.112	-0.0918	0.0208	0.0857	0.183*	-0.230	0.272**	0.0779	0.281**	0.153	0.283**	0.169**
	(0.0782)	(0.0883)	(0.185)	(0.0875)	(0.0916)	(0.0920)	(0.168)	(0.0516)	(0.0925)	(0.0503)	(0.0999)	(0.0485)	(0.0544)
slack	0.0433	0.0210	-0.0540	0.0145	-0.0554	0.0183	-0.0610	0.0353^{+}	-0.0506	0.0388^{+}	-0.0234	0.0429*	0.00599
	(0.0613)	(0.0561)	(0.0795)	(0.0288)	(0.0437)	(0.0243)	(0.0487)	(0.0204)	(0.0419)	(0.0226)	(0.0425)	(0.0200)	(0.0325)
CEO	0.0325	-0.0433	-0.0858	0.0136	-0.0162	0.0622	0.0242	-0.00819	-0.0144	0.0324	0.00785	-0.00889	-0.0248
	(0.112)	(0.135)	(0.147)	(0.0617)	(0.0810)	(0.0819)	(0.105)	(0.0716)	(0.0806)	(0.0753)	(0.0884)	(0.0675)	(0.0816)
patent stock	0.0284	0.0991	-0.107	0.129*	-0.00464	0.000	0.000	0.0935*	0.0146	0.0948*	-0.00870	0.101*	0.0816*
	(0.0523)	(0.0730)	(0.151)	(0.0553)	(0.0614)	(0.000)	(0.000)	(0.0386)	(0.0646)	(0.0403)	(0.0597)	(0.0393)	(0.0386)
portfolio	0.008**	0.036**	0.046**	0.006**	0.0260**	-0.006**	0.001	0.00641*	0.0245**	0.007**	0.023**	0.008**	0.0178**
	(0.003)	(0.009)	(0.011)	(0.002)	(0.004)	(0.002)	(0.006)	(0.003)	(0.004)	(0.002)	(0.004)	(0.002)	(0.004)
external	0.00197	0.821*	0.889*	-0.591**	0.0737	-0.113	0.228	-0.396*	0.193	-0.600**	0.0235	-0.647**	0.202
	(0.335)	(0.342)	(0.439)	(0.223)	(0.251)	(0.247)	(0.349)	(0.183)	(0.224)	(0.193)	(0.263)	(0.183)	(0.216)
NCE	-1.435**	-0.327	-0.484	-0.868**	-0.757*	-0.888**	-0.727*			-0.596**	-0.736*	-0.601**	-0.230
	(0.417)	(0.426)	(0.694)	(0.246)	(0.340)	(0.307)	(0.362)			(0.205)	(0.313)	(0.205)	(0.257)
bio	0.160	0.0968	-0.400	-0.126	-0.284	-1.196**	-1.038*			0.509^{+}	-0.253	0.390	0.105
	(0.449)	(0.518)	(0.766)	(0.273)	(0.406)	(0.439)	(0.462)			(0.269)	(0.417)	(0.251)	(0.312)
tech. diversity	3.209**	1.157^{+}	0.896	1.503**	1.145**	-1.082**	-0.557	1.269**	1.097**	2.097**	1.411**	1.911**	1.340**
	(0.650)	(0.634)	(1.019)	(0.337)	(0.389)	(0.389)	(0.655)	(0.253)	(0.341)	(0.304)	(0.478)	(0.248)	(0.363)
competition	-11.76**	7.156	4.769	-3.857^{+}	-3.116	-4.023*	-0.971	-5.183*	-2.695	-6.421**	-3.896	-5.756**	-2.627
	(3.392)	(4.678)	(6.093)	(2.333)	(2.387)	(1.914)	(4.144)	(2.082)	(2.546)	(1.721)	(2.417)	(1.814)	(2.060)
novelty								-0.645**	-0.0978				
								(0.231)	(0.440)				
Year Fixed Effects	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Firm Fixed Effects	N	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y
Bus. Segment Fixed Effects	Y	Y	Y	Y	Y	N	N	Y	Y	Y	Y	Y	Y
Therapeutic Area Fixed Effects	N	N	N	N	N	Y	Y	N	N	N	N	N	N
N	256	392	392	785	762	21915	10616	787	762	736	713	787	762
Pseudo-R^2	0.313	0.170	0.215			0.0530	0.0367	0.235	0.218	0.241	0.196	0.240	0.194
Log Likelihood	-485.7	-515.0	-486.8	-1379.8	-871.5	-8552.1	-3034.6	-1573.4	-979.9	-1480.5	-953.8	-1562.2	-1009.8

Standard errors in parentheses: $^{+}$ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$. Unless stated regressions are negative binomial regressions. Standard errors clustered at the firm level. CEM = Coarsened Exact Matching. Negative Binomial Regressions

Table 39: Chapter 2: analyses using alternative measures to originality for Hypothesis 1

Dependent Variable	Originality	Radicalness	Breakthrough	Generality	Generality
R&D Decentralization	**-0.317****	**-0.146***	**0.756**	**-0.0861***	**-0.0159***
	(0.102)	**(0.070)**	**(0.503)**	**(0.0365)**	**(0.0079)**
Corporate Decentralization	0.352+	0.265	-1.623	0.0952	0.0237
	(0.206)	(0.168)	(1.016)	(0.0841)	(0.0191)
Model	FL	FL	FL	FL	OLS
Firm-level controls	Y	Y	Y	Y	Y
Business segment fixed effects	Y	Y	Y	Y	Y
Year fixed effects	Y	Y	Y	Y	Y
Firm fixed effects	N	N	N	N	Y
PS Matching	Y	Y	Y	N	N
N	144	144	144	779	779
Log Likelihood	-95.39	-80.36	-3.848	-497.1	-497.1

Standard errors in parentheses: + $p < 0.1$, * $p < 0.05$, ** $p < 0.01$; Standard errors clustered at firm level

FL = fractional logit, OLS= ordinary least squares, PS = propensity score (use caliper of 0.00035, but observe similar results using alternative matching approaches).

Chapter 3 robustness tests

In chapter 3, I undertake three separate robustness tests.

First, I evaluate whether the same results are obtained with 1-year-lagged values of R&D Decentralization. As can be seen in Table 40 both hypotheses 1 and 2 are supported using lagged values of this variable as outlined in Chapter 3.

Second, as illustrated in Table 14, all the hypotheses are supported using firm-fixed effects.

Third, Table 41 outlines analyses in which I change the unit of analysis from the firm-year to the individual invention or drug-candidate. Both Hypotheses 1 and 2 continue to be supported using this approach in which I can control for individual drug-level variance (e.g. therapeutic class).

Table 40: Chapter 3: robustness analyses – lagged R&D Decentralization

Hypothesis DV	H1 External	H2 Acq	H2 Alliance	H2 License	Mech. Low	Mech. Med	Mech. High
R&D Decentralization	**0.180***	**0.189**	**-0.308+**	**0.266***	**0.106**	**0.246***	**0.0601**
	(0.0802)	**(0.180)**	**(0.166)**	**(0.120)**	**(0.142)**	**(0.115)**	**(0.248)**
R&D Functional Differentiation	-0.0503	-0.120	0.0107	-0.0355	-0.0306	0.367**	0.250
	(0.0844)	(0.167)	(0.136)	(0.153)	(0.157)	(0.137)	(0.271)
Corporate Decentralization	0.210	0.0239	-0.0702	0.641**	0.490+	0.623**	0.676
	(0.158)	(0.377)	(0.272)	(0.236)	(0.273)	(0.182)	(0.517)
Business Development Role	0.0793	-0.0112	-0.0859	0.149	-0.0314	-0.167	-0.224
	(0.0813)	(0.159)	(0.135)	(0.113)	(0.123)	(0.127)	(0.230)
Performance	-0.327	-0.694	0.453	-0.535	-0.320	-1.053	-2.025
	(0.614)	(1.214)	(0.779)	(0.661)	(1.203)	(0.915)	(1.337)
R&D Intensity	-0.123	0.0884	0.534+	-0.739+	0.166	-0.656*	-0.406
	(0.254)	(0.384)	(0.319)	(0.390)	(0.501)	(0.282)	(0.685)
SG&A	-0.0608	-0.166	0.0766	-0.132	-0.217	-0.150	-0.338
	(0.0753)	(0.172)	(0.120)	(0.168)	(0.147)	(0.105)	(0.274)
Size	0.0624	0.0737	0.212+	0.00520	0.322+	0.0892	0.478+
	(0.0918)	(0.214)	(0.126)	(0.162)	(0.186)	(0.110)	(0.286)
Slack	0.00487	0.0725	0.00446	-0.00637	0.0918+	0.0381	0.0374
	(0.0295)	(0.047)	(0.0575)	(0.0438)	(0.0492)	(0.0446)	(0.0737)
New CEO	-0.203*	-0.494+	-0.00570	-0.0557	-0.298+	-0.357**	-0.373
	(0.0937)	(0.278)	(0.165)	(0.103)	(0.160)	(0.136)	(0.299)
Total Patent Stock	-0.0268	0.167*	-0.108	0.0139	0.0134	0.0279	-0.150
	(0.0489)	(0.081)	(0.0890)	(0.0592)	(0.0806)	(0.0657)	(0.119)
Patent Family Count	0.0625	-0.984+	-0.153	0.616	-0.408	-0.210	0.0146
	(0.291)	(0.550)	(0.397)	(0.395)	(0.566)	(0.324)	(0.714)
Competition	-4.881+	-14.49**	2.216	8.279*	-1.349	0.236	4.750
	(2.817)	(4.037)	(3.247)	(3.430)	(3.763)	(3.918)	(4.202)
SBU	-0.687**	-1.658	0.142	-1.239**	0.562	-0.173	-0.108
	(0.258)	(1.371)	(0.330)	(0.282)	(0.387)	(0.404)	(0.544)
Technical Differentiation	-1.163**	-0.787	1.207	-0.408	-2.222	0.307	-0.958
	(0.386)	(0.845)	(0.864)	(0.650)	(1.517)	(0.881)	(1.302)
Clinical Experience	-0.353	-0.907	0.588	-0.526	0.470	-0.0175	0.534
	(0.299)	(0.671)	(0.710)	(0.328)	(0.454)	(0.446)	(1.200)
Internal Overall Portfolio	-0.0106**	-0.015**	-0.0067*	0.00216	-0.0114**	-0.0081**	-0.00270
	(0.00236)	(0.005)	(0.0028)	(0.00259)	(0.00326)	(0.00304)	(0.00497)
External Overall Portfolio	0.00550	0.0157+	0.00444	0.00317	0.00211	0.0112*	0.00140
	(0.00351)	(0.008)	(0.0057)	(0.00335)	(0.00377)	(0.00488)	(0.0102)
Portfolio Novelty	-0.714*	-1.853**	0.177	-0.731+	-0.311	-0.997+	-0.160
	(0.351)	(0.568)	(0.598)	(0.439)	(0.639)	(0.581)	(0.789)
Bio	-0.223	-0.126	1.151*	-0.0404	-0.583	0.177	-0.00513
	(0.303)	(0.560)	(0.515)	(0.402)	(0.850)	(0.525)	(0.626)
Year Fixed Effects	Y	Y	Y	Y	Y	Y	Y
Business Category Fixed Effects	Y	Y	Y	Y	Y	Y	Y
Therapeutic Category Fixed Effects	Y	Y	Y	Y	Y	Y	Y
N	748	767	767	767	627	697	440
Log Likelihood	-473.5	-210.1	-258.1	-319.4	-393.6	-450.6	-270.4

Standard errors in parentheses: + $p < 0.1$, * $p < 0.05$, ** $p < 0.01$; Standard errors clustered at firm level
Fractional Logit Regressions

Table 41: Chapter 3: robustness analyses – individual drug-level analysis

Hypothesis DV	H1 External	H2 Alliance	H2 License	H2 Acquisition
R&D Decentralization	**0.185***	**0.00376**	**0.317****	**0.185+**
	(0.0937)	**(0.0949)**	**(0.0749)**	**(0.0953)**
Corporate Decentralization	0.0354	0.0363	0.435**	-0.391*
	(0.173)	(0.151)	(0.129)	(0.167)
Business Development Role	0.00823	-0.151*	0.0925	0.0156
	(0.0732)	(0.0732)	(0.0616)	(0.0747)
Performance	-0.511	-0.775	0.305	-1.239*
	(0.701)	(0.558)	(0.512)	(0.619)
R&D Intensity	-0.309	-0.197	0.0454	-0.849+
	(0.399)	(0.345)	(0.331)	(0.435)
SG&A	0.107	0.388**	-0.155	0.273*
	(0.120)	(0.116)	(0.106)	(0.131)
Size	-0.0501	-0.163	0.0861	-0.183
	(0.121)	(0.112)	(0.104)	(0.130)
Slack	0.00043	-0.0443	0.0238	0.00693
	(0.0505)	(0.0377)	(0.0322)	(0.0390)
New CEO	-0.174*	0.0139	-0.0708	-0.513**
	(0.0847)	(0.0949)	(0.0855)	(0.118)
Total Patent Stock	-0.0000	-0.000306**	0.000153*	0.00000014
	(0.0001)	(0.0000791)	(0.0000684)	(0.0000840)
Patent stock therapeutic class	0.000473	0.000767+	0.000385	0.000110
	(0.00051)	(0.000451)	(0.000377)	(0.000494)
Competition	-6.027*	-3.383	8.186**	-21.10**
	(2.567)	(2.343)	(2.326)	(1.961)
SBU	-0.0469	-0.0865**	-0.0299	-0.0806*
	(0.0323)	(0.0312)	(0.0260)	(0.0344)
Technical Differentiation	-0.349	-1.209**	-0.228	0.606
	(0.392)	(0.334)	(0.325)	(0.387)
Clinical Experience	-0.0028	-0.00272+	-0.00494**	0.000701
	(0.0021)	(0.00157)	(0.00128)	(0.00165)
Internal Overall Portfolio	-0.0049**	-0.00612**	0.00156	-0.0159**
	(0.00174)	(0.00180)	(0.00148)	(0.00199)
External Overall Portfolio	0.00422	0.0104**	0.00755**	-0.00173
	(0.00348)	(0.00215)	(0.00186)	(0.00223)
Internal Portfolio Ther class	-0.0229+	-0.0266**	-0.000549	-0.0485**
	(0.0135)	(0.00988)	(0.00770)	(0.0115)
External Portfolio Ther class	0.00422	-0.000478	0.00755**	0.0118
	(0.00348)	(0.00907)	(0.00186)	(0.0100)
NCE	-0.584**	-0.424**	-0.776**	-0.403**
	(0.129)	(0.0996)	(0.0804)	(0.107)
Year Fixed Effects	Y	Y	Y	Y
Therapeutic Area Fixed Effects	Y	Y	Y	Y
Clinical Phase Fixed Effects	Y	Y	Y	Y
Progression Controls	N	Y	Y	Y
N	12016	12016	12016	12016
Log Likelihood	-7039.5	-11670.4	-11670.4	-11670.4

Standard errors in parentheses: $^{+}$ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$; Standard errors clustered at firm level
Fractional logit regressions

Chapter 4 robustness tests

In Chapter 4, as for chapters 2 and 3, I examine the impact of using lagged versions of *Corporate Decentralization* as opposed to the unlagged values. For a two- and three-year rolling averages (current and past one or two years average) of *Corporate Decentralization*, *SG&A* and *Top 5 Products* I obtain similar results for Hypotheses 1. In contrast for Hypothesis 2, although I see directional support in the form of negative coefficients for *R&D Decentralization* x *Top 5 Products*, the result for the 2-year rolling average is statistically insignificant. The results are illustrated in Table 42 and further discussed in Chapter 4.

Second, I examine whether the main results are robust to changes in the product concentration measure (Hypothesis 2). Namely instead of the Top 5 products, I examine the Top 1 and 3 products. I find broadly similar results to the main analyses as illustrated in Table 43.

Table 42: Chapter 4: robustness analyses – lagged structural variables

DV= 1-yr New Sales Proportion	2-year rolling average	3-year rolling average
Corporate Decentralization	**7.736****	**10.01****
	(2.598)	**(3.343)**
H1: Corporate Decentralization x SG&A	**-0.719****	**-0.906****
	(0.274)	**(0.326)**
H2: Corporate Decentralization x Top 5 Products	**-2.138**	**-4.390**$^{+}$
	(1.862)	**(2.618)**
SG&A	-0.0219	-0.270
	(0.206)	(0.245)
Top 5 Products	0.438	2.520^{+}
	(1.071)	(1.423)
R&D Decentralization	-0.470*	-0.553^{+}
	(0.238)	(0.283)
R&D Functional Differentiation	0.479	0.414
	(0.339)	(0.375)
Performance	-1.811	-2.063^{+}
	(1.163)	(1.209)
R&D Intensity	-1.957*	-2.387**
	(0.875)	(0.822)
Sales	0.0513	0.0391
	(0.264)	(0.234)
CEO	0.313^{+}	0.287
	(0.183)	(0.178)
Patent Stock	-0.492**	-0.432*
	(0.188)	(0.199)
New Approved	0.128*	0.179**
	(0.0504)	(0.0487)
Competition	-1.953	-0.777
	(5.237)	(6.752)
Technical Diversification	0.230	0.309
	(0.402)	(0.537)
Portfolio	0.0229	0.203
	(0.474)	(0.536)
Progress	0.0373*	0.0279
	(0.0165)	(0.0172)
External	0.0608	0.152
	(0.657)	(0.566)
NCE	-0.0459	0.177
	(0.654)	(0.778)
Bio	-0.461	-0.113
	(0.570)	(0.624)
Portfolio Novelty	1.811	1.109
	(1.236)	(1.124)
Year Fixed Effects	Y	Y
Category Fixed Effects	Y	Y
Firm Fixed Effects	Y	Y
Matching	N	N
N	386	367
Log Likelihood	-30.09	-27.23

Standard errors in parentheses: $^{+}$ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$; Errors clustered at firm level
Fractional Logit Regressions

Table 43: Chapter 4: robustness analyses – different product concentration variables

DV= 1-yr New Sales Proportion	Top 1 Products	Top 3 Products
H1: Corporate Decentralization	**1.579****	**1.552****
	(0.477)	**(0.591)**
H2: Corporate Decentralization x SG&A	**-0.508***	**-0.437***
	(0.246)	**(0.220)**
H3: Corporate Decentralization	**-2.949**$^{+}$	**-1.177**
x Top 1 or 3 Products	**(1.750)**	**(1.200)**
SG&A	0.468*	0.483*
	(0.214)	(0.206)
Top 1 or 3 Products	-0.717	-1.913**
	(0.576)	(0.646)
R&D Decentralization	-0.184	-0.212
	(0.228)	(0.225)
R&D Functional Differentiation	0.638^{+}	0.607^{+}
	(0.339)	(0.328)
Performance	-0.470	-0.157
	(0.985)	(0.911)
R&D Intensity	-0.530	-0.384
	(0.636)	(0.641)
Sales	-0.713**	-0.771**
	(0.239)	(0.245)
CEO	0.285	0.305
	(0.203)	(0.214)
Patent Stock	-0.439*	-0.498**
	(0.185)	(0.186)
New Approved	0.136**	0.129**
	(0.0512)	(0.0500)
Competition	-2.072	-1.343
	(4.670)	(4.433)
Technical Diversification	0.190	0.209
	(0.463)	(0.458)
Portfolio	-0.0559	0.0259
	(0.448)	(0.451)
Progress	0.0419*	0.0423*
	(0.0171)	(0.0168)
External	-0.205	-0.0426
	(0.614)	(0.579)
NCE	0.180	0.261
	(0.678)	(0.650)
Bio	-0.477	-0.351
	(0.664)	(0.577)
Portfolio Novelty	1.893	2.043^{+}
	(1.214)	(1.221)
Year Fixed Effects	Y	Y
Category Fixed Effects	Y	Y
Firm Fixed Effects	Y	Y
Matching	N	N
N	396	396
Log Likelihood	-32.23	-32.20

Standard errors in parentheses: $^{+}$ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$; Errors clustered at firm level
Fractional Logit Regressions

Appendix 7: Additional Mechanistic Analyses

Chapter 2 mechanistic analyses

The full regression tables for these analyses are illustrated in Table 44 to Table 50. In Table 44 the variable *Tech. Diversity* measures the degree of diversity of firms' development portfolios and is operationalized through the breadth of therapeutic classes of a firm's current development portfolio. This variable is measured using a Herfindahl index (subtracted from 1 to ensure higher values represent more diverse portfolios) and is estimated using a similar approach to other studies in the pharmaceutical industry empirical context (Diestre & Rajagopalan, 2012). The key assumption in this analysis is that a more diverse development portfolio is associated with a broader array of knowledge within a focal firm. This assumption was validated through the managerial interviews that highlighted that the therapeutic classes associated with firms' portfolios provided a reflection of the internal knowledge base within a focal firm. For example:

> *"We dropped oncology from our portfolio and eventually lost our capability in the area meaning it will be difficult to pick up new candidates in this domain in the future"*

Consistent with my theoretical argumentation the interaction term *Tech. Diversity* x *R&D Decentralization* is statistically significant and negative for the pre-clinical to phase 1 transition examined in Hypothesis 3. This suggests that the benefits of rich intra-organizational knowledge flows, which are limited in the case of firms with a narrower array of technical knowledge, are outweighed by the stronger incentives associated with R&D decentralization. At high *Tech. Diversity*, the opposite occurs.

In my theoretical argumentation I suggest that the importance of rich intra-organizational knowledge flows decreases as inventions progress through the various stages of development. I observe that the coefficients for *R&D decentralization* is significantly lower for the pre-clinical to phase 1 transition than the phase 1 to 2 and phase 3 to pre-registration transitions (p-values for Wald Tests comparing coefficients across regressions are 0.01 and 0.00 respectively). This is consistent with the importance of knowledge flows declining through development as R&D centralization appears to facilitate invention progression less through the later stages of development implying that

access to a firm's broader knowledge base is less important. However, for the critical phase 2 to 3 transition the coefficient for *R&D Decentralization* is not significantly different from that for the pre-clinical to phase 1 transition (p-value for Wald Test comparing coefficients is 0.79). This suggests that knowledge flows may still play an important role for the phase 2 to 3 transition as firms may require additional technical due diligence to ensure that they can commit the resources to progress a drug candidate into phase 3 clinical trials.

Table 44: Chapter 2 mechanistic analysis examining how breadth of firms' knowledge can impact role of R&D Decentralization in early development

Dependent Variable	**Number of inventions progressing to next phase**			
Phase Transition	**PC-1**	**1-2**	**2-3**	**3-PR**
R&D Decentralization	0.714*	-0.0239	0.831**	0.596+
	(0.306)	(0.614)	(0.310)	(0.350)
R&D Functional Differentiation	-0.0725	0.141+	0.0697	-0.0433
	(0.0775)	(0.0773)	(0.0778)	(0.0793)
Corporate Decentralization	0.168	0.113	0.0797	0.0126
	(0.129)	(0.179)	(0.136)	(0.138)
R&D Decentralization x Tech. Diversity	**-1.150****	**-0.157**	**-1.279****	**-0.800+**
	(0.393)	**(0.769)**	**(0.398)**	**(0.457)**
Tech. Diversity	2.032**	1.908**	1.655**	1.399**
	(0.268)	(0.256)	(0.343)	(0.225)
Performance	-0.00447	0.620+	0.302	0.673+
	(0.412)	(0.358)	(0.419)	(0.398)
R&D Intensity	0.586**	0.295	0.241	0.595**
	(0.202)	(0.202)	(0.266)	(0.186)
Size	0.287**	0.0892+	0.153**	0.105*
	(0.0498)	(0.0472)	(0.0508)	(0.0494)
Slack	0.0403*	-0.0112	0.00407	0.0480*
	(0.0205)	(0.0268)	(0.0319)	(0.0212)
CEO	-0.00382	0.00654	-0.00970	-0.183*
	(0.0696)	(0.0733)	(0.0801)	(0.0793)
Patent Stock	0.101**	0.0135	0.0819*	0.0132
	(0.0385)	(0.0363)	(0.0401)	(0.0316)
Portfolio	0.00723**	0.0286**	0.0178**	0.0545**
	(0.00250)	(0.00590)	(0.00345)	(0.00517)
External	-0.690**	0.114	0.217	0.0949
	(0.190)	(0.166)	(0.216)	(0.131)
NCE	-0.600**	0.299	-0.172	-0.652**
	(0.207)	(0.192)	(0.231)	(0.189)
Bio	0.410	0.887**	0.220	-0.166
	(0.252)	(0.266)	(0.265)	(0.201)
Competition	-6.109**	-1.593	-2.574	3.214*
	(1.871)	(2.292)	(2.109)	(1.360)
Year Fixed Effects	Y	Y	Y	Y
Business Segment Fixed Effects	Y	Y	Y	Y
N	787	764	762	785
Pseudo-R^2	0.242	0.227	0.195	0.216
Log Likelihood	-1559.3	-1195.6	-1008.6	-1032.6

Standard errors in parentheses: $^{+}$ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$; Standard errors clustered at firm level
Negative binomial regressions

Two alternative measures of the novelty of a firm's portfolio are *NCE* and *Novelty*. *NCE* represents the proportion of drug-candidates within a firm's portfolio that are new chemical entities. New chemical entities represent new drug candidates for which no component has been previously approved by the Federal Drug Administration. *Novelty* represents the mean novelty of firms' portfolios on a 0-2 scale (Klueter, 2013). Drug candidates whose mechanism of action and origin of material are new to the focal firm in a specific therapeutic class have a *Novelty* value of 2, drug-candidates where one of the mechanism of action or origin of material are new have a *Novelty* value of 1 and if neither the mechanism of action nor the origin of material within a specific therapeutic class are new to the focal firm then the *Novelty* value is 0. Drug candidates that represent a new mechanism in a specific therapeutic class for a firm entail greater challenges as scientists need to develop an understanding of both the mechanism and how to apply that mechanism in a drug candidate i.e. suitable pharmo-kinetics profile, appropriate delivery mechanism, understanding how the drug candidate impacts target receptors in the body. This increases the technical complexity in developing a drug candidate. Similar considerations apply if the origin of material is new to a specific therapeutic class e.g. if a firm has never used antibodies in oncology this provides a greater technical challenge. However, the firm may have experience of this mechanism or have used a material in the same class in in a different therapeutic class and be able to access this valuable information through cross-organizational knowledge flows.

R&D centralization should facilitate access to a firm's broader organizational knowledge thereby enabling more novel inventions to progress through the early stages of development. Empirically if this is the case the interaction terms *R&D Decentralization* x *Novelty* and *R&D Decentralization* x *NCE* should be negative and statistically significant. Table 45 illustrates support for this argumentation. Also, consistent with the hypothesis development in the main paper, the interaction term is only significant for early development i.e. pre-clinical to phase 1 transition. This suggests that the importance of cross-organizational knowledge flows diminishes as an invention progresses through the development process.

Table 45: Chapter 2 mechanistic analysis examining how complexity of firms' development portfolio can impact role of R&D Decentralization in early development

Dependent Variable	**Number of inventions progressing to next phase**							
Phase Transition	**PC-1**	**1-2**	**2-3**	**3-PR**	**PC-1**	**1-2**	**2-3**	**3-PR**
R&D Decentralization	0.651**	-0.339	0.281	0.301	0.381	-0.392	-0.578	0.104
	(0.220)	(0.284)	(0.329)	(0.238)	(0.405)	(0.344)	(0.466)	(0.455)
R&D Functional Differentiation	-0.0728	0.148+	0.0570	-0.0480	-0.0460	0.187*	0.0753	-0.0674
	(0.0786)	(0.0772)	(0.0803)	(0.0784)	(0.0786)	(0.0781)	(0.0785)	(0.0765)
Corporate Decentralization	0.172	0.121	0.0695	0.0179	0.0830	0.0719	0.0531	-0.0345
	(0.131)	(0.182)	(0.135)	(0.138)	(0.120)	(0.179)	(0.139)	(0.130)
R&D Decentralization x NCE	**-1.474****	**0.336**	**-0.775**	**-0.605**				
	(0.363)	**(0.458)**	**(0.539)**	**(0.511)**				
NCE	-0.495*	0.250	-0.128	-0.586**				
	(0.199)	(0.207)	(0.235)	(0.191)				
R&D Decentralization x Novelty					**-0.669+**	**0.266**	**0.495**	**-0.140**
					(0.403)	**(0.415)**	**(0.525)**	**(0.527)**
Novelty					-0.619**	-0.349	-0.332	-0.428+
					(0.227)	(0.315)	(0.344)	(0.252)
Performance	-0.0257	0.616+	0.317	0.745+	0.0429	0.427	0.290	0.782*
	(0.410)	(0.360)	(0.420)	(0.393)	(0.341)	(0.346)	(0.394)	(0.368)
R&D Intensity	0.580**	0.301	0.241	0.652**	0.683**	0.255	0.244	0.669**
	(0.204)	(0.200)	(0.261)	(0.178)	(0.167)	(0.231)	(0.254)	(0.206)
Size	0.284**	0.0916+	0.159**	0.106*	0.274**	0.112+	0.154**	0.101+
	(0.0492)	(0.0473)	(0.0531)	(0.0503)	(0.0525)	(0.0653)	(0.0581)	(0.0516)
Slack	0.0435*	-0.0113	0.00643	0.0471*	0.0369+	-0.0116	0.00185	0.0399*
	(0.0205)	(0.0264)	(0.0329)	(0.0204)	(0.0204)	(0.0270)	(0.0332)	(0.0185)
CEO	0.0000474	0.00739	-0.0131	-0.183*	-0.0068	-0.0008	-0.0141	-0.166+
	(0.0689)	(0.0733)	(0.0793)	(0.0791)	(0.0717)	(0.0731)	(0.0787)	(0.0848)
Patent Stock	0.109**	0.00917	0.0845*	0.0150	0.0904*	0.0198	0.0771+	0.00151
	(0.0397)	(0.0365)	(0.0397)	(0.0296)	(0.0379)	(0.0380)	(0.0430)	(0.0297)
Portfolio	0.00717**	0.0286**	0.0182**	0.0542**	0.0064*	0.0308**	0.0191**	0.0557**
	(0.00254)	(0.00595)	(0.00338)	(0.00511)	(0.0025)	(0.0059)	(0.0035)	(0.0053)
External	-0.682**	0.107	0.209	0.0946	-0.401*	0.174	0.293	0.159
	(0.191)	(0.163)	(0.219)	(0.132)	(0.184)	(0.165)	(0.200)	(0.134)
Bio	0.402	0.850**	0.176	-0.169				
	(0.251)	(0.264)	(0.268)	(0.201)				
Tech. Diversity	1.961**	1.895**	1.423**	1.317**	1.285**	1.510**	1.121**	0.939**
	(0.249)	(0.251)	(0.330)	(0.227)	(0.256)	(0.319)	(0.291)	(0.202)
Competition	-6.000**	-1.616	-2.290	3.433*	-4.929*	0.114	-1.376	3.750*
	(1.887)	(2.313)	(2.034)	(1.438)	(2.051)	(2.227)	(2.085)	(1.470)
Year Fixed Effects	Y	Y	Y	Y	Y	Y	Y	Y
Business Segment Fixed Effects	Y	Y	Y	Y	Y	Y	Y	Y
N	787	764	762	785	787	764	762	785
Pseudo-R^2	0.244	0.227	0.194	0.216	0.236	0.222	0.192	0.212
Log Likelihood	-1555.7	-1195.3	-1010.4	-1033.2	-1572.1	-1203.0	-1011.9	-1038.9

Standard errors in parentheses: + $p < 0.1$, * $p < 0.05$, ** $p < 0.01$; Standard errors clustered at firm level
Negative binomial regressions

Table 46 illustrates the regression analysis examining how the mean patent grant-lag for a firm's set of patent families filed in a focal year is associated with *R&D Decentralization*. Consistent with an incentives based argumentation, R&D decentralization is associated with shorter lags between the filing and granting of patents.

This is because greater efforts are undertaken by managers in firms with decentralized R&D to get patents granted. This is still after controlling for factors such as the originality and number of claims associated with firms' patents which may also influence the time taken for patents to proceed from filing to grant.

Table 46: Chapter 2 mechanistic analysis examining how patent grant lag is associated with firms' structural measures

Dependent Variable	Grant Lag (Days)	Grant Lag (Days)
R&D Decentralization	**-81.65****	**-50.20***
	(28.72)	**(20.03)**
R&D functional differentiation	63.20^{+}	15.69
	(33.63)	(29.00)
Corporate Decentralization	61.68	70.18
	(63.94)	(63.00)
originality	-200.3*	-134.8
	(96.97)	(91.80)
claims	-3.116	1.470
	(3.073)	(3.013)
Non-patent cites	5.528**	1.643
	(1.762)	(1.753)
performance	-334.1^{+}	-214.7
	(169.0)	(139.4)
R&D Intensity	-91.11	4.625
	(68.25)	(45.67)
size	3.232	-36.07
	(22.44)	(24.66)
slack	0.478	-0.0646
	(8.024)	(9.731)
CEO	18.39	19.71
	(16.60)	(17.48)
tech. diversity	-170.3	-164.8
	(205.8)	(214.5)
patent stock	13.03	32.50
	(15.12)	(26.77)
competition	1585.9^{+}	-157.4
	(795.5)	(530.2)
Year FE	Y	Y
Firm FE	N	Y
Business Segment FE	Y	Y
N	782	782
R^2	0.618	0.644

Standard errors in parentheses: $^{+}$ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$; Standard errors clustered at firm level. Ordinary least squares regressions as Grant Lag is normally distributed.

Table 47: Chapter 2 mechanistic analysis examining whether firms simply progress inferior drug-candidates. Drug candidates entering phase 2, likelihood and hazard of progressing into phase 3

Model	1	2	3	4	5	6	7	8
Model Type	**Logit - linear time function**					**Cox Proportional Hazards model**		
R&D Functional Differentiation12	**0.0737**	**0.0828**	**0.0926**	**0.0949**	**0.0916**	**0.0586**	**0.0580**	**0.0868**
	(0.234)	**(0.238)**	**(0.249)**	**(0.251)**	**(0.255)**	**(0.166)**	**(0.169)**	**(0.175)**
Firm-year level controls	Y	Y	Y	Y	Y	Y	Y	Y
Business Segment Fixed Effects	N	Y	Y	Y	Y	Y	Y	Y
Year Fixed Effects	N	N	Y	Y	Y	Y	Y	Y
Drug-level controls	N	N	N	Y	Y	N	Y	Y
Therapeutic Area Fixed Effects (Drug level)	N	N	N	N	Y	N	N	Y
N	5216	5216	5216	5216	5168	4473	4473	4473
Pseudo R^2	0.0142	0.0181	0.0346	0.0347	0.0590	0.0203	0.0206	0.0360
Log Likelihood	-1354.4	-1349.0	-1326.3	-1326.2	-1289.2	-2096.8	-2096.2	-2063.2

Standard errors in parentheses: $^{+}$ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$; Standard errors clustered at firm level.

Table 48: Chapter 2 mechanistic analysis examining whether firms simply progress inferior drug-candidates. Drug candidates entering phase 3, likelihood and hazard of progressing into pre-registration

Model	1	2	3	4	5	6	7	8
Model Type	**Logit - linear time function**					**Cox Proportional Hazards model**		
Corporate Decentralization23	**0.131**	**0.180**	**0.126**	**0.0551**	**0.107**	**-0.0178**	**-0.109**	**-0.0747**
	(0.330)	**(0.318)**	**(0.336)**	**(0.340)**	**(0.379)**	**(0.308)**	**(0.326)**	**(0.320)**
Firm-year level controls	Y	Y	Y	Y	Y	Y	Y	Y
Business Segment Fixed Effects	N	Y	Y	Y	Y	Y	Y	Y
Year Fixed Effects	N	N	Y	Y	Y	Y	Y	Y
Drug-level controls	N	N	N	Y	Y	N	Y	Y
Therapeutic Area Fixed Effects (Drug level)	N	N	N	N	Y	N	N	Y
N	3578	3578	3578	3578	3578	2712	2712	2712
Pseudo R^2	0.00536	0.00898	0.0249	0.0281	0.0474	0.0156	0.0208	0.0287
Log Likelihood	-1393.6	-1388.5	-1366.3	-1361.7	-1334.8	-2083.3	-2072.3	-2055.5

Standard errors in parentheses: $^{+}$ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$; Standard Errors clustered at firm level.

Table 47 and Table 48 illustrate a series of tests undertaken to evaluate whether greater overall decentralization and R&D functional differentiation are associated with the progression of inferior drug-candidates through development thereby explaining why more candidates progress for firms with these structures. To test whether this is the case, the likelihood of a drug that has progressed from Phase 1 to 2 progressing into Phase 3 is examined for firms with and without functionally differentiated R&D (i.e. separate research and separate development units) and the likelihood of a drug candidate that has been progressed from Phase 2 to 3 progressing into Pre-Registration (PR) Status is evaluated for firms that are more or less decentralized at a corporate level. Two econometric approaches are used to examine the likelihood of a drug progressing from one phase to the next. First, using a maximum likelihood approach that accounts for the discrete nature of the time-element of the data set (i.e. clinical trial phase is only available per year), logit analyses are undertaken in which the unit of analysis is the drug-candidate-year and the dependent variable indicates whether the drug candidate moves from one phase to the next (Allison, 1982). A linear time function is used as one of the dependent variables, which is set to 1 when a firm enters the focal phase (phase 2 in the case of *R&D Functional Differentiation* and phase 3 in the case of *Corporate Decentralization*) and increases by 1 for each subsequent year. In the case of *R&D Functional Differentiation*, the focus is only on drugs in phase 2 and the progression focus is movement from phase 2 to 3. For *Corporate Decentralization*, the focus is on drugs in phase 3 and the progression focus is from phase 3 to PR. Second, Cox proportional hazards model are used to examine the relative hazard of a drug moving from one phase to the next. The advantage of this approach is that that it is unconstrained in its underlying time function assumptions unlike the first approach. Again, the analysis is at the drug candidate-year level and the dependent variable and phase focus is the same as for the logit model used in the first approach.

In both approaches the same full set of controls and independent variables that are used to test Hypotheses 3-4 are utilized as well as including individual drug controls (if drug is NCE and if it is externally sourced), year, business segment and drug therapeutic class controls. If greater decentralization/ differentiation is associated with the progression of inventions that are less likely to progress through the later stages of the innovation

process then the coefficient for *R&D functional Differentiation12* (i.e. R&D functional differentiation of the firm when a drug candidate moves from phase 1 to 2) and *Corporate Decentralization23* (i.e. the degree of corporate decentralization when a drug candidate moves from phase 2 to 3) should both be negative and statistically significant. Using this analysis no evidence is observed to suggest that functional differentiation of R&D and increased corporate decentralization are associated with the progression of inferior inventions that fail to progress through the later stages of the development process as the coefficients for *R&D functional Differentiation12* and *Corporate Decentralization23* are not statistically significant (see Table 47 and Table 48).

In Table 49 the average time taken for a drug candidate to move from Phase 2 to 3 across all firms in the sample is the focal dependent variable, with the unit of analysis being the firm. The negative coefficients for *Corporate Decentralization* indicate that greater corporate decentralization is associated with shorter times for progression from phase 2 to 3. This is consistent with an incentives-based argumentation as managers exert more effort to progress inventions when the firm is more decentralized.

In Table 50 the average compensation of executives (as defined as reporting to the CEO) is examined using Execucomp data. Consistent with the main incentives-based argumentation, I observe that firms with functionally differentiated R&D have higher total compensation on average (Table 50 Model 2) for R&D executives, after controlling for a variety of firm-specific factors. This may partly explain why more drug-candidates progress from Phase 1 to 2 and consistent with the interview-based evidence outlined earlier in this appendix. I also observe that greater corporate decentralization is associated with lower salaries but is unrelated to total compensation (Table 50 Models 3 and 4), after controlling for a variety of firm-specific factors. This implies that greater corporate decentralization is associated with a higher variable component of compensation. This is again consistent with the argumentation that decentralization is associated with the usage of higher-powered incentives. This analysis is limited in that I do not have access to compensation data for my complete sample of firm-years (e.g. lack of access of compensation data of Japanese-listed firms). However, this analysis is consistent with greater decentralization being associated with the use of higher powered incentives.

Table 49: Chapter 2 mechanistic analysis examining average time it takes for drug-candidates to move from Phase 2 to 3

OLS model using average values per firm over period 1995-2015		
DV= Average time progress P2-3 (Years)	**Model 1**	**Model 2**
R&D Decentralization		-0.495
		(0.744)
R&D Functional Differentiation		0.284
		(0.456)
Corporate Decentralization	**-1.898***	**-1.741+**
	(0.899)	**(0.937)**
Size	-0.0355	-0.00840
	(0.168)	(0.172)
R&D Intensity	0.257	0.346
	(0.540)	(0.642)
Slack	-0.161	-0.163
	(0.157)	(0.170)
External	0.200	0.366
	(0.968)	(1.042)
NCE	0.241	-0.321
	(1.298)	(1.575)
Bio	-0.0663	-0.661
	(1.247)	(1.625)
Tech. Diversity	1.621	1.841
	(1.430)	(1.436)
Performance	0.151	-0.116
	(2.615)	(2.896)
SBU	0.189+	0.163
	(0.108)	(0.115)
Patent Family count	-0.000452	-0.000461
	(0.000646)	(0.000686)
Number of Firms	47	47
R^2	0.277	0.294
Log-Likelihood	-40.46	-39.87

Standard errors in parentheses: + $p < 0.1$, * $p < 0.05$, ** $p < 0.01$; Standard Errors clustered at firm level.

Table 50: Chapter 2 mechanistic analyses examining how executive compensation and organization design elements are associated

Function	**R&D Executives**		**All Executives including CEO**	
Dependent Variable	Model 1 Log (Salary)	Model 2 Log (Total Compensation)	Model 3 Log (Salary)	Model 4 Log (Total Compensation)
R&D Decentralization	-0.0293 (0.0496)	0.139 (0.286)	-0.00833 (0.0226)	-0.307 (0.187)
R&D Functional Differentiation	0.0388 (0.0341)	**0.579* (0.255)**	0.0527 (0.0398)	0.234 (0.163)
Corporate Decentralization	-0.0711 (0.112)	0.205 (0.654)	**-0.0847*** **(0.0390)**	-0.0871 (0.318)
Firm level controls (Main Paper Table 4)	Y	Y	Y	Y
Business Segment Fixed Effects	Y	Y	Y	Y
Year Fixed Effects	Y	Y	Y	Y
N R^2	326 0.782	279 0.373	555 0.738	390 0.484

Standard errors in parentheses: $^{+}$ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$; Standard Errors clustered at firm level. Ordinary Least Squares regressions

Chapter 3 supplemental analyses

I conduct three supplemental analyses to further investigate the mechanisms associated with my two hypotheses in Chapter 3. First, I examine how the impact of organization design on the proportion of inventions sourced externally varies with the degree of novelty of the relevant inventions. Chapter 3 outlines the main analyses using the variable *Novelty*. I also use an alternative measure of novelty of a firm's portfolio based on New Chemical Entity (NCE) status. I thus examine the proportion of NCE and non-NCE drug-candidates that are sourced externally. These results are illustrated in Table 51. The non-matched model only provides directional support but both the PSM and CEM models continue to support the argumentation I outline in Chapter 3, in that firms that have decentralized R&D will tend to source more novel inventions externally than firms with centralized R&D. However, for less novel inventions there is no difference in the proportion of external sourcing of inventions between centralized and decentralized firms.

Table 51: Chapter 3: robustness analysis – alternative novelty measure (NCE)

DV	External non-NCE			External NCE		
Type of Model	**FL**	**FL PSM**	**OLS CEM**	**FL**	**FL PSM**	**OLS CEM**
R&D Decentralization	**0.0680**	**0.0419**	**0.0549**	**0.187**	**0.438***	**0.0733***
	(0.138)	**(0.199)**	**(0.0523)**	**(0.142)**	**(0.189)**	**(0.0357)**
R&D Functional Differentiation	0.104	0.264	0.00584	0.0636	-0.235	-0.0759
	(0.114)	(0.256)	(0.0609)	(0.148)	(0.268)	(0.0509)
Corporate Decentralization	0.466*	-0.182	0.0605	0.514*	0.540	0.191+
	(0.210)	(0.433)	(0.102)	(0.262)	(0.479)	(0.106)
Business Development Role	-0.106	-0.0994	-0.0525	0.142	-0.411*	-0.0187
	(0.115)	(0.188)	(0.0422)	(0.120)	(0.202)	(0.0460)
Performance	-0.326	0.547	-0.560	-1.614+	1.896	-0.264
	(1.037)	(1.447)	(0.517)	(0.827)	(1.375)	(0.409)
R&D Intensity	-0.321	0.373	-0.00900	0.390	0.913+	-0.160
	(0.375)	(0.626)	(0.261)	(0.355)	(0.551)	(0.207)
SG&A	-0.163	-0.574*	0.0194	-0.528**	-0.615+	-0.0837
	(0.100)	(0.232)	(0.0374)	(0.205)	(0.322)	(0.0637)
Size	0.215+	0.740*	0.0417	0.591**	0.255	0.0197
	(0.111)	(0.289)	(0.0468)	(0.213)	(0.325)	(0.0518)
Slack	0.00666	0.0418	-0.0192	0.0608	-0.140	-0.00721
	(0.0410)	(0.121)	(0.0117)	(0.0672)	(0.0977)	(0.0215)
New CEO	-0.168	-0.0565	0.0191	-0.313*	-0.199	0.00506
	(0.137)	(0.207)	(0.0589)	(0.150)	(0.254)	(0.0480)
Total Patent Stock	0.0506	0.0150	-0.0678+	-0.0311	0.0672	-0.00382
	(0.0686)	(0.131)	(0.0396)	(0.0814)	(0.103)	(0.0375)
Patent Family Count	0.302	0.331	0.269	-0.133	-0.508	0.134
	(0.401)	(0.574)	(0.228)	(0.393)	(0.504)	(0.170)
Competition	0.579	-13.64+	-7.367**	-1.590	10.25	1.258
	(3.872)	(7.180)	(1.594)	(4.853)	(10.90)	(2.665)
SBU	0.141	193.2**	-0.247+	-0.486	-0.514	-0.0982
	(0.433)	(64.70)	(0.139)	(0.388)	(0.729)	(0.163)
Technical Differentiation	-0.824	0.926	0.965**	0.456	3.162+	-0.891
	(0.790)	(1.294)	(0.328)	(0.996)	(1.897)	(0.632)
Clinical Experience	-0.114	0.372	0.319	-0.719	-1.948+	-0.449*
	(0.527)	(0.917)	(0.280)	(0.602)	(1.090)	(0.215)
Internal Overall Portfolio	-0.00205	-0.0157*	-0.0063**	-0.0084**	0.0107+	0.000116
	(0.00267)	(0.00639)	(0.00197)	(0.00318)	(0.00639)	(0.00162)
External Overall Portfolio	0.00350	-0.00059	-0.00262	0.0155**	0.0192+	0.00600**
	(0.00486)	(0.00756)	(0.00217)	(0.00557)	(0.0114)	(0.00205)
Portfolio Novelty	0.237	0.617	-0.0321	-1.203*	-1.630	-0.189
	(0.606)	(1.033)	(0.309)	(0.593)	(1.297)	(0.264)
Bio	-0.397	0.334	0.146	-0.321	-1.462	-0.403
	(0.838)	(1.381)	(0.312)	(0.695)	(1.814)	(0.393)
Year Fixed Effects	Y	Y	Y	Y	Y	Y
Business Category Fixed Effects	Y	Y	Y	Y	Y	Y
Therapeutic Category Fixed Effects	Y	Y	Y	Y	Y	Y
N	702	224	332	658	209	304
Log Likelihood	-455.0	-138.2		-399.8	-120.4	

Standard errors in parentheses: + $p < 0.1$, * $p < 0.05$, ** $p < 0.01$; Standard errors clustered at firm level
FL = Factional Logit; PSM = Propensity Score Matching; CEM = Coarsened Exact Matching
OLS = Ordinary Least Squares

Second, the impact of a business development group is examined. I argue that business development groups are integrating units (Lawrence & Lorsch, 1967) and effectively could make more decentralized firms more centralized by reducing the autonomy of individual R&D units. I find no evidence to support this assessment when examining the main models used to test Hypothesis 1 (Models 1 and 2 in Table 52) as the interaction terms between *R&D Decentralization* and *Business Development Role* are statistically insignificant. However re-examining Hypothesis 2 in which the mode of sourcing external inventions is considered I find negative and significant interaction terms for the analysis examining the proportion of inventions sourced externally via acquisitions (Models 3 and 4 in Table 52). This suggests that for "larger ticket" items such as acquisitions, business development units can reduce the propensity of decentralized R&D units to source via this mode. This is consistent with the logic that R&D units are unable to make acquisitions without the buy-in of a corporate business development unit. This is also consistent with the findings of my interviews in which R&D and Business Development managers highlight that business development units often play a much bigger role in acquisitions as opposed to licensing deals.

Third, I examine how the primary relationship indicated by Hypothesis 1 in Chapter 3 changes by the stage of development or clinical phase in which an invention is sourced. I argue that as an invention progresses through development the degree of uncertainty surrounding that invention declines as more favorable information comes to light. As a result of this decreased risk of failure of such inventions they become more costly to source externally. Thus, for the later stages of development decentralized R&D units will be less likely to source such inventions externally as there will be an increased likelihood that such units have to obtain corporate buy-in. I observe that for Phases 0 to 2 there is a strong association between R&D Decentralization and an increased proportion of externally sourced drug candidates as illustrated by Models 1 to 6 in Table 53. However for sourcing of phase 3 drug candidates (Models 7 and 8) the relationship is much weaker consistent with decentralized R&D units being less able to source such costly inventions externally thereby eliminating the difference between centralized and decentralized R&D units with respect to the proportion of inventions that are externally sourced.

Table 52: Chapter 3 supplemental analysis examining moderating impact of business development units on the relationships implied by Hypotheses 1 and 2

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
Dependent Variable	**External**		**Acquisition**		**Alliance**		**License**	
Type of Model	**FL**	**FL PSM**	**FL**	**FL PSM**	**FL**	**FL PSM**	**FL**	**FL PSM**
R&D Decentralization	0.212^{+}	0.387*	0.257	1.250*	-0.197	-0.421^{+}	0.282*	0.246
	(0.124)	(0.186)	(0.203)	(0.527)	(0.199)	(0.244)	(0.132)	(0.218)
R&D Functional Differentiation	-0.0848	-0.00379	-0.250	-0.342	0.130	0.863*	-0.137	-0.558^{+}
	(0.0668)	(0.201)	(0.178)	(0.641)	(0.127)	(0.353)	(0.129)	(0.311)
Organizational Decentralization	0.290^{+}	-0.569^{+}	-0.170	-1.785^{+}	0.0419	-0.695	0.655**	-0.137
	(0.155)	(0.316)	(0.351)	(0.931)	(0.259)	(0.488)	(0.219)	(0.532)
Business Development Role	0.0518	0.104	0.0694	1.231**	-0.0798	-0.509	0.0838	-0.294
	(0.0814)	(0.208)	(0.156)	(0.347)	(0.137)	(0.349)	(0.119)	(0.297)
R&D Cent. x BD Role	**-0.0975**	**-0.316**	**-0.872***	**-2.649****	**0.108**	**0.186**	**0.185**	**0.457**
	(0.170)	**(0.288)**	**(0.407)**	**(0.634)**	**(0.271)**	**(0.415)**	**(0.222)**	**(0.350)**
Performance	-0.352	2.619**	-0.673	0.934	0.265	-0.493	-0.413	4.521**
	(0.631)	(0.692)	(1.206)	(2.601)	(0.769)	(1.369)	(0.671)	(1.550)
R&D Intensity	-0.0945	0.602^{+}	0.166	0.231	0.461	-1.156	-0.724^{+}	2.290**
	(0.238)	(0.363)	(0.358)	(0.970)	(0.313)	(0.834)	(0.380)	(0.723)
SG&A	-0.0706	-0.198	-0.163	0.144	0.0975	0.0956	-0.114	-0.788**
	(0.0855)	(0.169)	(0.167)	(0.537)	(0.122)	(0.316)	(0.162)	(0.213)
Size	0.117	0.211	0.0304	-0.125	0.212^{+}	-0.0545	0.00196	0.637*
	(0.101)	(0.198)	(0.202)	(0.553)	(0.126)	(0.310)	(0.162)	(0.260)
Slack	0.0292	-0.127	0.0638	-0.227	-0.00266	0.0316	0.00528	-0.0909
	(0.0363)	(0.0817)	(0.0447)	(0.180)	(0.0571)	(0.129)	(0.0468)	(0.0975)
New CEO	-0.195*	0.401*	-0.456^{+}	0.588	0.0318	0.153	-0.0804	0.250
	(0.0978)	(0.177)	(0.264)	(0.657)	(0.164)	(0.299)	(0.105)	(0.246)
Total Patent Stock	-0.00721	-0.0384	0.133	0.0858	-0.110	-0.395*	0.0185	0.200
	(0.0481)	(0.0846)	(0.0818)	(0.295)	(0.0885)	(0.155)	(0.0613)	(0.137)
Patent Family Count	0.0810	-0.846*	-0.827	-0.910	-0.212	0.321	0.626	-1.052
	(0.308)	(0.401)	(0.546)	(1.083)	(0.356)	(0.833)	(0.408)	(0.665)
Competition	-4.890^{+}	-11.02^{+}	-14.17**	-3.567	1.873	-17.13^{+}	8.261*	-7.664
	(2.804)	(6.009)	(4.065)	(15.40)	(3.089)	(9.399)	(3.300)	(6.020)
SBU	-0.103	82.09	-1.592	321.5**	0.153	1.752	-0.949**	-283.4**
	(0.265)	(63.13)	(1.366)	(116.3)	(0.342)	(61.98)	(0.286)	(53.13)
Technical Differentiation	-0.218	3.075**	-0.500	-0.977	1.089	7.867**	-0.585	4.662**
	(0.400)	(0.841)	(0.837)	(1.967)	(0.873)	(1.853)	(0.684)	(1.246)
Clinical Experience	-0.515	-0.194	-0.774	-1.391	0.627	3.249**	-0.607^{+}	-1.241
	(0.355)	(0.540)	(0.612)	(3.015)	(0.675)	(1.027)	(0.334)	(0.836)
Internal Overall Portfolio	-0.00823**	-0.00895**	-0.0148**	-0.00440	-0.00700**	-0.0154^{+}	0.00281	-0.00220
	(0.00211)	(0.00327)	(0.00485)	(0.0106)	(0.00269)	(0.00809)	(0.00249)	(0.00482)
External Overall Portfolio	0.00832*	-0.000878	0.0164*	0.0103	0.00447	-0.0217^{+}	0.00340	0.00258
	(0.00354)	(0.00556)	(0.00776)	(0.0204)	(0.00597)	(0.0122)	(0.00337)	(0.00937)
Portfolio Novelty	-1.047**	-1.240*	-1.822**	-1.683	0.277	1.626	-0.754^{+}	-1.637*
	(0.373)	(0.572)	(0.559)	(1.317)	(0.599)	(1.085)	(0.435)	(0.741)
Bio	0.315	0.0858	-0.143	-2.725	1.108*	4.021**	-0.0690	0.445
	(0.287)	(0.761)	(0.555)	(1.856)	(0.520)	(1.022)	(0.396)	(1.026)
Year Fixed Effects	Y	Y	Y	Y	Y	Y	Y	Y
Business Category Fixed Effects	Y	Y	Y	Y	Y	Y	Y	Y
Therapeutic Cat. Fixed Effects	Y	Y	Y	Y	Y	Y	Y	Y
N	769	165	769	172	769	172	769	172
R^2	0.0318	0.0782	0.0904	0.197	0.0739	0.156	0.0469	0.0963
Log Likelihood	-488.9	-109.6	-211.2	-52.39	-258.2	-56.29	-320.0	-80.29

Standard errors in parentheses: $^{+}$ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$; Standard Errors clustered at firm level.
FL = Fractional Logit; PSM = Propensity Score Matching

Table 53: Chapter 3 supplemental analysis examining how the relationship between the proportion of inventions externally sourced and R&D Decentralization varies by clinical development phase

DV= External	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
Type of Model	**FL**	**FL PSM**	**FL**	**FL PSM**	**FL**	**FL PSM**	**FL**	**FL PSM**
Phase	**0**	**0**	**1**	**1**	**2**	**2**	**3**	**3**
R&D Decentralization	**0.200***	**0.298****	**0.341***	**0.499****	**0.352**$^{+}$	**0.355***	**0.256**	**0.373**$^{+}$
	(0.0800)	**(0.115)**	**(0.165)**	**(0.173)**	**(0.185)**	**(0.177)**	**(0.196)**	**(0.224)**
R&D Functional Diffn.	0.0641	-0.141	-0.108	0.736*	-0.0381	-0.0441	-0.119	-0.278
	(0.0561)	(0.134)	(0.133)	(0.367)	(0.135)	(0.257)	(0.134)	(0.315)
Organizational Cent.	0.455**	0.428	0.0814	0.333	0.0811	-0.856	-0.124	-0.0304
	(0.113)	(0.274)	(0.275)	(0.605)	(0.288)	(0.610)	(0.264)	(0.521)
Business Dev. Role	-0.0360	0.0428	0.0132	-0.0481	-0.0859	-0.290^{+}	-0.112	0.198
	(0.0602)	(0.0995)	(0.127)	(0.230)	(0.115)	(0.167)	(0.131)	(0.288)
Performance	-0.0657	-0.757	-1.205	1.326	-1.225	-2.264*	-0.871	1.414
	(0.553)	(0.757)	(0.836)	(3.545)	(0.993)	(1.147)	(1.014)	(1.689)
R&D Intensity	0.151	0.0794	0.0855	-0.479	0.728	0.402	-0.658	0.107
	(0.208)	(0.282)	(0.496)	(1.298)	(0.495)	(0.777)	(0.705)	(1.030)
SG&A	0.0258	0.154	-0.0844	-0.739	-0.327*	-0.255	0.178	0.899^{+}
	(0.0757)	(0.144)	(0.144)	(0.529)	(0.157)	(0.415)	(0.201)	(0.475)
Size	0.137^{+}	0.241	0.328	0.694	0.695**	0.508	0.143	-0.0786
	(0.0802)	(0.187)	(0.200)	(0.686)	(0.220)	(0.470)	(0.219)	(0.568)
Slack	0.0169	0.0214	0.0389	0.477**	0.00360	0.114	-0.0335	0.0289
	(0.0374)	(0.0470)	(0.0514)	(0.119)	(0.0518)	(0.105)	(0.0566)	(0.0934)
New CEO	-0.130	-0.389**	-0.479**	-0.246	-0.177	-0.0732	0.0241	0.139
	(0.0863)	(0.144)	(0.185)	(0.283)	(0.184)	(0.364)	(0.163)	(0.325)
Total Patent Stock	0.0367	-0.0256	0.138*	0.360^{+}	-0.112^{+}	0.141	0.154^{+}	0.207
	(0.0386)	(0.0750)	(0.0573)	(0.186)	(0.0602)	(0.186)	(0.0803)	(0.179)
Patent Family Count	0.208	-0.392	0.129	-0.239	0.916*	0.324	-0.477	-1.729*
	(0.215)	(0.311)	(0.287)	(0.876)	(0.423)	(0.654)	(0.557)	(0.676)
Competition	-1.229	-1.681	2.832	11.29	-2.325	23.15	-1.564	21.74^{+}
	(1.695)	(4.776)	(5.117)	(15.05)	(3.159)	(16.08)	(4.217)	(13.14)
SBU	0.108*	0.196	-0.0402	-1.117^{+}	0.269**	0.132	0.270**	0.481**
	(0.0460)	(0.124)	(0.127)	(0.580)	(0.0658)	(0.323)	(0.0857)	(0.136)
Technical Differentiation	-0.905	0.125	-0.0424	2.864	-1.075	-2.118	-1.075	-0.966
	(0.641)	(0.876)	(1.014)	(2.005)	(1.027)	(1.680)	(0.851)	(1.366)
Clinical Experience	-0.0485	-0.108	-0.512	-1.503	0.370	-1.622	-0.704	-1.362
	(0.252)	(0.526)	(0.353)	(0.996)	(0.502)	(1.431)	(0.449)	(1.474)
Internal Overall Portfolio	-0.00002	0.00204	-0.00048	0.0109	0.000336	0.0186**	0.00427^{+}	0.0189*
	(0.00132)	(0.00392)	(0.00304)	(0.00801)	(0.00319)	(0.00609)	(0.00234)	(0.00749)
External Overall Portfolio	0.00712**	0.00639^{+}	0.0112**	0.00163	0.00485	0.0181	-0.00237	0.00890
	(0.00230)	(0.00388)	(0.00414)	(0.00902)	(0.00742)	(0.0112)	(0.00642)	(0.00944)
Portfolio Novelty	-0.903**	-0.815*	-1.261**	-1.969	0.0905	-0.326	-0.437	-0.457
	(0.306)	(0.405)	(0.465)	(1.468)	(0.544)	(1.078)	(0.435)	(1.232)
Bio	0.257	0.587	0.286	0.785	-1.244*	-1.491	-1.489**	-0.959
	(0.271)	(0.491)	(0.531)	(1.631)	(0.512)	(1.235)	(0.494)	(1.347)
Year Fixed Effects	Y	Y	Y	Y	Y	Y	Y	Y
Business Category Fixed Effects	Y	Y	Y	Y	Y	Y	Y	Y
Therapeutic Category Fixed Effects	Y	Y	Y	Y	Y	Y	Y	Y
N	759	231	736	171	736	228	752	235
R^2	0.184	0.227	0.153	0.329	0.114	0.174	0.107	0.165
Log Likelihood	-1654.9	-509.4	-867.1	-182.2	-939.6	-305.1	-840.6	-267.3

Standard errors in parentheses: $^{+}$ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$; Standard Errors clustered at firm level.
FL = Fractional Logit; PSM = Propensity Score Matching

Chapter 4 supplemental analyses

I conduct one supplemental analyses to further investigate the mechanisms associated with my two hypotheses in Chapter 4. I examine how the number of product functional roles (Guadalupe et al., 2014) within an organization can influence the impact of *Corporate Decentralization* on firms' sales of new products. This follows a similar logic to the second supplemental analysis in Chapter 3 described above. Namely, product functional units can have the impact of more strongly centralizing certain elements of business units' activities associated with the commercialization of their new products. This should result in the difference between more and less centralized firms in terms of commercialization of new products being reduced. The analysis conducted to test this argumentation compares a sub-sample of firms that have a high number of product functional roles with a sample of firms that have a lower number of product functional roles. Table 27 illustrates the results of this analysis and I observe that for firms with a smaller number of product functional roles, the coefficient for *Corporate Decentralization* is positive and statistically significant. However, for the sub-sample of firms with a higher number of product functional roles, I find that *Corporate Decentralization* is much lower in magnitude. This is consistent with the fact that such roles have the effect of centralizing a firm's actions potentially lowering the benefits of increased incentives and local market knowledge. Wald tests further illustrate that there is a significant difference in the coefficients to *Corporate Decentralization* for the sub-samples of observations with higher and lower levels of product functional roles.

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