KNOWLEDGE TRANSIT: THE CREATION, DEVELOPMENT, AND ORCHESTRATION OF INNOVATION ACROSS SPACE

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ABSTRACT

The disaggregation of global value chains has accelerated the development of a fabric of connectedness between firms, locations, and inventors. The modern global business world is now characterized by these connections, which serve as conduits of high value knowledge between specialist repositories, or centers of excellence. The properties of knowledge repositories are a function of the co-evolution of their constituent firms and the locations themselves. Thus, it is of great interest to scholars of international business, economic geography, and innovation studies to understand the roles and characteristics of the firms and locations that participate in global value chains.

This dissertation explores the movement of knowledge from seemingly disparate locations and firms as it coalesces into ideas, and then follows the path of transformation into a commercialized product or service. In the first chapter, I laid the theoretical groundwork for the dissertation and review how the different studies contribute to the our understanding of how firm and location characteristics interact with global innovation connectedness, and vice versa. Three chapters that study innovation dynamics at within global value chains then follow.

In the second chapter, I explore the characteristics of orchestrating firms, high order specialists that coordinate the movement of knowledge and activities in global value chains. With evidence from the pharmaceutical industry I find that not all orchestrating firms are created equal: a core insider group, known as “majors”, possess a unique legitimacy that enables the absorption of risk and grants access to greater resources that are required to control the value capture from market-defining innovation. In the third chapter, I discuss the interdependencies of orchestrating firms and industrial change by examining the Detroit auto cluster. I argue that the very forces that led to significant manufacturing loss in the Detroit area may also be behind the resilience of its knowledge production, a finding underwritten by significant innovation connectedness to other auto clusters. In the fourth and final chapter, I find that knowledge connectivity is a crucial driver of exploration into new technological areas, and that firms may be connected both internationally and domestically. Further, I find that the operational footprint of the firm is a vital amplifier of its connectivity efforts.

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It takes a village to produce a doctoral dissertation. This document is the product of many years of work, and many more people that deserve untold credit for their unwavering support. The research in this dissertation has emerged as all research does: in fit and starts, successes and failures, and through the persistent discussions with immediate colleagues and the broader academic community. These ideas emerged from countless hours in meeting rooms, offices, and conference halls. They have come to be developed through the patient and insightful mentoring that a doctoral student needs. Yet, they have persisted because of the enormous support that only a loving family can give.

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CHAPTER 1: INTRODUCTION TO KNOWLEDGE TRANSIT: THE CREATION, DEVELOPMENT, AND ORCHESTRATION OF INNOVATION ACROSS SPACE

Dissertation Overview

The global business landscape has shifted dramatically in recent decades. The disaggregation of global value chains has led to the “fine slicing” of the full set of activities that produce a good or service (Mudambi, 2008; Sturgeon et al., 2008). Intangibles - high knowledge, creative activities - are crucial to value creation (Morck & Yeung, 1991) and are are inexorably tied to geographic space (Florida, 2002). These shifts in the distribution of high knowledge activities have accelerated the co-evolution between firms and locations (Balland, Boschma, & Frenken, 2015). To the extent that GVCs have mobile (firms, people) and immobile (locations) components (Mudambi & Swift, 2012), the co-evolutionary process between them is predicated upon the movement of knowledge (Cantwell, Dunning, & Lundan, 2010; Cano-Kollmann et al., 2016). The roles and strategies of firms and locations - and the linkages between them - is the focus of this dissertation.

Global value chains (GVCs) comprise all of the activities that relate to the production of a good or service, from idea conception to delivery to the end user (Gereffi, Humphrey, & Strugeon, 2005). Advances in information, communication, and transportation technologies have enabled lead firms to disaggregate GVCs into fine-grained activities and assign them to efficient locations around the world (Mudambi, 2008). This fundamental shift in the way global business is conducted puts enormous emphasis on high value activities, such as orchestration and specialization (Dedrick, Kraemer, & Linden, 2010). The dispersed nature of knowledge-based activities has drawn attention to the interdependencies of firms and locations and the connections that link the entire system.

Innovation is the key to value creation, but complex systems underwrite the path from knowledge to ideas to ultimately, marketplace disruption and value capture. Knowledge accumulates in locations as a function of the specialized activities that are undertaken by firms there (Marshall, 1920), ultimately spilling over to adjacent industrial contexts (Glaeser, et al., 1992). Increasingly however, the transformation of knowledge to ideas is unbound from space (Amin & Cohendet, 2004). The linkages between firms, locations, and inventors serve as conduits. The result is a global innovation system built on the foundation of increasing connectedness, both inside and outside of the firm, and also between locations (Cano-Kollmann et al., 2016). Connectedness leverages the linkages between organizations - and people - to act as knowledge conduits (Bathelt, Maskell, & Malmberg, 2004; Lorenzen & Mudambi, 2013). How firms and locations influence the movement of knowledge around the globe is a novel and little understood phenomenon with multiple layers: some of which will be addressed in this dissertation.

As knowledge increasingly emanates from specialist firms and connected locations, greater emphasis is placed on downstream intangibles (Teece, 1986; Gans & Stern, 2003; Mudambi, 2008). To the extent that knowledge may coalesce from disparate locations into innovative ideas, so too may the transformation from ideas to commercialized products or services involve movement beyond its origin. The orchestration of GVCs is a specialist activity unto itself, and firms at the top of the food chain dictate which firms and locations participate in the process (Dedrick, et al., 2010). Such is the complexity of knowledge in GVCs: firms must understand technologies that they may not even produce (Brusoni, Prencipe, & Pavitt, 2001), as organizational boundaries continue to blur and specialists take on different activities (Cantwell, 2013). Yet, not all specialists are created equal, and the heterogeneous characteristics of value-appropriating firms are of great interest when seeking to understand the lynchpins of global innovation systems. Similarly, the importance of dispersed knowledge is not necessarily constant throughout the full value chain (Alcacer, 2006).

This dissertation explores the roles and strategies of firms and locations that transport knowledge across the entire GVC. Specifically, it asks three questions. First, what are the properties of orchestrating firms that demonstrate a superior ability to move knowledge across the entire value chain? Second, how do the internal industrial dynamics within a location stimulate global connectivity? Finally, how might knowledge linkages impact the extent to which firms explore new technologies? As GVCs rely heavily on the strength of knowledge networks, an examination of the role of orchestrating firms and specialist locations will yield a greater understanding of what is becoming an increasingly complex global phenomenon. This dissertation will attempt to address the roles of firms and locations in three chapters, which will be described below.

The first chapter of this dissertation studies the phenomenon of "majors": firms that hold central orchestrating positions in an industry and are consistently able to achieve outsized market success. We argue that these firms have organizational legitimacy, a factor that supersedes conventional measures of firm dominance like size, age and R&D intensity. Stakeholders take for granted that these firms are the industry’s insiders. This allows them to pursue strategic options that are not available to other firms when transferring knowledge across the entirety of the GVC. We examine this phenomenon in the context of pharmaceuticals, a global industry whose performance is dependent on a small number of products (blockbusters) that achieve extremely high levels of sales. We identify majors using a media-based metric of legitimacy. We show that drugs marketed by majors are considerably more likely to reach blockbuster status than drugs marketed by non-majors. Furthermore, we demonstrate that non-majors must rely on the inherent characteristics of the product itself, while majors are able to create blockbusters from breakthrough and non-breakthrough products alike. These results support our hypotheses that legitimacy allows majors to select from a wider range of options in the pursuit of high returns.

The second chapter explores the industrial dynamics and innovative connectedness of firms in a key GVC location. This paper uses a comprehensive dataset of 35 years of patenting activity in the U.S. to analyze the evolution of innovative activity in the Detroit auto cluster and its degree of connectedness to global knowledge networks. We use this empirical setting to explore the resilience of knowledge creation within an industrial cluster as it suffers structural changes associated with a long-term decline in the manufacturing activity. In this study of the Detroit auto cluster, we contribute to prior literature in at least three aspects. First, our analysis confirms that knowledge is “sticky” and that innovation in clusters can increase in a context of industrial decline. Second, we analyze both the technological focus of the knowledge production of Detroit over more than three decades and map the evolution of the global connectedness of local innovation networks. Finally, we extend the extant literature to suggest that the "stickiness" of local knowledge is sustained by both an increasing technological specialization at the local level and a growing connectedness to global centers of excellence. It is the contention of this paper that the very forces that bring about the decline in production in a cluster - the disaggregation of global value chains - may also be the ones that generate a center of gravity with respect to knowledge generation.

The final chapter of this dissertation focuses on the connectedness of firms. The multinational enterprise (MNE) is the superior form of organization to play arbitrageur of country differences, particularly with respect to high knowledge activities. To this end, extant IB literature has devoted significant efforts to the transfer of knowledge across countries via local embeddedness. However, in a modern business environment characterized by dispersed value chain activities and falling spatial transaction costs, collaborative innovation relationships may be far more complex. In this paper, we argue that the connectedness of inventor networks – rather than knowledge spillovers - may transcend requirements of local embeddedness and serve as a crucial source of new ideas and exploration into new technologies. To be clear, this argument acknowledges that connections may be motivated by the creation of temporary clusters or co-location (Maskel, Bathelt, and Malmberg, 2006): those meetings, conferences, or trade shows that see like minds come together. Further, we posit that these collaborations stem out of locations at the subnational level, such as cities, and fall along the somewhat orthogonal dimensions of foreign and domestic connections. Finally, we argue that the international operational footprint of the firm serves as a positive moderator on the impact of connectedness on technological exploration.

Overall, this dissertation seeks to shed light on the interdependencies of firms and locations within GVCs and the knowledge linkages that bind them. It attempts to examine the characteristics of orchestrating firms, the evolution of connectedness and orchestrating firms within clusters, and finally, the impact of connectedness on innovative outcomes. Global innovation systems continue to evolve, and this dissertation will contribute to our understanding of the modern complexities that have led to a connected - but distinct - economy.

CHAPTER 2: MAJORS, ORGANIZATIONAL LEGITIMACY, AND RENTS FROM BLOCKBUSTER INNOVATION

Introduction

The phenomenon of “major” firms—firms that hold a central position in an industry and consistently achieve outsized returns—is a defining characteristic of a wide range of industries. In the pharmaceutical industry, majors have been termed “Big Pharma” (Agarwal, Desai, Holcomb, & Oberoi, 2001). In the accounting industry, majors have been successively referred to as the “Big Eight” (Craswell, Francis & Taylor, 1995), the “Big Six” (Titman & Trueman, 1986), the “Big Five” (Greenwood & Suddaby, 2006) and the “Big Four” (Kornberger, Carter, & Ross-Smith, 2010), as the industry has consolidated through a series of horizontal mergers. In investment banking, the analogous term is “Bulge Bracket” (Hayes, 1971). In the oil industry it is the “Seven Sisters” (Sampson, 1991). The U.S. automobile industry was long dominated by the “Big Three” (MacDuffie & Helper, 1997). Regardless of the industry, major firms are disproportionately endowed with the relevant success factors.

What do these firms have that others do not? We argue that majors’ advantage is not fully explained by existing theories of value extraction. Specifically, arguments such as absorptive capacity (Cohen & Levinthal, 1990) and the creation of a common language with external partners (Lane & Lubatkin, 1998) do not fully explain why only certain firms are able to achieve exceptionally large rents. In this chapter, we argue that these major firms are "taken for granted" (Suchman, 1995) as the key players in an industry, a position that they leverage to their advantage. This enables them to attract and nurture the projects with a potential for success, and then implement the appropriate strategies to generate exceptional market outcomes. As knowledge flows across global innovation networks, orchestrating firms are crucial to the distribution of value and the assignment of roles to firms and locations alike (Mudambi, 2008). The superior orchestration of knowledge across the full value chain is rooted in the leveraging of intangibles (Dedrick, Kraemer, & Linden, 2010). Yet, not all orchestrating firms are equal. The goal of this chapter is to explain why.

Majors are the outcome of a phenomenon whereby organizations are categorized into insiders and outsiders (Merton, 1972; Cattani, Ferriani, &Allison, 2014), also referred to as "legitimate players" and "non-players" (Zuckerman, 1999). Majors as legitimate players have greater access to resources (Meyer & Rowan, 1977; Pfeffer & Salancik, 1978) and are able to take greater risks (Desai, 2008; Bansal, & Clelland, 2004; Sharfman & Fernando, 2008). This implies that majors can create immense financial success out of a wide range of starting conditions.

We study majors in the context of the global pharmaceutical industry, an industry characterized by high-risk technology competition. Such competition often has significant "winner-take-all" characteristics (Brynjolfsson, Hu, & Simester, 2011). Payoffs from innovation are discontinuous, so that a very small number of products "hit the jackpot" (Dierickx & Cool, 1989: 1508) and capture the lion's share of market rents (Tushman & Anderson, 1986). These exceptional market outcomes may be called "blockbusters" and have been characterized as a requisite for success – and perhaps even survival – in this industry (Cutler, 2007). This chapter uses a comprehensive dataset of all drugs approved by the U.S. Food and Drug Administration (FDA) over the period of 1993-2008, matched with firm level controls. We find that even after controlling for the size, age, innovative capabilities, location, and prior innovative and financial success of the drug's controlling firm, the firm's status as a major has a significant impact on the probability that a drug will become a blockbuster.

In this chapter, we argue that majors possess unique status formed of cognitive legitimacy, or a "taken-for-granted" status (Suchman, 1995) derived from the general public. Legitimacy may be conferred via the news media (Deephouse, 1996; Pollock & Rindova, 2003), which acts as an intermediary between organizations and the general public that faces difficulty evaluating complex choices (Zuckerman, 1999). This study uses news media reports of all firms controlling late stage pharmaceutical innovations to construct a measure of media legitimacy. Taken-for-granted legitimacy (Suchman, 1995) has been long integrated into the discourse of the pharmaceutical industry (Greenwood & Suddaby, 2005): the set of firms in the top 10 percent of media mentions corresponds closely with the term "Big Pharma", which has been used to define the insider group of pharmaceutical firms (Agarwal et al., 2001). We demonstrate that legitimacy has a discontinuous impact on the likelihood of blockbuster success: the top firms benefit substantially from it, while the rest do not. This is consistent with the notion of majors. Our primary argument is supported by the finding that for non-majors, breakthrough innovation is a significant predictor of blockbuster success. In contrast, majors are able to produce blockbuster outcomes from non-breakthrough innovation as well.

This chapter makes a number of contributions. First, we develop a theory of the major as a key player in global technology markets, especially those reliant on blockbuster innovation: a small number of projects with extraordinary returns. While the concept of the major has been around for some time, it has thus far not been firmly grounded in theory. We link major status to organizational legitimacy. Second, we demonstrate empirically that the association of a major with a drug launch significantly increases the likelihood that it becomes a blockbuster. Similarly, we show that breakthrough innovation is a not necessary condition for major firms to achieve blockbuster success with a product. For non-majors, breakthrough innovation is a crucial determinant. Our findings are robust to different benchmarks of what constitutes a blockbuster product, as well as different specifications of the relevant sample of drugs. Taken together, our results suggest that certain firms hold a central position in the development of new products, and that this position and ability to orchestrate across global value chains is not simply due to their size or the strength of their R&D investment. Rather, they appear to possess legitimacy that allows them to maintain controlling positions in business networks on the basis of which they can extract truly extraordinary financial outcomes from innovative success.

Theory and Hypotheses

Dominant firms that generate persistently high returns have attracted the interest of scholars for several decades (Mueller, 1977; Geroski & Jacquemin, 1984; 1988). In this literature, supernormal returns are sustained either through the exertion of market power (Carter, 1978) or through innovation (Roberts, 1999). These dominant firms directly correspond in terms of performance attributes to the firms that we label as majors. We suggest that this literature does not adequately recognize the full scope of characteristics that underpin the performance of major firms. In particular, we argue that major firms possess organizational legitimacy and employ it as a strategic resource (Dowling & Pfeffer, 1975; Pfeffer & Salancik. 1978) that enables superior performance.

Organizational Legitimacy

The concept of organizational legitimacy has deep roots. Parsons (1960) defined legitimacy as the organization's justification to exist, as judged by those around it, while Weber (1968) integrated the concepts of status and power. Legitimacy is more broadly the "generalized perception or assumption that the actions of an entity are desirable, proper, or appropriate within some socially constructed system of norms, values, beliefs, and definitions" (Suchman, 1995: 574). It flows from social audiences and may be intermediated or reinforced by critics (Zuckerman, 1999; Cattani et al., 2014). In other words, organizational legitimacy is a form of status (Deephouse, 1996; Ashforth & Gibbs, 1990). *Cognitive legitimacy* is a sense that an organization's status is taken for granted by audiences: it confers an assumption of inevitability that can be used to categorize organizations within a particular decision set (Bitektine, 2011; Suchman, 1995). The extent to which an organization is publicly known may reflect its degree of cognitive legitimacy (Aldrich & Fiol, 1994). In so doing, organizations with this form of legitimacy have lower benchmarks of evaluation from audiences (Meyer & Rowan, 1977).

Firms often seek out organizational legitimacy because it is a resource to be employed in the pursuit of other resources, talent, technologies, and support from key stakeholders (Zimmerman & Zeitz, 2002). As audiences converge on a consensus regarding the story of an organization (Cattani et al., 2008), it gains a degree of credibility (DiMaggio, 1991). This is because audiences will perceive the actions of a legitimate organization to be appropriate and inevitable (Suchman, 1995). Those with organizational legitimacy are less likely to face resistance from partners and stakeholders when charting new territory (Dowling & Pfeffer, 1975; Meyer & Rowan, 1977; Pfeffer & Salancik, 1978), and can thus pursue greater levels of risk (Sharfman & Fernando, 2008). Similarly, under conditions of uncertainty, legitimate firms are seen as stable, and better exchange partners (Podolny, 1994).

In the milieu of global markets for technology, it can be inferred that organizational legitimacy is a valuable asset to those firms scanning the landscape for innovations to pursue, either through internal or external means (Arora et al*.,* 2009). Legitimacy offers better access to resources (Dowling & Pfeffer, 1975), a buffer against failure (Desai, 2008), and a platform upon which to take greater risk (Sharfman & Fernando, 2008). The use of organizational legitimacy on the part of firms in technology markets may therefore be seen as an asset in the control and orchestration of innovation and the pursuit of blockbuster outcomes. Thus,

Hypothesis 1: Control by a firm with higher levels of organizational legitimacy makes it significantly more likely that a product becomes a blockbuster.

Majors

While major firms are features of a wide range of industries, including pharmaceuticals, accounting, automotive, oil and investment banking, the term has never been formally defined in a manner that crosses industry boundaries. Therefore, the link between a firm's position as a major and its market performance has been underspecified. we argue that using the concept of organizational legitimacy can enable us to more fully capture the nature of majors, over and above tangible measures of firm characteristics.

It has been recognized at least since Schumpeter (1942) that "a few firms that are continuously innovative" often dominate industries requiring large investments in R&D

(Malerba & Orsenigo, 1995: 48). These firms use a full range of resources to appropriate rents from innovation (Pavitt, 1984). As with any significant competitor in global technology markets, majors possess many of the other prerequisite tools to participate: strong scientific foundations and significant scale. Firm size and profitability are positively correlated in such industries, strong in-house R&D can enable firms to integrate external knowledge (Cohen & Levinthal, 1990), and the accumulation of knowledge over time enhances competitive advantage (Dierickx & Cool, 1989). Those firms that orchestrate the activities of global value chains are invariably centrally positioned, making choices about the roles of firms and locations with respect to particular activities (Mudambo, 2008). The investments required to undertake blockbuster projects are often substantial and science and marketing may be necessary conditions to select and integrate technologies. However, other sources of organizational advantage may be crucial as well. Firm-specific factors have been argued to be crucial determinants of performance (Demsetz, 1973).

Legitimate firms have the support of their audience when they commit to a technology—its stakeholders (the "audience") take for granted that the major can make good on the substantial investment in the technology. Because the opportunities for blockbuster success in innovation driven industries are rare and the underlying global value chains are complex, those firms that are able to access a broader range of resources and innovations - a position afforded by organizational legitimacy - are better positioned to convert the opportunities that arise. Thus, legitimate firms are able to take actions that are not available to outsiders.

When audiences evaluate actors, the audiences undergo a two-stage process: they first sort organizations into high or low status categories, and then conduct evaluations conditional upon the sorting process (Zuckerman, 1999; Phillips & Zuckerman, 2001; Sharkey, 2014). Organizations may be classified as being insiders or peripheral players (Cattani et al. 2014). Insiders—the organizations categorized as legitimate in the first stage—proceed to the stage in which their actual merits are assessed, while the illegitimate firms do not get further consideration from the audience (Zuckerman, 1999). Categorization as a legitimate player (Zuckerman, 1999) is key to the concept of a major. We argue that as insiders, majors are able to orchestrate knowledge processes (Dhanaraj & Parkhe, 2006) and leverage intangibles (Mudambi, 2008, Dedrick et al., 2010) at a superior level. Legitimate players are central to the exchange relationships within an industry, particularly under conditions of uncertainty or risk (Podolny, 1994). This centrality means that membership in the group of legitimate organizations must be limited. Categorization is an initial screen that initiates the membership process (Phillips & Zuckerman, 2001). Further, in order to be categorized as legitimate, the organization needs repeated interactions with, and ultimate a consensus from, audiences (Cattani et al., 2014). In intermediated markets, audiences have limited bandwidth to evaluate actors, and thus must rely on critics to represent their intentions (Zuckerman, 1999). Thus, the effect of legitimacy will not be linear. Instead, the effect will come through categorization of the organization as an insider.

Although size, incumbency, and R&D intensity are all important when examining core industry players (Pavitt, Robson, & Townsend, 1987), legitimacy remains the factor that is most difficult to replicate. Were size or R&D intensity to be the sole determinants, non-majors would be able to acquire (or contract) all the necessary resources and capabilities to produce exceptional new technologies. Thus,

Hypothesis 2: Control by a major makes it significantly more likely that a product becomes a blockbuster, as compared to a control by a non-major, after controlling for firm size and age.

Breakthrough Innovation and Market Success

Innovation-based competition operates on two tracks. Competition can be based on scientific success or market success. Breakthrough innovation connotes technical achievement, while blockbuster products imply wide market diffusion. To date, the literature has demonstrated that these two dimensions are positively correlated, although imperfectly (Gittelman & Kogut, 2003). While radical scientific discovery is inherently disconnected from mainstream knowledge, innovation with widespread appeal has strong ties to the scientific frontier (Uzzi, Mukherjee, Stringer, & Jones, 2013). Under certain circumstances, the logics of scientific success and market success may operate at cross purposes. Furthermore, products that are not technical breakthroughs may still achieve market success (Henderson & Clark, 1990).

Just as payoffs from commercialization are discontinuous, the distribution of innovative activity is highly skewed. Truly breakthrough innovations are rare (Kuhn, 1962; Tushman & Anderson, 1986). This recognition enables us to pose some interesting questions with respect to the relationship between dramatic scientific success (breakthrough innovation) and exceptional market success (blockbusters). Does the emergence of one guarantee the emergence of the other? Moreover, is breakthrough innovation a necessary condition for blockbuster outcomes for all types of firm?

The innovation literature firmly connects knowledge and the creation of value (Grant, 1996). However, the pursuit of breakthrough innovation creates risks for extant cash flows as new products cannibalize mature ones (Mudambi & Swift, 2014). In fact, the very discovery of new technology has the capacity to destabilize entire industries (Tushman & Anderson, 1986; Christensen, 1997).

We have argued to this point that majors possess a level of insider status and legitimacy that affords greater risk tolerance and access to a broader range of resources. To this end, organizational scholars have noted that outsiders are likely to conform to isomorphic pressures, while insiders are more likely to pursue paths that differ from the norm (Zuckerman, 1999; Phillips & Zuckerman, 2001). Taken in the context of this chapter, theory would therefore suggest that non-major firms rely on paths to success that stakeholders consider the norm. In a high technology industry like pharmaceuticals this path is the pursuit of breakthrough innovation.

Thus,

Hypothesis 3: Breakthrough innovation exerts a positive influence on a product's likelihood of becoming is a blockbuster, when controlled by a non-major.

In contrast, major firms can extend their search for blockbusters into a wider domain of knowledge. This may include projects aimed at breakthrough innovation as well as those that are minor advances on extant technology. When firms make decisions about which innovations to support (Arora et al., 2009), implicit in that decision is not just the confidence in the technology itself, but the ability to extract rents from that technology. What majors' legitimacy enables is a differentiating path (Zuckerman, 1999) that takes on greater risk (Desai, 2008; Bansal & Clelland, 2004). By leveraging points of credibility with stakeholders, majors have the freedom to select technologies that are seemingly antithetical to the R&D focused innovation pipeline, but possess potential for great success nevertheless.

Empirical Setting: The Global Pharmaceutical Industry

We now discuss the historical path of innovation in the pharmaceutical industry and describe the role of blockbuster drugs and the firms that control them. We focus on the importance of knowledge transfers with regard to blockbuster drugs: drugs that achieve greater than $1 billion in annual sales. These drugs play a key role in this industry. Between 2000 and 2005, these drugs accounted for 28 to 36 percent of total global pharmaceutical sales (Cutler 2007). When patents on blockbuster drugs expire, profits from those drugs drop rapidly (Thomas 2012).

The pharmaceutical industry bifurcated beginning with the antibiotics revolution in the 1940s, into what became the branded and generic strategic groups (Galambos & Sewell, 1997; Lee, 2003). During the 1940s and 1950s, the branded strategic group focused on expensive, large-scale R&D, and the big firms in this group rapidly churned out new therapies. The generic firms were those that elected to imitate the products of the branded firms. Turnover during this period was considerable – the identity of the top five firms by market share changed constantly (Lee 2003). However, despite considerable market share volatility, the antibiotic revolution did not significantly change the number of firms in the market (Munos 2009).

Innovation in the global pharmaceutical industry comes from a range of firms, operating at different points of the innovation funnel. Large numbers of small, specialized firms (e.g., biotechs) focus on early stage drug development. Large pharmaceutical firms have their own drug development operations, but also cooperate with smaller firms as well as with organizations like universities that focus on more basic research. Some analysts believe that new innovation will stem from a variety of sources, such as universities and small biotechnology firms (Kneller, 2010).

Knowledge transfers are common in the pharmaceutical industry—particularly with blockbuster drugs. Development begins with discovery and preclinical testing, followed by three phases of clinical trials (DiMasi, Hansen, & Grabowski, 2003), then submission of the clinical trial data to the FDA for approval. Finally, the drug may go to market. While a single firm may perform all of these steps, drug licensing is common. Small firms are particularly likely to enter into licensing agreements. Between 1988 and 2000, among firms with fewer than 25 compounds in development, about 70 percent of phase 3 clinical trials involved an alliance with another firm (Danzon, Wang & Wang, 2005). Further, these firms worked with larger partners in the vast majority of cases, pointing to advantages stemming from large resource pools. However, Danzon et al. (2005) also found that alliances are common among large firms. Even a large firm may lack the resources to convert a major innovative drug into a blockbuster. While larger firms do not necessarily have an advantage in successfully taking a drug through development (Cockburn & Henderson 2001; Danzon et al., 2005), they may have an advantage in achieving greater financial gains following drug approval—larger firms show a stronger link between R&D intensity and future earnings (Ciftci & Cready 2011).

Empirical Analysis

Data and Sample

We examine the full set of 3,250 pharmaceutical innovations approved by the U.S. Food and Drug Administration (FDA) between 1993 and 2008. Our sample is comprised of New Drug Applications (NDA) and Abbreviated New Drug Applications (ANDA). The NDAs represent novel drugs that have not been previously marketed, while the ANDAs represent generic drugs, which are copies of existing drugs whose patents are expiring. The FDA's Center for Drug Evaluation and Research (CDER) maintains the *Electronic Orange Book*: the repository of drug application data, complete with underlying patents and product types identified. Of the 3,250 observations, 1,082 represent NDAs and 2,168 represent ANDAs. After accounting for missing financial data and other necessary explanatory data, our final sample contained 2,978 drug applications.

We use the NDA and ANDA as our unit of analysis. For each observation, we add drug, firm, location, and industry data. All variables are defined for the peak revenue year, the approval year, or both; we note which one is used in the variable definitions. The determination of a drug reaching breakthrough status is a function of scientific discovery; it is made at the time of approval, or prior to launch. Therefore, significant market risk remains: the introduction and development of that innovation is a subsequent challenge for the firm (Baba & Walsh, 2010). For most of the firm-level variables, we use the value associated with the drug's peak year, since we are interested in capturing the period of the product's blockbuster status—the drug's peak year is the point at which this occurs.

To supplement drug level data, we used information from the *Orange Book* and the *USPTO.* At the firm level, we used data from firm *Compustat*, *10-k* reports, and *Mergent Online* to control for firm level variables, including location and industry classifications, for each application. Overall, we have built a data set that presents a comprehensive picture of the firm and industry related issues that drive the selection, development and control of each drug. Finally, to measure the legitimacy of the controlling firms, we used the *Lexis Nexis* database to capture relevant news mentions. Firms and drugs originate from a variety of locations around the world, and the controlling firm occupies a central global orchestration role.

Estimation Model

We estimate the probability that a drug reaches blockbuster status at any point in its history. The dependent variable in our study is dichotomous: either a drug reaches blockbuster status, or it does not. We selected a Probit model, i.e., $P(Y_i = 1|X_i) = \Phi(X_i\beta)$ where Φ is the standard normal cumulative density function, is the probability of the *i*th drug becoming a blockbuster, and X_i is our vector of drug and firm explanatory variables.

Measures

Blockbuster Drugs: The dependent variable *Y* is equal to 1 if a drug achieved blockbuster status, and 0 if not. We classify a drug as a blockbuster if it achieves peak annual global sales of greater than $1 billion (Munos, 2009; Lazonick & Tulum, 2011).

Legitimacy: Organizational legitimacy is not directly observable to the researcher (Zimmerman & Zetiz, 2002). However, as the construct evolved in the literature, scholars began to link novel measures of public presence to specific forms of legitimacy. Recall that cognitive legitimacy represents the extent to which the general public is aware and accepting of an organization (Suchman, 1995). Likewise, there are some markets in which intermediaries help to form the public's opinion of legitimate organizations (Zuckerman, 1999). One such intermediary is the news media (Deephouse, 1996; Baum & Powell, 1995; Elsbach, 1994). Journalists serve as critical and evaluative constituents, choosing which information to include in media reports and the manner in which key facts are framed (Deephouse, 1996: 1999; Pollock & Rindova, 2003). Thus, media legitimacy presents a reasonable proxy for the extent to which the general public accepts firm as a member of a particular industry or market.

In order to calculate the media legitimacy of the firm, we used the *Lexis Nexis* database. For each firm, we conducted a search of the firm's name and the term "pharmaceutical". This search was conducted with a beginning date of 1980, and a concluding date of the peak sales year of the associated drug in our database. The number of stories in which the firm appeared was aggregated for each year, generating a cumulative total of the media mentions. For firms that were the result of mergers, the cumulative totals were combined (i.e., Bristol Myers and Squibb were combined for the years after the 1989 merger).

We discounted the mentions from each year using an annual depreciation model. Status and reputation are closely linked (Rao, 1994). As brand equity depreciates over time, so too might the value of media legitimacy: thus following Borkovsky, Goldfarb, Haviv, & Moorthy (2013), we pegged our annual discount rate to 25.47%. For the purposes of robustness, we also calculated discount rates at 5% increments from 5% up to 30%. The result was a continuous measure of the organizational legitimacy of the firm.

Major: The *Major* variable is equal to 1 if the firm commercializing the drug is a major in the drug's peak sales year, and 0 otherwise. To calculate this, we took the 90th percentile of the continuous measure in a given year of media legitimacy, and coded firms above it as being major firms. Firms may be of high, low, and middling status (Phillips & Zuckerman, 2001). We used the 85th percentile of media legitimacy to generate the lower bound of status: firms below it were coded as non-majors. Firms with legitimacy scores between the 85th and 90th percentile were not placed in either group. The firms that emerge as majors from our analysis closely track the opinions of industry experts regarding "Big Pharma" (Martinez & Goldstein, 2007; Hawthorne, 2011). Further, our list is a near perfect match with the list drawn up by Agarwal et al. (2001).

Consistent with our earlier argument, major status is conferred as a function of legitimacy, rather than size. Size may serve as a proxy for an insider position. However, "Big Pharma" is a generally accepted term for the major players in the pharmaceutical industry, i.e., a taken-for-granted evaluation of status. The "Big Pharma" firms are not necessarily the largest firms in the industry. For example, Boehringer Ingelheim and Amgen, both non-majors, employed 41,300 and 48,000 people respectively in 2008. By contrast, Eli Lilly and Bristol Myers Squibb, both majors, employed 40,450 and 42,000 people respectively in 2008.

Breakthrough Drugs: Substantive innovations, although informed by market knowledge, are often classified as "breakthrough" by way of their extent of scientific breakthrough (Baba & Walsh, 2010). In our data, those drugs that have been classified as

New Molecular Entities (NME) by the FDA are those with an underlying molecular structure that is new to the U.S. market. To be clear, we use the FDA classification of breakthrough innovations as an *exogenous* event. The presence of a newly developed active ingredient can be considered a breakthrough innovation, with all others representing incremental innovations, or improvements to existing products (Dunlap, Kotabe, & Mudambi, 2010). We coded *Breakthrough* as "1" if a drug was classified as an NME, and "0" otherwise. It should be noted that a significant percentage of NMEs are "orphan" drugs, or those that treat fewer than 200,000 Americans (FDA, 2013). The FDA opened a specific category of "breakthrough" drugs on July 9, 2012, and 2013 was the first year in which new drugs were approved with this designation (FDA, 2013).

Market Applicability: New Efficacy Supplements: Over time, parent firms file applications for New Efficacy Supplements (NES) with the FDA. An NES can be a change to the dosage or a new therapeutic indication. NES applications represent an exploitative action on the part of the firm, as the drug in question remains the same (and retains the original application number), but the label is modified. If a product treats wider reaching indications, the capacity for additional NES filing increases. Thus, by capturing the exploitative path of a drug, we generate a proxy for its therapeutic impact and market applicability (Dunlap et al., 2010). Our database contains 12,270 NES filings across the 3,250 drug applications. To each drug level observation, we attach the number of NES filings that had accumulated up to the point of the peak sales period.

Many breakthrough innovations are orphan drugs, while some have potential for broad market success. The latter are likely to generate more NES filings. The number of NES filings associated with a drug would therefore capture much of the market success of breakthrough innovation. Thus, the NES variable controls for commercial aspects of our "breakthrough drug" variable, leaving "breakthrough drug" as a proxy for pure scientific achievement.

Total Firm Patents: As the firm amasses knowledge through R&D, its patent stocks will grow and represent a history of innovative activity (Cantwell, 1989; Griliches, 1992). Similarly, the firm's stock of patents may indeed spur on further R&D efforts (Arora, Ceccagnoli, & Cohen, 2008). The scientific knowledge of the firm is therefore rooted in its stock of patents. Despite the market-driven requirement to extract rents from the protected innovation (Teece, 1986), the fault lines of knowledge fall along incentive structures: R&D scientists ultimately create and build on the scientific domain (Mudambi & Swift, 2009). To the extent that the scientific community cites "prior art", the onward flow of knowledge cements a patent's place in the hierarchy of innovation (Jaffe, Trajtenberg, & Henderson, 1993). Therefore, we represent the commercializing firm's scientific knowledge as the stock of USPTO patents assigned to the firm as of the drug's peak sales year.

R&D Intensity: R&D intensity, which has been tied to firm performance (Deeds, Decarolis, & Coombs, 1997) and innovative activity (DeSanctis, Glass, & Ensing, 2002), is an important control, particularly given our use of patents as an innovative output of the firm (Griliches, 1992). R&D intensity is constructed as the R&D expenditure of the firm in a given year divided by its total sales. We attach these to each observation based on the drug's peak sales year.

Firm Size and Age: Firm size presents an important control in our quantitative analysis. As elucidated in the theory development section, majors are insiders that leverage substantial legitimacy to create organizational advantage. Size and age are particular correlates associated with majors. However, size may also present direct benefits to pharmaceutical firms. The resource requirements of FDA directives to demonstrate both safety and efficacy in new drugs has led to a reduction in the number of firms capable of producing and developing pharmaceutical innovations (Thomas, 1990). Furthermore, firm size has been found to speed up the FDA approval process (Olson, 1997). We used the number of full time (or equivalent) employees in the firm to represent firm size. For the purposes of robustness, we also evaluate size using the total assets of the firm, thus capturing both the labor and capital aspects of size.

For the same reason that size may imbue a firm with greater resources to navigate the complexities of the FDA regulatory system, experience is an important predictor of approval speed and success (Olson, 1997; Carpenter, 2002). Parent firm age, represented by time (in years) from the date of incorporation, captures both regulatory knowledge and an ability to mitigate an uncertain development process (Carpenter, 2004). We attach these variables to each observation based on the drug's peak sales year.

Other firm controls: To control for location effects, we include a set of indicator variables based on the headquarters country of the parent firm. Since few pharmaceutical firms are truly global (Rugman, 2005), the regional influences of the U.S., and United Kingdom may be strongest. We also include Return on Sales as a measure of the firm level success, which may both guide and constrain innovative efforts (Nelson & Winter, 1982). Finally, we control for the peak year of the drug.

Results

Table 2.1 presents the descriptive statistics for both the dependent variables for the probit regressions and the associated explanatory variables and controls. As the data show, only 6% of all products are blockbusters, while majors control 26% of all products. Majors engage in non-blockbuster production, while non-majors engage in blockbuster production. **Table 2.2** displays the correlation matrix. While variables with an inherent connection, such as Total Patents and Total Employees, have a natural correlation, there is little evidence of multicollinearity among the independent variables.

Table 2.3 displays our first core models. Because coefficient interpretation is difficult in a nonlinear model, we include the average marginal effects of the explanatory variables of all models (Hoetker 2007): in this table, the primary model is presented as "a" (i.e. column 1a) and the marginal effects follow as model "b" (i.e. column 1b). In Model 1a, we estimated the effect of organizational legitimacy as a continuous measure on the likelihood of a drug being a blockbuster. Our argument hinges on the major firm possessing legitimacy, controlling for other major correlates at the firm level and other determinants of blockbuster success. This finding supports *hypothesis 1*, the notion that legitimacy as a basic measure strongly predicts blockbuster outcomes (Legitimacy: 3.77×10^{-5}, $p<0.01$, marginal effect: 3.21×10^{-6}). Of note in this model is the positive and significant impact of market applicability on blockbuster success (Market Applicability: 0.047, $p<0.01$, marginal effect: 3.97×10^{-3}), as well as the diminished effect of breakthrough innovation. This finding provides some initial clues as to the crucial levers of blockbuster success: market potential may be a strong effect independent of firm status, while breakthrough innovation may be closely linked to firms. Of note, the size of the firm is not a determinant of blockbuster success, although age is a positive factor.

Column 2a in **Table 2.3** presents a lower benchmark of major status, the 85th percentile of media mentions. In this model, major status is a positive and significant driver of blockbuster outcomes (Major 0.407, $p<0.01$, marginal effect 0.035). This is a higher magnitude finding than that of the continuous measure of legitimacy. Market applicability remains positive and significant (Market Applicability: 0.047, $p<0.01$, marginal effect: $4.02 \text{x} 10^{-3}$) and largely similar as model 1, adding further evidence to suspicious of a firm-independent effect.

Our third and core model can be found in column 3a of **Table 2.3**. In this estimation, we use the 90th percentile benchmark of legitimacy to define major firms. This model lends strong support to *hypothesis 2*: not only is the result positive and significant (Major 0.753, $p<0.01$, marginal effect 0.064), but also the magnitude of the effect is nearly twice that of the 85th percentile. As the discontinuous definition of major becomes more restrictive, the importance of breakthrough begins to fade (Breakthrough 0.197, $p<0.1$, marginal effect 0.017). However, market applicability remains similar in its significance and magnitude. Of note is that the R&D intensity of the firm is a positive and significant driver of blockbuster success (R&D Intensity 0.259, $p<0.01$, marginal effect 0.022), reinforcing the notion of ongoing efforts bolstering integration efforts and technology search. Neither size nor age are factors in this model.

Table 2.4 represents the bifurcation of the sample sets into major and non-major groups. Column 1a shows the results of our estimation using the non-major subset of firms (<85th percentile). We find that within this group, breakthrough represents a positive and significant driver of blockbuster success (Breakthrough 0.983, p<0.01, marginal effect 0.035), thus strongly supporting *hypothesis 3*. Also within this group, market applicability retains strong support (Market Applicability: 0.049, p<0.01, marginal effect: 0.002). Of note, marginal increases in the legitimacy of the firm do not have any impact: this further reinforces the discontinuous nature of status. Column 2a displays our model for the major subset (90th percentile). In it, we find that within the groups of high status, additional levels of legitimacy are not drivers of blockbuster outcomes. Furthermore, breakthrough innovation is not a significant negative driver of blockbuster success for major firms. This non-finding does suggest that majors may operate at high levels without breakthrough products.

Model 3a of **Table 2.4** recombines the sample and explores the impact of market applicability across firms of high and low status. While this model retains strong support for *hypothesis 2* with a positive and significant impact of major status on blockbuster outcomes (Major 0.815, p<0.01, marginal effect 0.069), no support is found for the differential effect of market potential, confirming our prior belief that only the scientific aspects of the project are sensitive to firm status. The overall core probit model diagnostics show a strong overall fit for all models in **Tables 2.3** and **2**.**4**.

Table 2.5 presents the first of a series of robustness checks. One other potential issue could be the use of NDAs and ANDAs to define the full sample set. We estimated an additional version of our core models using the NDAs only (smaller number of observations, n=1,001). The NDA subset, which is a category exogenously determined by the FDA, represents innovations that are new to the market. By focusing on a narrower group of innovations, the effect of majors was put to a more stringent test. All hypotheses retain support, however.

One other potential issue we faced in analyzing the data set is that some drugs that were approved prior to 2008 may have yet to peak. This introduces a potential truncation issue. To determine whether such truncation could affect our results, we adjust the dollar threshold for our definition of blockbuster drugs. **Table 2.6** presents our results using an annual revenue marks of $1.5 billion $2.0 billion and $2.5 billion respectively. In the interests of brevity, we ran extended regressions on the $2.0 billion benchmark. In all models, the statistical significance of both the estimation and the coefficients remains strong. This suggests that truncation of some drug revenues is unlikely to have an impact on our conclusions.

Discussion

The concept of a major firm is not new, but it is seriously under-theorized. Major firms are a feature of a variety of industries where "everybody knows" who they are. The “big three” automotive firms (MacDuffie & Helper, 1997), “studio majors” (DeFillippi & Arthur, 1998; Miller & Shamsie, 2001), and “big four” (Kornberger, Carter, & Ross-Smith, 2010) accounting firms are among the examples elucidated early in the present paper. A significant contribution of this chapter is to suggest that majors possess unique capabilities *beyond* those that are directly observable. Rather they possess organizational legitimacy (Suchman, 1995) and use it strategically to acquire resources, place big bets and explore challenging technological domains. The legitimacy that majors possess stems from a categorization process in which audiences sort organizations into insiders and outsiders (Zuckerman, 1999).

We use evidence from the pharmaceutical industry to show that a product's likelihood of becoming a blockbuster significantly increases when it is controlled by a major. Using a data set of all drugs approved by the FDA in the period 1993-2008 (2,978 usable observations), we estimate a probit model to show that the effect of a major on a product's becoming a blockbuster is robust to different benchmarks of blockbuster, and different definitions of pharmaceutical products. It is important to note that our empirical analysis controls for other key predictors of blockbuster success, including firms size, age, R&D-intensity, firm-level knowledge stock, and location. Thus, major status captures something over and above the important drivers of firm success that have been identified in the literature (Hansen & Wernerfelt, 1989).

We further show that majors' legitimacy allows them to pursue paths that are off-limits to non-majors (Zuckerman, 1999; Phillips & Zuckerman, 2001). Majors are free to explore the technological landscape more broadly and select breakthrough and non-breakthrough innovations alike to control globally. By contrast, non-majors must rely on the inherent characteristics of the project itself. In the pharmaceutical industry, non-majors need breakthrough products in order to achieve blockbuster outcomes. Majors, on the other hand, were able to create blockbusters from breakthrough and non-breakthrough products alike.

The modern major firm can be a traditional player, such as Merck, which has a history of drug discovery, development, and downstream control. However, majors can also arise from mergers that weave together constituent parts and relative strengths, such as that of the marriage of Bristol-Myers and Squibb in 1989. Both cases involve the orchestration of knowledge across the entire value chain, however. In all major-creating acquisitions except for that of Novartis in 1996, at least one partner had a history of blockbuster development on its own. Additionally, in nearly 80 percent of the cases involving majors, mergers occur *prior* to drugs' achieving peak sales. In other cases, major firms have acquired or merged with firms that may be considered majors themselves (i.e., Pfizer-Wyeth, 2009; GlaxoWellcome-SmithKline Beecham, 2000). Taken together, our data suggests that while there are many sources of innovation, only a few firms can carry breakthrough drugs up to the level where blockbuster rents are earned.

A particularly salient example may be the evolution of the drug Lipitor. Lipitor is a second-generation statin used to treat high cholesterol. It was discovered at Warner Lambert's Parke Davis division in 1985, although the product was not readily seen as a breakthrough innovation and was nearly canceled (Simons, 2003). The existing statin market was well established at the time of Lipitor's discovery (Li, 2006). However, Lipitor had one potential advantage: its lowest dose was more effective than the highest dose of its competitors (Simons, 2003). In 1996, as the drug neared its launch, Warner Lambert was a large firm, with 38,000 employees. However, it was not a major, and would not ultimately become a major. Warner Lambert struck a marketing agreement with Pfizer, seeking to leverage Pfizer's status as a major. At launch, projections of the alliance suggested that Lipitor would generate $300 million in worldwide revenue (Li, 2006). Pfizer added a key positioning argument to help market Lipitor to the medical community: its relative efficiency allowed doctors to prescribe lower doses (Simons, 2003). Within a year post-launch, Lipitor reached 18 percent market share (Simons, 2003). By 2000, with a clearer picture of Lipitor's potential, Pfizer acquired Warner Lambert for $90 billion. Lipitor went on to bring in more than $13 billion in global revenues per year.

The Lipitor example illustrates the role of major status. While it is impossible to know what could have happened, it is unlikely that Warner Lambert could have pushed Lipitor to the heights it achieved under Pfizer. On the basis of the analysis in this chapter, we contend that only Pfizer, or perhaps another major, could accomplish this feat.

This study has several limitations. First, we use secondary sources to triangulate on the discovery, knowledge transfer, and commercialization processes that take place in the pharmaceutical industry. Qualitative analysis that incorporates primary data sources, such as interviews with pharmaceutical executives, would serve to validate our findings. We leave that to future research. Second, we use secondary data to capture knowledge transfer mechanisms. The pharmaceutical industry is notoriously secretive. As a result, some databases are subject to measurement error. Qualitative work in future studies might alleviate this issue.

Drugs with the potential to become blockbusters are rare, as are the opportunities to commercialize: only 116 drugs reached blockbuster status between 1980 and 2010. The role of the major is especially important in maximizing returns. Majors continue to research and engage in the product development cycle anywhere from the very early stages to post-launch. Majors' insider status gives them unique access to resources, and an ability to take on risk. Their accumulation of knowledge ensures that they understand the discovery science to sufficiently select new products (Brusoni, Principe, & Pavitt, 2001; Arora et al., 2009). Ultimately, majors can envision the diffusion trajectory of candidate products and steepen the revenue function to generate exceptional rents.

Tables

Table 2.1: Variable Descriptions & Summary Statistics

Variable	**Description**	**Source**	**Mean**	**SD**
Blockbuster	Dummy variable for product achieving blockbuster status.	*EvaluatePharma*	0.06	0.23
Breakthrough	Dummy variable for breakthrough innovation designation at time of approval.	*U.S. Food and Drug Administration*	0.11	0.31
Legitimacy: Cumulative News Mentions	Cumulative present value total of pharmaceutical news stories in which the controlling firm is mentioned.	*Lexis Nexis*	2,898.02	4,446.21
Legitimacy: Major (90th Percentile)	Dummy variable for “Major”, using the 90th percentile of news mentions in a given year.	*Lexis Nexis*	0.26	0.44
Market Applicability	Number of new efficacy supplements file for each product as of the product peak sales year.	*U.S. Food and Drug Administration*	4.11	6.45
Firm Total Patents	Patent stock of the controlling firm as of the product peak sales year.	*U.S. Patent & Trademark Office*	2,137.19	4,031.93
Firm R&D Intensity.	Research and Development Intensity (R&D Expense/Sales) of the controlling firm in the product peak sales year.	*Compustat, Mergent Online, Firm 10K Reports*	1.38	20.84
Firm Total Employees	Total number of full time employees of the controlling firm in the product peak sales year (thousands).	*Compustat, Mergent Online, Firm 10K Reports*	38.77	44.57
Firm Age	Age of the controlling firm in the product peak sales year (years).	*Compustat, Mergent Online, Firm 10K Reports*	69.32	44.32
Firm Return on Sales	Return on Sales (ROS %) of the controlling firm in the product peak sales year.	*Compustat, Mergent Online, Firm 10K Reports*	-2.04	35.69
Firm HQ: U.S.	Dummy variable for the headquarters location of the commercializing firm: United States.	*Compustat, Mergent Online, Firm 10K Reports*	0.44	0.50
Firm HQ: U.K.	Dummy variable for the headquarters location of the commercializing firm: United Kingdom.	*Compustat, Mergent Online, Firm 10K Reports*	0.04	0.20

Table 2.2: Correlation Matrix

		1	2	3	4	5	6	7	8	9	10	11	12
1	*Blockbuster*	1.00											
2	*Breakthrough*	0.18	1.00										
3	*Market Applicability*	0.31	0.36	1.00									
4	*Legitimacy: Cumulative News Mentions*	0.30	0.19	0.25	1.00								
5	*Legitimacy: Major (90th Percentile)*	0.29	0.21	0.27	0.70	1.00							
6	*Firm Total Patents*	0.16	0.17	0.19	0.56	0.70	1.00						
7	*Firm R&D Intensity*	-0.01	-0.01	-0.01	-0.04	-0.04	-0.03	1.00					
8	*Firm Total Employees*	0.15	0.15	0.20	0.48	0.56	0.73	-0.06	1.00				
9	*Firm Age*	0.16	0.09	0.20	0.40	0.53	0.41	-0.07	0.50	1.00			
10	*Firm Return on Sales*	0.12	0.01	0.02	0.04	0.04	0.03	-0.53	0.05	0.07	1.00		
11	*Firm HQ: U.S.*	0.05	0.06	0.06	-0.05	0.00	-0.10	0.07	-0.20	-0.27	-0.07	1.00	
12	*Firm HQ: U.K.*	0.20	0.11	0.14	0.46	0.28	0.08	-0.02	0.1	70.22	0.02	-0.19	1.00

Table 2.3: Estimation of the likelihood of an innovation being blockbuster drug. All innovations, 1993-2008. Probit model and average marginal effects.

	Estimates	**Average Marginal Effects**	**Estimates**	**Average Marginal Effects**	**Estimates**	**Average Marginal Effects**
VARIABLES	**(1a)**	**(1b)**	**(2a)**	**(2b)**	**(3a)**	**(3b)**
Legitimacy (Continuous)	3.77x10^{-5}***	3.21x10^{-6}***				
	(3.69)	(3.68)				
Legitimacy (Major: 85th Percentile)			0.407***	0.035***		
			(3.96)	(4.03)		
Legitimacy (Major: 90th Percentile)					0.753***	0.064***
					(4.77)	(4.82)
Market Applicability	0.047***	3.97x10^{-3}***	0.047***	4.02x10^{-3}***	0.046***	3.92x10^{-3}***
	(8.05)	(7.97)	(8.13)	(8.04)	(7.91)	(7.88)
Breakthrough	0.218*	0.185*	0.237*	0.020*	0.197*	0.017*
	(1.74)	(1.72)	(1.89)	(1.87)	(1.57)	(1.56)
Firm: Total Patents	2.55x10^{-5}*	2.15x10^{-6}*	3.72x10^{-5}**	3.20x10^{-6}**	7.67x10^{-6}	6.50x10^{-7}
	(1.64)	(1.64)	(2.32)	(2.30)	(0.44)	(0.44)
Firm: R&D Intensity	0.341***	0.290***	0.369***	0.032***	0.259***	0.022***
	(4.10)	(4.06)	(4.21)	(4.20)	(2.89)	(2.87)
Firm: Total Employees	-0.002	-1.46x10^{-4}	-0.002	-1.55x10^{-4}	-0.001	-9.88x10^{-5}
	(-1.13)	(-1.13)	(-1.01)	(-1.01)	(-0.68)	(-0.68)
Firm: Age	0.004***	3.53x10^{-4}***	0.003**	2.80x10^{-4}**	0.001	6.67x10^{-5}
	(3.08)	(3.03)	(2.35)	(2.32)	(0.48)	(0.48)
Firm: Return on Sales	1.212***	0.103***	1.306***	0.112***	1.025***	0.087***
	(4.08)	(4.00)	(4.19)	(4.11)	(3.23)	(3.17)
Firm: HQ U.S.	0.435***	0.037***	0.524***	0.045***	0.403***	0.034***
	(4.30)	(4.26)	(5.17)	(5.11)	(3.59)	(3.55)
Firm: HQ U.K.	0.496**	0.042**	0.844***	0.073***	0.778***	0.066***
	(2.35)	(2.35)	(5.09)	(5.09)	(4.70)	(4.74)
Year Dummies	Y	Y	Y	Y	Y	Y
Observations	2,978	2,978	2,978	2,978	2,978	2,978
Model Chi-Square	345.71***		324.88***		360.54***	
d.f.	22		22		22	
Pseudo R-Squared	0.28		0.28		0.29	
log pseudolikelihood	-485.37		-485.75		-477.06	

Robust z-statistics in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.10$

Table 2.4: Estimation of the likelihood of an innovation being blockbuster drug. All innovations, 1993-2008. Full Sample and Major (>90th Percentile) and Non-Major (<85th Percentile) Subsets. Probit Model and Average Marginal Effects.

	Estimates	**Average Marginal Effects**	**Estimates**	**Average Marginal Effects**	**Estimates**	**Average Marginal Effects**
VARIABLES	**(1a: Non-Major Subset)**	**(1b: Non-Major Subset)**	**(2a: Major Subset)**	**(2b: Major Subset)**	**(3a: Full Sample)**	**(3b: Full Sample)**
Legitimacy (Continuous)	-3.64x10^{-4}	-1.30x10^{-5}	2.85x10^{-5}	5.75x10^{-6}		
	(-1.36)	(-1.35)	(1.36)	(1.35)		
Legitimacy (Major: 90th Percentile)					0.815***	0.069***
					(4.22)	(4.19)
Legitimacy (Major: 90th Percentile) * Realized Market Success					-0.007	-6.33x10^{-4}
					(-0.64)	(-0.64)
Market Applicability	0.049***	0.002***	0.048***	0.010***	0.052***	0.004***
	(3.60)	(3.09)	(6.23)	(6.63)	(5.39)	(5.22)
Breakthrough	0.983***	0.035***	-0.242	-0.049	0.196	0.017
	(4.26)	(3.85)	(-1.62)	(-1.63)	(1.57)	(1.56)
Firm: Total Patents	1.78x10^{-5}	6.37x10^{-7}	-5.39x10^{-5}	-1.09x10^{-5}	7.06x10^{-6}	5.99x10^{-7}
	(0.58)	(0.58)	(-1.61)	(-1.61)	(0.40)	(0.40)
Firm: R&D Intensity	0.010	3.42x10-4	1.644	0.331	0.256***	0.022***
	(0.06)	(0.06)	(1.03)	(1.03)	(2.79)	(2.77)
Firm: Total Employees	-0.004	-1.55x10^{-4}	-0.002	-4.14x10^{-5}	-0.001	-9.94x10^{-5}
	(-1.61)	(-1.55)	(-0.39)	(-0.39)	(-0.69)	(-0.69)
Firm: Age	0.002	7.64x10^{-5}	-0.008***	-0.002***	0.001	5.95x10^{-5}
	(1.03)	(1.02)	(-3.40)	(-3.45)	(0.42)	(0.42)
Firm: Return on Sales	0.770**	0.028*	-2.077*	-0.419*	1.016***	0.086***
	(2.15)	(1.99)	(-1.70)	(-1.69)	(3.16)	(3.11)
Firm: HQ U.S.	-0.102	-0.003	0.210	0.042	0.407***	0.034***
	(-0.42)	(-0.42)	(0.74)	(0.74)	(3.61)	(3.57)
Firm: HQ U.K. [a]	-	-	0.789**	0.159**	0.780***	0.067***
	-	-	(2.02)	(2.05)	(4.72)	(4.75)
Year Dummies	Y	Y	Y	Y	Y	Y
Observations	1,285	1,285	813	813	2,978	2,978
Model Chi-Square	71.43***		111.68***		368.11***	
d.f.	11		20		23	
Pseudo R-Squared	0.25		0.20		0.29	
log pseudolikelihood	-91.93		-297.63		-476.82	

Robust z-statistics in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.10$
a: U.K. Location Omitted In Restricted Model

Table 2.5: Estimation of the likelihood of an innovation being blockbuster drug. All innovations, 1993-2008. Robustness Check 1: NDA Subsample. Probit model.

	Estimates	**Estimates**	**Estimates**	**Estimates**	**Estimates**
VARIABLES	**(1: Full Sample)**	**(2: Full Sample)**	**(3: Non-Major Subset)**	**(4: Major Subset)**	**(5: Full Sample)**
Legitimacy (Continuous)	$2.78x10^{-5}$***		$-3.24x10^{-4}$	$-1.29x10^{-6}$	
	(2.68)		(-1.04)	(-0.06)	
Legitimacy (Major: 90th Percentile)		0.673***			0.635***
		(4.09)			(3.04)
Legitimacy (Major: 90th Percentile) * Realized Market Success					0.004
					(0.32)
Market Applicability	0.037***	0.037***	0.032**	0.040***	0.034***
	(6.50)	(6.40)	(2.52)	(5.46)	(3.21)
Breakthrough	-0.160	-0.175	0.433*	-0.419***	-0.175
	(-1.43)	(-1.55)	(1.90)	(-2.96)	(-1.55)
Firm: Total Patents	$1.13x10^{-5}$	$-5.00x10^{-6}$	$9.14x10^{-6}$	$-2.30x10^{-5}$	$-4.71x10^{-6}$
	(0.72)	(-0.28)	(0.31)	(-0.73)	(-0.26)
Firm: R&D Intensity	0.341	0.164	-0.558	1.564	0.171
	(0.97)	(0.45)	(-1.01)	(0.95)	(0.46)
Firm: Total Employees	-0.002	-0.002	-0.005*	-0.002	-0.002
	(-1.41)	(-1.19)	(-1.80)	(-0.47)	(-1.18)
Firm: Age	0.003	$-5.320x10^{-6}$	0.001	-0.006***	$-1.29x10^{-5}$
	(1.63)	(-0.03)	(0.51)	(-2.61)	(-0.01)
Firm: Return on Sales	0.743***	0.605**	0.403	-1.111	0.608**
	(2.79)	(2.17)	(1.10)	(-0.91)	(2.19)
Firm: HQ U.S.	0.231*	0.200	-0.350	0.282	0.199
	(1.84)	(1.53)	(-1.35)	(1.00)	(1.52)
Firm: HQ U.K. [a]	0.208	0.400**		0.837**	0.399**
	(0.95)	(2.30)		(2.15)	(2.29)
Year Dummies	Y	Y	Y	Y	Y
Observations	1,001	1,001	328	529	1,001
Model Chi-Square	110.82***	120.54***	31.72***	31.72***	122.02***
d.f.	22	22	11	11	23
Pseudo R-Squared	0.13	0.15	0.14	0.14	0.15
log pseudolikelihood	-403.92	-403.92	-76.22	-76.22	-397.56

Robust z-statistics in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.10$

a: U.K. Location Omitted In Restricted Model

Table 2.6: Estimation of the likelihood of an innovation being blockbuster drug. All innovations, 1993-2008. Robustness Check 2: Blockbuster Drug Levels. Probit model.

	Estimates	**Estimates**	**Estimates**	**Estimates**	**Estimates**	**Estimates**
VARIABLES	**(1: Full Sample: \$1.5 Billion Benchmark)**	**(2: Full Sample: \$2.0 Billion Benchmark)**	**(3: Full Sample: \$2.5 Billion Benchmark)**	**(4: Non-Major Subset: \$2.0 Billion Benchmark)**	**(4: Major Subset: \$2.0 Billion Benchmark)**	**(4: Full Sample: \$2.0 Billion Benchmark)**
Legitimacy (Continuous)				-2.97x10^{-4}	8.64x10^{-6}	
				(-0.73)	(0.22)	
Legitimacy (Major: 90th Percentile)	1.140***	1.185**	1.275*			1.266**
	(2.64)	(2.22)	(1.84)			(2.04)
Legitimacy (Major: 90th Percentile) * Realized Market Success						-0.005
						(-0.30)
Market Applicability	0.051***	0.057***	0.059***	0.050***	0.061***	0.061***
	(6.81)	(7.07)	(6.42)	(2.80)	(6.03)	(3.70)
Breakthrough	0.835***	0.853***	0.943***	0.939**	0.678***	0.849***
	(4.90)	(4.18)	(3.74)	(2.57)	(2.89)	(4.17)
Firm: Total Patents	1.85x10^{-5}	5.74x10^{-5}	5.43x10^{-5}	3.70x10^{-5}	-1.61x10^{-6}	5.62x10^{-5}
	(0.53)	(1.47)	(1.24)	(0.46)	(-0.03)	(1.45)
Firm: R&D Intensity	-0.075	-0.061	-0.042	-0.509	1.091	-0.080
	(-0.24)	(-0.21)	(-0.14)	(-0.60)	(0.34)	(-0.24)
Firm: Total Employees	-0.009*	-0.018**	-0.016*	-0.012	-0.023*	-0.018**
	(-1.80)	(-2.56)	(-1.96)	(-1.01)	(-1.65)	(-2.54)
Firm: Age	-0.007**	-0.005	-0.007	0.002	-0.013***	-0.006
	(-2.42)	(-1.63)	(-1.60)	(0.60)	(-2.75)	(-1.62)
Firm: Return on Sales	0.599*	0.461	0.182	0.507	0.050	0.454
	(1.84)	(1.53)	(1.00)	(1.22)	(0.02)	(1.46)
Firm: HQ U.S.	-0.230	-0.329	-0.488	-0.042	-0.764	-0.329
	(-1.10)	(-1.36)	(-1.64)	(-0.11)	(-1.47)	(-1.35)
Firm: HQ U.K. ^{a}	0.750**	0.999***	0.662*		0.682	0.990***
	(2.51)	(2.84)	(1.67)		(1.19)	(2.88)
Year Dummies	Y	Y	Y	Y	Y	Y
Observations	1,285	1,285	813	813	2,978	2,978
Model Chi-Square	71.43***		111.68***		368.11***	
d.f.	11		20		23	
Pseudo R-Squared	0.25		0.20		0.29	
log pseudolikelihood	-91.93		-297.63		-476.82	

Robust z-statistics in parentheses. *** p<0.01, ** p<0.05, * p<0.10
a: U.K. Location Omitted In Restricted Model

CHAPTER 3: THRIVING INNOVATION AMIDST MANUFACTURING DECLINE: THE DETROIT AUTO CLUSTER AND THE RESILIENCE OF LOCAL KNOWLEDGE PRODUCTION

Introduction

As the industrial center of the North American automobile industry, Detroit was a model of growth for the better part of the 20th century. The specialization of the automotive industry in the Detroit area bore many of the hallmarks of a Marshallian cluster (Marshall, 1920), driven by economies of scale in inputs and access to common labor pools. Eventually, the cluster evolved: lead firm concentration rose to the oligopoly level (Klepper, 2007), and supplier networks tightened and co-located to the Detroit area (MacDuffie, 2013; Sturgeon et al., 2008). The shift to a more rigid hub and spoke configuration ultimately left the industry vulnerable (Markusen, 1996), while the movement of manufacturing activities to more efficient locations led to significant job losses (DiGaetano & Lawless, 1999)[1]. Many have suggested that Detroit has suffered irreparable damage (LeDuff, 2013). We argue, however, that the decline in manufacturing activity, associated with images of abandoned factories and urban depopulation, did not mean the end of the Detroit auto cluster; it only marked the transition to a different stage.

Agglomeration externalities draw on the connectivity of firms and people within a defined geographic space. Firms sharing common resources (Marshall, 1920) benefit from knowledge spillovers through labor mobility (Arrow, 1962), or innovate in the face of local competition (Porter, 1998). Over time, as the cluster ecosystem achieves some

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[1] For instance, the state of Michigan that relies heavily on the Detroit auto cluster had the lowest growth of state product at 0.01% (Institute for Strategy and Competitiveness, Harvard Business School, 2009) and employment at-0.32% (Bureau of Economic Analysis, 2009) over the decade ending 2007.

measure of concentration and specialization, many of the benefits of agglomeration economies may become vulnerabilities (Markusen, 1996) and the decline of the Detroit auto cluster is an illustration of such an outcome.

While recent literature has argued that the loss of production strength in Detroit has brought about economic decline, the local knowledge intensive activities of R&D and design have continued to thrive and expand (Sturgeon et al., 2008). Our empirical evidence provides detailed support for this argument. Our analysis shows that innovative activity in the Detroit auto cluster increased over the last three decades, at a pace much higher than the U.S. average.

We found that Detroit's innovative growth is paired with an increase in connectedness to other locations, i.e., the degree to which the innovative activity in Detroit is conducted through collaboration amongst geographically dispersed teams. In particular, Detroit is connected to global locations with significant auto industry agglomeration, i.e., global centers of excellence in the auto industry. We argue that the emergence of these connections is no accident. As they compete to retain their positions in the global auto industry, the "Big Three" Detroit automakers (and firms in their supplier network) have reached out to the industry's global knowledge hotspots in an attempt to maintain their technological edge. Continuing local R&D activity has generated gravitational pull, renewing Detroit's position in the global auto industry innovation system[2].

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[2] While we argue that the Detroit auto cluster's focus on linkages to global knowledge hotspots was a positive factor, it was not a guarantee of innovative resilience. As noted by Grabher (1993) in his analysis of the Ruhr region of Germany, local "lock-in" and a failure to maintain global linkages were associated with long-term cluster decline. Shrank & Whitford (2011) develop a broader theory in which competency shortfalls are a crucial determinant of network failure.

Knowledge creation within industry clusters relies on both local and global linkages (Lorenzen & Mudambi, 2013). High levels of both local activity and external connectedness sustain the health of a cluster's innovative output (Bathelt et al., 2004). The untraded interdependencies within a cluster both enable and result from the transfer of tacit knowledge (Storper, 1995). While firms will source knowledge locally when possible, they will go long distances if the knowledge they seek is not locally available. These local and remote collaborations have different characteristics and produce different results (Gittelman, 2007). However, the multiplex view of the effects of geographic connections and technological distance on innovation in clusters is clearly underdeveloped. It is in this space that our chapter intends to make a contribution.

Firms disperse their innovative activities across geographic space and diversify them across technological space. The interplay of these two dimensions creates an array of possible linkages and knowledge sourcing patterns. Gittelman (2007) found that spatial distribution of collaborative teams tends to be strongly bimodal, with a large number of local collaborations and a large number of very long distance collaborations, but few at intermediate distances. However, we argue in this paper that internal specialization and connectivity to distant centers of excellence are both vital to cluster health. One of our main contributions is to provide empirical evidence for the heretofore theoretical position that a cluster’s continued centrality in its global industry is inseparable from an innovation profile that specializes locally while diversifying globally.

Our setting is the Detroit auto cluster, which has been studied from many different perspectives. However, there has not been an in-depth empirical analysis focused on the evolution of Detroit's innovative activity. Our findings extend and integrate prior scholarly work on the characteristics of innovation in the auto industry (Pavlínek, 2012; Sturgeon et al., 2008; Sturgeon et al., 2009b) and underpin it with a theoretical framework that draws from the literature on knowledge creation in clusters (Arikan, 2009; Bathelt et al., 2004; Lorenzen & Mudambi, 2013) and orchestration in global value chains (GVCs) (Dedrick et al., 2010).

The disaggregation of the auto industry value chains (Mudambi, 2008) changed the nature of the activities performed in Detroit, leading to the loss of manufacturing jobs (Sturgeon et al., 2008; Klier & Rubenstein, 2010). However, Detroit remains the headquarters of the Big Three American automakers (GM, Ford and Chrysler), which continue to orchestrate supplier networks and ancillary activities (Sturgeon et al., 2009b). Hence, the area is still the hub of the North American auto industry (Klier & McMillen, 2008). Detroit's organizational shift from a manufacturing-centered to knowledge-centered cluster lead to modified human resource bundles (MacDuffie, 1995). These bundles rely on and integrate highly complex and interconnected knowledge-based work that remains focused on automotive innovation. The discussion of this evolution forms a key component of this chapter.

In sum, our work explains the complex phenomenon of cluster evolution by analyzing fine-grained patent data related to the Detroit auto cluster over more than three decades of history. This detailed analysis of innovation makes several contributions. First, it confirms empirically the finding of Sturgeon et al. (2008) regarding the persistence and concentration of industrial innovation activity after the manufacturing activity of a cluster has declined. Second, it identifies that the growth in patenting is highly correlated with a sharp increase in the connectedness of the cluster. As noted by

Arikan: "*the more cluster firms engage in knowledge exchanges with outside entities, the stronger the positive relationship between the number of realized interfirm knowledge exchanges within the cluster and the cluster's knowledge creation capability*" (Arikan, 2009: 670). Third, it extends the current research on local knowledge stickiness by suggesting that it is based on two main pillars: the increased specialization within the cluster, and the geographic ties to global centers of industry excellence in distant locations where relevant knowledge is present. We contend that these two drivers of the resilience of the Detroit cluster's innovative activities are the outcome of the same dynamics that brought out its manufacturing decline.

Theory

The structural change triggered by falling spatial transaction costs and the consequent fine-slicing of GVCs[3] (Mudambi, 2008) and relocation of production activities to more efficient locations can make a cluster vulnerable. The resilience of the cluster to these profound changes may be linked to its knowledge generation capabilities. Within GVCs, value accrues disproportionately to high knowledge activities that are critically dependent on global connectivity, i.e., the breadth and nature of linkages to other locations where relevant knowledge assets are present (Lorenzen & Mudambi, 2013). Connectivity is therefore vital to foster the knowledge creation capabilities of a cluster (Arikan, 2009). In this chapter, we study cluster evolution in response to GVC

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[3] When trade is disaggregated and geographically dispersed across national borders, a global value chain (GVC) exists (Gereffi et al., 2005). GVCs incorporate all the activities related to producing a good or service and delivering the same to end user.

realignment and attempt to pinpoint the factors that underpin the resilience of local innovative activity.

Traditionally, the literature on clusters has been anchored in two major streams – those emphasizing the importance of specialization (Marshall, 1920) and those pointing to role of diversity (Jacobs, 1969). Specialization-based arguments focus, in the main, on the efficiencies in the provision and use of inputs (Marshall-Arrow-Romer externalities) (Glaeser et al., 1992) and outputs (competitive pressures as firms innovate to remain alive) (Porter, 1998). The benefits of specialization arise from economies of scale on shared services and knowledge spillovers from labor mobility. In contrast, diversity-based arguments derive their motive force from diverse urban environments that enable intense face-to-face interactions and constant experimentation (Jacobs, 1969), factors that have been argued to be critical for explorative innovation processes (March, 1991; Rosenkopf & Nerkar, 2001). Ultimately, both externality forms influence clusters, and the innovative activities of firms draw on, and contribute to, cluster health. The challenge within a cluster is balancing the mix of deep (specialized) influences and diverse ones, particularly when faced with environmental turbulence.

More recent perspectives on clusters focus on their structure and internal organization (Markusen, 1996). The structure of a cluster is a function of shifts in the market and the concentration of constituent firms (Klepper, 2010). The ability of the cluster to renew itself over time is contingent on internal density (Boschma & ter Wal, 2007) and the extent to which embedded firms transmit and receive knowledge (Meyer et al. 2011). Co-location or proximity is still important for knowledge transfer (Cantwell & Santangelo, 1999). However, the literature has yet to address the notion that co-location or “proximity” may be calibrated in different spatial dimensions (Lazonick, 1993). The integration of both location and structure-centered perspectives is facilitated by the study of the connectivity created inside and between clusters (Bathelt et al., 2004; Lorenzen & Mudambi, 2013).

Local collaboration (connectivity inside clusters) is typically the preferred option for knowledge creating actors. It is reasonable to expect that a dense network of connections will increase the stickiness of the local knowledge. However, sustained success often requires a transition from one set of competencies to another (Bresnahan et al., 2001). When relevant knowledge is locally unavailable, there is little practical difference between searching for that knowledge within a moderate distance (e.g. a few hundred miles) and a very long distance (Gittelman, 2007). These external connections that span across borders and through geographic space, can increase internal knowledge generation (Arikan, 2009). They allow the firms in the cluster to avoid technology traps (Giuliani, 2013), making local innovative activity less vulnerable to structural changes. In other words, connectivity should contribute to the resilience of innovation within the cluster. Structural change in a cluster presents challenges, and, as this chapter will suggest, opportunities for renewal (Karna et al., 2013).

Storper and Walker (1989) argue that industries “produce” regions, following four basic locational patterns: localization, clustering, dispersal and shifting centers. This process culminates in new centers of an old industry rising up with enough gravitational pull to accelerate the decline of the old core industrial area. In this perspective, industrial regions operate as nexi of “untraded interdependences" (Storper, 1995). The benefits of physical co-location accumulate through location connection externalities (Storper &

Venables, 2004), yet as clusters evolve, the transplantation of new ideas is fundamentally important to their rejuvenation. This balance is potentially crucial when the cluster's structural form evolves (Storper 1995; Markusen, 1996).

Locations and Boundaries

Local "buzz" (Storper & Venables, 2004) is motivated by both the tacitness of the knowledge (Cantwell & Santangelo, 1999) and the presence of knowledge spillovers (Arrow, 1962). Physical co-location can resolve the problems associated with the identification and transmission of tacit knowledge (Gertler, 2003). In person contact is efficient, robust, and serves to motivate collaborators (Storper & Venables, 2004). Tacit knowledge is a crucial determinant of successful and impactful innovation (Schulze & Hoegl, 2006).

However, many clusters straddle political boundaries and these can temper the advantages of geographical proximity. National borders have been characterized as discontinuities in geographic space (Beugelsdijk & Mudambi, 2013), since operating across them involves significant spatial transaction costs (McCallum, 1995). Sub-national proximity is fundamentally different from international proximity, since the latter involves transiting from institutional environment to another.

Border effects can be ameliorated by activist policy. International understandings like trade agreements, customs unions, cross-border industry pacts and the like can significantly reduce the spatial transaction costs of operating across borders. Such policy can ensure that local spillovers facilitated by geographical proximity extend to neighboring regions in adjacent countries, despite the natural filters that come from national borders.

Knowledge exchanges are not tied to a limited geographic space (Amin & Cohendet, 2004) and can extend beyond the local milieu when necessary (Gittelman, 2007). There are now increasing numbers of knowledge pools and centers of excellence around the world that specialize in high knowledge activities (Cantwell & Janne, 1999; Lorenzen, 2005; Scalera et al., 2014). Firms search for knowledge in locations where these relevant specialized capabilities exist (Lundvall, 2007). These knowledge exchanges across long distance are not driven by the same factors that motivate local knowledge exchanges.

Networks and Connectivity

Connectivity connotes the breadth and nature of a location's linkages to other locations while connectedness refers to its empirical measurement (Lorenzen & Mudambi, 2013). Organization-based linkages or pipelines (Bathelt et al., 2004) and person-based linkages or epistemic communities (Lissoni, 2001) are the two conduits through which knowledge traverses long distances. These remote linkages are not driven by the convenience of adjacency but rather by the necessity to obtain valuable, unique knowledge not available elsewhere. In other words, when knowledge cannot be found within geographic proximity, firms create organized proximity in order to orchestrate these collaborations (Lazonick, 1993). To justify this effort, knowledge essential to the subjacent innovation process must be present in remote locations (Gittelman, 2007); in sum, the main reason to go beyond geographic proximity is the presence of centers of excellence elsewhere.

The literature has acknowledged that co-location within a cluster is not a sufficient condition for knowledge transfer (Maskell & Lorenzen, 2004; McCann & Mudambi, 2005): diffusion is highly selective. It has been shown to be limited to members of epistemic communities (Lissoni, 2001) or social networks (Giuliani, 2005; Cantwell & Mudambi, 2011). Further, it is contingent on the absorptive capacity of both the source firms and the receivers of knowledge (Cohen & Levinthal, 1990; Schulze et al., 2014). It is the collaboration with local inventors that enables much of the tacit knowledge to be unlocked by remotely located specialist firms (Cantwell & Santangelo, 1999).

Investigations into the nature of R&D spillovers within geographic space reveal the underlying mechanisms of knowledge flows within clusters (Jaffe et al., 1993). The presence of interpersonal networks in clusters is a crucial driver of their innovative output (Saxenian, 1996). It is the interactions of firms and scientists that facilitates knowledge transfer (Audretsch & Feldman, 1996). Both firms and individuals build linkages outside the cluster (Lorenzen & Mudambi, 2013) which allow the flow of ideas and facilitate innovative collaboration (Giuliani, 2013). Clusters retain and grow knowledge, but must balance disparate connections with the outside world with the move towards higher levels of internal density (Boschma & ter Wal, 2007).

Multinational Enterprises

The main conduit of knowledge movement is the multinational enterprise (MNE). Particularly in the auto industry, MNEs are the orchestrators of the value networks (Dedrick et al., 2010), exercising a hierarchical influence over the location of suppliers and all the ancillary activities, including R&D (Pavlínek, 2012). Multinationals see host locations as sources of knowledge (Mudambi & Navarra, 2004), and the MNE network itself can be used to transfer and integrate that knowledge (McCann & Mudambi, 2005). Firms that are embedded in clusters are best able to facilitate knowledge transfer through either social networks (Lorenzen, 2007) or ties with local scientists (Cantwell & Santangelo, 1999). Indeed, leading MNEs are able to access and leverage the best resources within key clusters, while lagging MNEs are shut out (Cantwell & Mudambi, 2011). More specifically however, the characteristics of the knowledge itself will dictate how transmission occurs outside of the cluster (Tallman et al., 2004).

The orchestration of knowledge by the MNE - a specialized capability unto itself - determines the appropriation of value (Dedrick et al., 2010) and the location of intangibles (Mudambi, 2008). To the extent that lead firms exert control over the full production network (Pavlínek, 2012), they may also determine the path of innovation outside of the cluster (Sturgeon et al., 2009a). It would hold then, that those firms that lead specialization within a cluster may also be the ones that, in the pursuit of external knowledge (Cantwell & Santangelo, 1999) establish connections to other centers of excellence (Lorenzen, 2005).

Cluster Evolution, Innovation and Structural Change

Extant literature has argued that industries shape the evolution of clusters (Storper & Walker, 1989). To this end, production systems may take different forms and may themselves change, thereby altering cluster hierarchy (Markusen, 1996). However, the disaggregation of GVCs and the shift from locally integrated systems to dispersed activities and locations (Mudambi, 2008) have brought about significant structural considerations that have required lead firms and suppliers to adjust the way in which they are organized (Sturgeon et al., 2008). The corresponding effects of specialization and concentration within a cluster reflect a shift in centrality (Storper & Walker, 1989). However, orchestration of GVCs by lead firms (Dedrick et al., 2010) also motivates knowledge-seeking to other centers of excellence (Lorenzen, 2005). This orchestration is carried out through organizational pipelines emanating from the cluster to distant centers and from distant centers into the cluster (Lorenzen & Mudambi, 2013). It is the contention of this chapter that the very forces that bring about the decline in production in a cluster may also be the ones that generate a center of gravity with respect to knowledge generation.

The balance of local untraded dependencies (Storper & Walker, 1989) with external sourcing of knowledge (Cantwell & Santangelo, 1999) is crucial to the health of a cluster (Bathelt et al., 2004). We argue that in the face of structural change brought about by shifts in GVCs (Mudambi, 2008; Sturgeon et al., 2008), MNEs shape this local/global balance depending on the profile of their knowledge assets. As lead firms in highly complex production networks, MNEs are likely to be the first to pursue external relationships (Pavlínek, 2012). The increasing connectedness to other centers within the same industry, derived from this orchestration of GVCs, helps to sustain local innovative activity. The resulting effect is strengthened and resilient knowledge production in the cluster.

The increase in the cluster's centrality in the industry is a necessary, but insufficient condition for the resilience of local knowledge production. Specialization serves as the predicate of broader knowledge integration (Mudambi et al., 2012). It is the combination of local specialization with external knowledge sourcing that underpins cluster health in the face of structural change. The connection to global centers of excellence is therefore a mechanism born of the need to source new knowledge (Gittelman, 2007) and the ability of MNEs to orchestrate GVC networks (Dedrick et al., 2010).

Empirical Context: Detroit as an Automotive Cluster

Located in the heartland of industrial America, Detroit was once the center of the global automotive industry. Although the auto industry in the U.S. was born in the corridor between Boston and Philadelphia, by the beginning of the twentieth century the production center of gravity had shifted to southeast Michigan. For much of the twentieth century, Detroit and its surrounding metropolitan area boomed with the growth of automobile manufacturing and its supporting industries. Right into the 1980s, even as the assembly plants were decentralized across the country, the production of auto parts remained heavily concentrated in the Detroit metro area, spilling to neighboring areas in Indiana and Ohio (Klier & McMillen, 2008).

The city of Detroit today has come to be a poster child for the postindustrial urban decline and social malaise that has affected most cities in the industrial “rust belt” of the northern United States. Beginning in the late 1960s, foreign competition forced the industry towards greater scale economies by concentrating assembly facilities into fewer and larger plants. At the same time, foreign car producers were gaining market share at the expense of the traditional American car companies. During the 1980s, many of these firms began assembling cars in the U.S. and located their plants mainly in the Midwest and South (Klier & McMillen, 2008; Sturgeon et al., 2008). As the auto industry changed through a combination of automation, outsourcing, global supply chains (Sturgeon et al., 2008), the move of production facilities to lower-cost (often foreign) locations, the Detroit area was hit by the loss of hundreds of thousands of jobs.

In the short four-year period between 1978 and 1982, the Detroit cluster lost nearly 200,000 manufacturing jobs, including 90,000 in the auto industry. In just the second quarter of 1982, the primary metal manufacturing sector cut 21,000 jobs in metro Detroit (Trachte & Ross, 1985). Unemployment rates continued to be much higher than the national average throughout the 1980s and into the 1990s (DiGaetano & Lawless, 1999). This affected blue-collar workers to a much higher degree than professional and technical workers, since Detroit retained its preeminence in automotive R&D and technology development (Sturgeon et al., 2008). High unemployment and consequently a diminished tax base pushed the Detroit municipal government to an inevitable fiscal crisis. In July 18, 2013, the city of Detroit filed for bankruptcy; it is the largest municipal bankruptcy to date (Davey & Williams, 2013).

However, there are a number of factors that moderate this negative picture. First, there are significant differences between the city of Detroit and the surrounding Southeast Michigan region through which the Detroit cluster extends. While the city itself has experienced a significant loss of population and has been plagued with government mismanagement, corruption and crime, many of its suburbs have witnessed the opposite. Several counties surrounding the city of Detroit remain relatively prosperous, benefitted in part by the migration of the most affluent Detroiters to the suburbs.

Second, Detroit remains the headquarters of the Big Three U.S. auto makers: Ford, General Motors, and Chrysler (Klier & McMillen, 2008). These MNEs continue to orchestrate significant global value chains (GVCs) within which they still determine the location of value creation (Dedrick et al., 2010). GVC orchestration places these lead firms at the center of the production and innovation ecosystems, and this is a knowledge activity unto itself (Bathelt et al., 2004).

Third, the gravitational pull of the Detroit cluster is evident in the co-location of suppliers (Sturgeon et al. 2008) and the subsequent increase in their concentration over time (Klepper, 2007). The collocation of these suppliers has its origins in the modularization and outsourcing trend that began in the 1980s and increased in the 1990s. Prominent examples include the spinoffs that became major new firms such as Delphi (spinoff from GM) or Visteon (from Ford) (MacDuffie, 2013). As a knowledge cluster intensifies, it attracts new inventors and collaborations (Ejermo & Karlsson, 2006). This process leads to greater specialization that brings about renewed networks of untraded dependencies (Storper & Walker, 1989). Increasingly, these are based on intangibles, rather than production (Mudambi, 2008). The Big Three U.S. automakers and their supplier networks have taken on a more concentrated role in Detroit-based innovation over time, accounting for a greater share of overall patents in the cluster.

Fourth, while the role of MNEs in extracting local knowledge is well-documented (Cantwell & Santangelo, 1999), the connections between clusters has only recently received attention in the literature (Lorenzen & Mudambi, 2013). As locations specialize in knowledge-based activities (Lundvall, 2007), MNEs' knowledge processes focus on technologically proximate knowledge, which is a natural extension of the search process

(Rosenkopf & Nerkar, 2001). These search processes give rise to organizational pipelines between clusters that become strong conduits of specialized collaboration (Bathelt et al., 2004). In Detroit we observe collaboration that follows these pipelines over great geographic distances.

To the extent that R&D knowledge travels locally (Almeida & Kogut, 1999) and the definitions of regions may vary (Flores et al., 2013), the geographic proximity of inventors may span national borders and include cultural proximity (Schmitt & Van Biesebroeck, 2013). The interwoven relationships in the Detroit cluster follow such a pattern: we document inventors in the cluster collaborating with Canada (southwestern Ontario) as well as with other top auto centers in the world: Germany, Japan, Great Britain, and France.

Data and Methods

We used patent data from the United States Patent and Trademark Office (USPTO) to examine the level of innovative activity in the Detroit region. USPTO patent data affords scholars the opportunity to analyze large tranches of innovation data, including technology class, location of inventors and the ownership of the intellectual property (IP) created in the invention. The difficulties associated with the collection of patent data have been alleviated by the creation of publicly accessible databases, such as that of the National Bureau of Economic Research (NBER) (Hall et al., 2001). For the purposes of this paper, we only examine utility patents.

More recently, there has been work aimed at disambiguating inventor data in order to map the knowledge creation networks at the level of individual inventors. One such project is the Harvard Patent Dataverse Network (DVN), a product of the Harvard Business School and the Harvard Institute of Quantitative Social Science (Li et al., 2014). The DVN work uses both raw data from the USPTO and processed data from the NBER set to create a disambiguated set of patent-inventor observations from 1975 through to 2010.

The original DVN dataset contains information on the location of individual inventors, including country, latitude and longitude, and (in the case of U.S.-based inventors) zip code. In order to map the innovative activity of Detroit, we used the Core Based Statistical Area (CBSA) as unit of analysis. CBSAs are statistical units defined by the Office of Management and Budget (OMB), based around urban centers with more than 10,000 people. The Detroit CBSA comprises six counties in Michigan: Lapeer, Livingston, Macomb, Oakland, St. Clair and Wayne. Using zip codes mapped onto the DVN data, we identified every inventor in the dataset located in those counties and therefore within the Detroit CBSA. We then coded the patents in which those Detroit-based inventors were listed and searched for all other inventors that were listed in those patents. The result is a dataset with 137,586 observations containing all inventors linked to the innovative activity in the Detroit CBSA, which maps onto 62,517 patents filed between 1975 and 2009, and granted by the end of 2010.

One important clarification is that our data is right-censored, since most of the patent applications submitted in the last two or three years before the cutoff date of 12/31/2010 are likely to be granted after that date. In order to have an accurate estimation of the innovative activity, we sorted patents by application date, not by issue date. This is an important distinction because the lag between the application and the grant of the patent can average nearly three years, with many patents taking even more than that. In sum, when using this dataset we need to be aware that the patent data sorted by application date means the data will be incomplete for the last few years. We can realistically assume that our data is approximately complete for the first thirty years (1975-2005) and suffers from an increasing number of missing observations as we get closer to the cutoff date of December 31, 2010. Thus, while we present data through to 2009, the final 2005-2009 period has some truncation.

For this chapter, we constructed measures of international and domestic inventor connectedness, which allows us to assess the extent to which Detroit-based inventors collaborate across geographic space. Taking the location analysis further, we leveraged the latitude and longitude coordinates to generate full maps of innovative activity and collaboration in both space and time.

Results

Detroit in the Context of the US Innovative Activity

This paper examines the innovative health of the Detroit cluster against the backdrop of manufacturing decline and widespread job loss. The increased concentration of lead firms (Sturgeon et al., 2009a) and subsequent supplier relationships (Klier & Rubenstein, 2010) brought about a shift in cluster hierarchies (Markusen, 1996). Throughout Detroit's transformation, knowledge, which is fundamentally sticky (Markusen, 1996), continued to beget further innovation. As **Table 3.1** demonstrates, the growth in knowledge productivity (in patents/million) was higher and grew faster than that of the U.S. overall. In broad terms, Detroit's growth in knowledge production ran counter to its manufacturing decline.

As the structure of the Detroit cluster changed, so too did that of automotive innovation in the United States. Our analysis of patent records extended beyond the Detroit cluster to compare to the relevant classes of patents relevant to the automotive industry. For this, we selected subcategories 53 and 55 from the Hall, Jaffe, and Trajtenberg (2001) taxonomy (Mechanical: Engines & Parts; Mechanical: Transportation) to represent the core mechanical patents behind the auto industry. **Table 3.2** shows two key trends: first, core mechanical patents (in sub-categories 53 and 55) as a share of Detroit overall grew from 27% in 1975-1979 to 37% in 2000-2004. This shows that core mechanical patents grew at a rate even greater than that of Detroit innovation overall. Second, we examined the set of core mechanical patents for the United States, and overlaid Detroit's share of those patents over time. The share of core mechanical patents emanating from Detroit grew from 8% in 1975-1979 to over 18% in 2000-2004. In other words, as Detroit was losing its preeminence as manufacturing center of the auto industry, it was agglomerating a larger share of the core innovative activity in the sector. This transformation from production to innovation is corroborated by our observed increase in specialization on two key technology subcategories that, by 2005-2009 made up one fifth of all Detroit-based patents.

Technologies and Top Innovators

Another way of analyzing the industry composition of the innovative activity in the cluster is by looking at the both patent classes and technological diversification. In order to simplify the analysis and obtain a general picture of the technologies that prevail in the Detroit innovation system, we reclassified the original patent classes to a simpler taxonomy, based on the work of Hall et al. (2001). The taxonomy includes the following six technology categories: chemical, computers & communications, drugs & medical, electrical & electronic, mechanical, and other. Each category includes several subcategories; in particular, the subcategories "Motors, Engines & Parts" and "Transportation" that we used jointly as a proxy for the auto industry are included in the Mechanical category.

The Detroit cluster story is one of evolution over geographic and technological space. Central to our thesis that the resilience of knowledge production within the cluster was contingent upon boundary spanning collaboration is the shift in technological focus. **Table 3.3** shows the results of an analysis of the technological focus of inventors in the Detroit cluster. We constructed an index of technological diversification by category and subcategory separately. The category index is calculated as one minus the sum of the squares of the proportion of patents in each of the categories in our patent taxonomy. The index by subcategory is calculated a one minus the sum of the sub-indices for each subcategory (calculated based on the sum of squares of the proportions of patents in each subcategory within each of the six broader categories). While the index by category provides with a general view, the level of disaggregation used for the index by subcategory makes the latter a more fine-grained measure of diversification across technology space.

Table 3.3 provides with an overview of the technological evolution of the Detroit CBSA. The index by category shows a slight trend toward diversification, growing from

0.727 in 1975-1979 to 0.740 in 2000-2004. The index by subcategory shows a similar trend, increasing from 0.259 to 0.291. This is itself an interesting finding. The stability of technology categories reflects the dominance of mechanical patents within the cluster. Consistent with changes in the modern automobile, the fastest growing technology categories in Detroit have been computers and communications, which have blossomed from over 3% to nearly 14% of Detroit-based patents. Given that Detroit is the traditional center of the American auto industry, it is not surprising that the top innovators in the area are (measured by patents granted) are the "Big 3" American car companies in this industry: Ford, General Motors and Chrysler[4]. **Table 3.4** demonstrates that collectively, the Big Three moves from a 23% share of Detroit patents to 25% in 2000-2004 (and a more substantial jump in the 2005-2009 period, which must been interpreted with caution, given the data truncation issues). The major point of concentration that we see in the data comes from suppliers, however. The suppliers that work closely with the Big Three: TRW, Delphi (formerly part of GM), Visteon (formerly Ford), Lear, Eaton, Borg Warner, and Magna collectively accounted for under 3% of Detroit-based patents in the 1975-1979 period. However, by 2000-2004, this group accounted for over 18% of Detroit patents. Well over 40% of Detroit patents belong to the Big Three and suppliers, a number that grows over time. This concentration attributable to the major automakers and their suppliers is consistent with the literature (Sturgeon et al., 2008).

Foreign automakers, many of them with large manufacturing operations in the U.S., have little to no formal innovation activity during our main study period (**Table 3.4**). Toward the end of the data period (2005-2009), we observed Toyota and Nissan

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[4] We have included patents with the assignee name "DaimlerChrysler" as Chrysler for the 1998-2007 period, and distinguished between Daimler and Chrysler in the prior and post periods.

beginning to develop Detroit-based patent output; however the U.S.-based auto groups remain the prime patent assignees. We note that BASF - a German firm - has maintained a Detroit innovation presence that dates back to the 1970s.

The seeming absence of foreign automakers in the Detroit patent data led us to undertake further analysis, aimed at examining the most recent data. We directly queried the USPTO website on the basis of key assignees looking for foreign automaker activity related to the Detroit cluster. **Table 3.5** displays patent counts, by assignee, for the 2007-2013 period[5], with a broader geographic filter: Michigan. In many ways, this new analysis picks up from where our main data left off. The Big Three maintain a dominant patenting position in Michigan, and the supplier network has adopted a strong complementary position. However, foreign automakers, particularly those from Japan and Germany, have begun to patent on an increasingly large scale in and around the Detroit area. Taken together, the foreign automakers in our analysis - Toyota, Nissan, Honda, BMW, Daimler, and Volkswagen - innovate in Michigan at a rate roughly one quarter that of the Big Three. This represents a significant jump from the 1975-2004 data, in which few foreign automakers show up in the patent data at all[6].

To take the analysis of foreign automakers further, we sought to match firm activities to the patent records. **Figure 3.1** shows the full timeline of Michigan-based patenting for the set of foreign automakers, on which we have overlaid the timing of key local events for these automakers. The figure highlights some key points with regard to the innovative activity of foreign automakers in the Detroit area. For example, the Toyota

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[5] The same provisos for 2013 patent data and the truncation of results applies.

[6] For the purposes of robustness, we also examined 1975-2004 data for Michigan overall, and observed little discernible difference in results.

Technical Center in Ann Arbor was established in 1977, and the firm has invested over $100 million in it, but much of the investment came after 2005 (Murray, 2007). Similarly, Nissan set up an R&D center in Farmington Hills, MI in 1988, but did not make major investments until 2002. As the data in **Figure 3.1** show, the Toyota and Nissan R&D centers in Michigan were largely dormant until around 2006 after which major R&D investments took place. These investments occur toward the end of a major structure change of the Detroit cluster. The concentration and specialization of auto activity that is centered around the Big Three occurs first, and then foreign R&D in the area begins to ramp up.

Figure 3.1 also reveals that German automakers' innovative activities in the Detroit area were similar to their Japanese competitors. BMW, Daimler, and Volkswagen were largely inactive players in region's R&D prior to the mid 2000s. However, in 2005 General Motors, BMW, Daimler and Chrysler formed an alliance to conduct hybrid drivetrain research. Coined the "Global Alliance for Hybrid Development", the joint venture was headquartered in Troy, Michigan (The New York Times, 2006). Collectively, this group has produced approximately 100 patents since 2006 in a key area at the cutting edge of automotive technology. This appearance of foreign firms developing next generation automotive technologies in the Detroit area suggests that the gravitational pull of the cluster is increasing on international dimensions. Further, the share of computers and communications technology categories in Detroit's patent production has risen from about 4 percent in the 1970s to almost 14 percent in the 2000s. Taken together, these observations suggest that Detroit's innovative activities include substantial efforts at exploring knowledge that will be critical to the future of the automobile, in addition to reinforcing its position in the industry’s core mechanical technologies.

The Connectedness of the Detroit Cluster

There is a positive correlation between Detroit's increases in both patent output and participation in the U.S. auto industry innovation and its connectedness to other locations, both within the U.S. and internationally. The disaggregation of the auto industry GVC saw two simultaneous changes: a shift of lower order activities out of Detroit and an increasing centralization of knowledge intensive activities there. The focus on knowledge can be seen in **Tables 3.1-3.3**, with the growth in patenting, the centralization of core mechanical patenting, and the concentration of key firms. Both of these simultaneous changes are part of the orchestration of the industry global value by the lead MNE firms (Dedrick et al., 2010). Orchestration leads to the development of organizational pipelines (Bathelt et al., 2004; Lorenzen & Mudambi, 2013) and ultimately the establishment of connections between clusters. Our data on innovation in the Detroit cluster demonstrate that connectivity has coincided with this broader trend.

Innovation emanating out of Detroit has demonstrated substantial gains in terms of both connectedness (the extent of linkages) and connectivity (range of linkages). **Table 3.1** displays the percent of overall Detroit patents that are internationally connected: i.e., a patent contains at least one inventor that resides outside of the United States. In the 1975-1979 period, 1.18% of Detroit patents contained international connectedness. By 2000-2004, the percent of internationally connected patents grew to

8.18%. These figures were largely consistent with the broader trends of globalization that had spread to many industries in the United States.

To measure connectivity of international knowledge creation, we developed an index of geographic dispersion. The procedure for this measure construction was as follows: we measured geographical dispersion for each patent as one minus the sum of the squares of the share of all inventors in each country. Therefore, our dispersion measure is bounded between a minimum value of 0 and a maximum value asymptotically approaching 1 as the inventors are dispersed across more and more countries. The results of our geographic dispersion index analysis can be found in **Table 3.1**. Overall, the results suggest that the Detroit cluster has moved from being an innovative island, where most of the activity is predominantly local, to a hub that coordinates innovation across multiple locations, both nationally and internationally. From the 1975-1979 period, in which the index was 0.005, Detroit's international connectivity rose to 0.0327 in 2000-2004, an increase of over 500 per cent. This level is higher than that of the United States overall.

The broader trend of international connectedness and connectivity stemming from Detroit-based innovation suggests that the cluster at least kept pace with a global move to a knowledge economy, despite significant manufacturing decline. However, there is greater detail that reveals the progression of international connections. This is related to the innovative activity in Detroit and how it is consistent with much of our prior theory with respect to the forces behind the disaggregation of GVCs creating a center of innovative gravity that has ensured the knowledge resilience of the cluster. Our data reveal four key findings in this regard: i) the strong centrality ties to centers of automotive excellence around the world (where are the connections), ii) the leading role of domestic firms in reaching out to other nations (the direction of connections), iii) the progression of the Big Three and suppliers driving connectedness (who makes the connections, and when), and finally, iv) the evolution of connections to global centers (how the connections develop).

An examination of the international collaborations on Detroit-based patents adds further context to the finding that the cluster has become increasingly connected. **Figures 3.2-3.4** show the network of patents with international inventors connected to Detroit in three different ten-year periods: 1975-1984, 1985-1994 and 1995-2004. **Table 3.6** provides additional color to the network maps displayed in **Figures 3.2-3.4**, and outlines the corresponding network measures for the same period for each collaborating country. Both the table and the figures make clear that the two countries most connected to Detroit are Canada and Germany. Canada and Germany maintain Detroit network centrality and betweenness that is more than double that of the United Kingdom and triple that of Japan. In sum, Detroit innovators collaborate more frequently with foreign inventors, and those foreign inventors are dispersed across more countries, with two clear leading locations: Canada and Germany. Of the rest of the countries connected to Detroit, the main collaborating locations are the United Kingdom, Japan and France. All these countries have well-developed automotive industries.

The geographic maps of inventor distribution shed more qualitative light on how the knowledge connections emanating out of Detroit link global centers of automotive excellence, rather than simply random locations around the world. **Figure 3.5** displays the global distribution of inventors on Detroit-based patents. From an elevated level, innovation has occurred the Detroit area, spilling over Canada and southwestern Ontario, and then has traveled over to Germany, Great Britain, France, and Japan. **Figure 3.6** shows the connection map to Europe, for example. In this map, we observe that the Detroit-based connections are made with southern Germany (Mannheim, Stuttgart, Munich), home to BMW, Daimler, and BASF. In the United Kingdom, the tightest inventor cluster is in southeast England (McLaren, Mini) with some scattering near Coventry (Jaguar, Land Rover). Finally, **Figure 3.7** shows a close clustering of inventors in Canada in southwestern Ontario, fairly close to Detroit itself. In a broad sense however, the global distribution of these inventor networks is non-random: the specific countries and locations within countries are related to global auto centers around the world.

There is a clear divide in the nature of the firms that have lead the international connections to and from the Detroit cluster. However, the distinction between domestic firm-led connections and foreign firm-lead connections is vital, as it speaks to the evolution of the gravitational pull of the cluster itself. **Figure 3.8** is very demonstrative in this regard. The bars in the chart show the breakout of internationally connected patents, by domestic or foreign firm. We observe in this chart that it is domestic firms that reach out to the world first, followed by periodic growth by foreign assignees "reaching in" to Detroit. The lines on the chart represent the geographic dispersion index, by firm type. Unsurprisingly, we see that domestic firms reach out to a broader range of locations, and this pattern grows at rate greater than that of foreign firms. As Detroit has become more of a hub of global automotive knowledge, the extent of connectivity has grown to incorporate the broader set of locations.

The third plank of our international connection analysis is the analysis of specific firms involved in global collaboration. Unsurprisingly, the same firms at the center of the Detroit cluster's specialization - the Big Three and their supplier network - are those that dominate the list of connected firms. Taken together, the major auto groups accounted for 10% of all internationally connected Detroit patents in 1975-1979 (**Table 3.7**). By 2000-2004, this set of firms accounted for nearly 30% of connected patents. As noted previously, BASF has a long established connection to Detroit. However, the presence of foreign automakers, as observed either in direct investment or international collaboration, does not appear on the map until the cluster's evolution is well under way.

The evolution of ties between Detroit and specific countries is the final aspect of the connections story. While Germany and Canada appear as centrally connected locations from the outset, their specific evolution was crucial to the ability of the Detroit cluster to gain a critical mass in knowledge and orchestration. However, the evolution of the connections to these countries was vastly different from the outset. The Canadian connection is build off of geographic proximity and the role of institutions, while Germany, long a hub of global R&D in a variety of industries including automotive, appears to have been a strong knowledge "fit".

Our data show that Germany is a two-way pipeline of knowledge for Detroit. As **Table 3.8** shows, the connectedness has grown strongly since the 1975-1979 period, and as the connections have grown the technological diversity index has increased as well. The patent records show that Ford and General Motors developed early connections to Germany, while BASF had established a beachhead in Detroit in the late 1970s. **Table 3.9** shows chemical patents falling as a percentage of the overall connected patents, and mechanical patents growing from 27% to 45%. Our argument is reinforced by data that shows that Germany is, by a large margin, the biggest generator of auto industry knowledge in Europe. As of 2007, Germany accounted by 67.1% of all R&D spending in automotive technology in Europe and employed 53.3% of the R&D personnel in the industry in the continent (Pavlínek, 2012).

We do not observe any residual increases in patenting stemming directly from the DaimlerChrysler era. However, as **Table 3.4** and **Table 3.7** demonstrate, Bosch and Siemens, both collaborators of Daimler, did increase their share of Detroit-linked patents in the 2000-2004 period. Furthermore, **Table 3.5** and **Figure 3.1** demonstrate that Daimler's patent output in the area increased dramatically in 2012, a product of the "Global Alliance for Hybrid Development" discussed earlier.

While Germany was the key center of excellence with ties to Detroit in our data, we also observed ties to Great Britain and France. These lagging connections appear to have been the result of a lower concentration of automotive knowledge. The British connections have emerged slowly over time, driven primarily by the Big Three and its supplier network, which account for 45% of all connected patents between the two locations. The same group accounted for a third of all Detroit-France patents. Compared to the Germany connections however, these locations, which are not known to be auto centers of excellence to the same extent, do not have nearly the volume of internationally connected patents. Japan, whose R&D profile resembles Germany more than it does Canada, displays a similar pattern with respect to a higher concentration of patenting firms. As discussed earlier however, the movement on the part of Japanese firms occurred after the Detroit cluster engaged in a higher level of specialization.

The Canadian story presents a much different backdrop than does Europe. Southwestern Ontario has strong ties to the automotive industry that are rooted in both institutions and the path dependency of firm activity. On the one hand, Canada is culturally similar to the United States, but significantly different on several measures, particularly those related to how firms operate. For instance, Canada has universal health care coverage for all residents (Beamish 1996), a crucial issue in the context of GM’s crippling healthcare costs (Hakim, 2004).

Despite Canada's proximity to the United States, and southwestern Ontario's proximity to Detroit, there are substantive social and institutional differences that may yield different innovation patterns. **Figure 3.9** shows a comparison of the technology composition of patents connecting Detroit and southwestern Ontario, and those linking Detroit and nearby Ann Arbor. The general trajectory of the patent composition does not differ greatly, with mechanical patents dominating and computer patents growing. This contrasts with the case of Germany where co-inventor patent linkages adapted to Detroit’s pattern over time, reflecting knowledge complementarities.

All of this suggests that the connectedness with Canada is driven by geographical proximity rather than the sophistication of knowledge present in Canada. As Sturgeon et al. (2009b: 4) note, "*The size and importance of the automotive industry in Canada’s Ontario Province is a legacy of its historic ties to the “Big 3” US automakers, General Motors, Ford and Chrysler, and Ontario’s proximity to the traditional heartland of the US industry in Michigan and the surrounding mid-western states. Canada had, and continues to have, marginally lower operating costs than the United States*". The path dependency dating back to the auto pact of 1965 and carrying forward to the North

American Free Trade Agreement (Beamish, 1996) ensured that the Big Three would have a production presence in Canada. Our data confirm this, with Ford, General Motors, and Chrysler appearing on many patents with inventors either directly in the Windsor, Ontario area (directly across the Detroit river) or nearby local production facilities. Taken together, the innovation patterns show that the legislated ties between the two countries, driven by activist policy, have persisted and allowed major auto manufacturers to extend the Detroit cluster and overcome country differences.

To summarize, we have demonstrated that the Detroit cluster has changed significantly over the last thirty-five years. As production activities moved away to more efficient locations, orchestrating firms (the Big Three) tightened supplier networks and together they intensified the specialization process within the cluster. It wasn't until later in Detroit's evolution that Japanese and German automakers began to engage in direct R&D in the area, either through local investments or international collaboration. Our data show that as the Detroit cluster evolved, the network ties to Canada and Germany began to develop most strongly, but for different reasons. Germany is a longstanding center of excellence, while trade agreements have forged path dependence in Canada. Ultimately however, the knowledge networks emanating out of Detroit continue to grow and are strongly tied to the very evolution that led to the decline in production in the first place.

Discussion and Concluding Remarks

In this paper, we discuss the implications of the structural changes induced by falling spatial transaction costs for traditional manufacturing clusters (Beugelsdijk et al., 2010). These changes lead to MNEs re-configuring their GVCs and relocating activities around the world (Mudambi, 2008). The evolution of a traditional Marshallian cluster (Marshall, 1920) to a more open hub and spoke configuration (Markusen, 1996) may bring about increased levels of firm focus in knowledge-based activity and continued innovative activity (Sturgeon et al., 2008). Agglomeration externalities are inherently tied to co-location of firms and the interactions of people (Porter, 1998): the buzz that arises from collective innovation (Storper & Venables, 2004) and the cues picked up by face to face interaction all seek to draw out tacit knowledge in the pursuit of new innovation.

Using a comprehensive dataset comprising 35 years of USPTO patents, we have generated a knowledge map of the Detroit area. Through our analysis, we found that Detroit has continued to innovate over the past three decades – most often at a significantly level of productivity than the United States as a whole. We also find that the Detroit cluster also has a level of international connectedness in co-invention that is greater than that of the U.S. The strength of patenting in the mechanical category shows that the Detroit auto cluster is still healthy in the creation of core industry knowledge, and the concentration of patenting attributable to the central firms in the industry continues to grow. In other words, in spite the structural changes suffered by its industrial complex, the innovative activity remains healthy and Detroit shows an increasing level of specialization in auto-related technologies. Furthermore, Detroit has reduced the risk of technology traps by increasing its connectedness with centers of excellence in auto industry, like Germany and Japan.

The cluster is robust enough to have a strong gravitational pull: it increasingly attracting firms from other automotive centers of excellence. Our data show that inbound ties from Germany and Japan, both considered global automotive hubs, increased in the

2000-2013 period. There are high-level collaborations with chemical clusters in Germany: a complementary research area to the mechanical and design strengths of Detroit. We also find strong connectedness to several other locations with strong auto industry presence – Japan, France and the United Kingdom. The connectivity to Japan has increased recently, sustained by a robust surge in the R&D activity of Japanese automakers in Michigan in the last two decades.

This study is not without its limitations. Firstly, we provide a top-level analysis and historical context of the evolution of the Detroit cluster, particularly with respect to the automotive industry. As with all exploratory research, greater depth may yield more findings or verify existing claims. Second, our data suggest a pattern of correlation, not causation. Therefore, we do not attempt to further elucidate why the Canada and Germany relationships evolved as they did, beyond what the historical context suggests. Third, our study tracks the evolution of the Detroit cluster over time. A comparative analysis with other industrial clusters that suffered similar structural transformations may strengthen our results. A possible candidate for an extension of our analysis is the Pittsburgh cluster, formerly the center of the American steel industry. However, a comparative study would move beyond the purview of this paper. We leave that to future studies.

As the structure of a cluster changes, so do research collaborations and the locations of R&D. The presence of the Big Three American automakers in Detroit led to the development of organizational pipelines, as these firms "reached out" and established operations overseas. Over time, foreign firms, particularly from Germany and later from Japan, "reached in" to Detroit, further increasing the complexity of the connectivity of the cluster. In other words, we argue that the same forces that affected the manufacturing activity in the Detroit industrial region, also created the conditions for its increased gravity as a center of knowledge creation in the auto industry. Manufacturing decline did not mean the end of Detroit, just the transition to a different stage. New innovation centers keep establishing in the area and new technologies are being developed. As Germany did decades ago, Japanese and (more recently) Korean firms are creating connections with Detroit. Overall, our contribution is to disentangle the drivers of Detroit's knowledge-creating resilience, and place them in context of the shifting value chain landscape in the automobile industry.

The modern automobile is changing rapidly, and Detroit is keenly aware of its shifting environment. This can be aptly summed up by Bill Ford, the Chairman of the Ford Motor Company: "*It used to be that the auto industry, and the car itself, were part of a self- contained ecosystem. If there were breakthroughs, they were developed within the industry. It was a much more controlled environment and not nearly as dynamic as today's. In fact, I think we ended up being rather insular as an industry, and on balance it was not a good thing.*" (Kaas & Fleming, 2014:1). The degree to Detroit remains a central player in a globally connected automotive world will crucial to the cluster's continued knowledge renaissance.

Tables and Figures

Table 3.1: A comparison of innovative activity and connectedness in Detroit vs. the United States

	Detroit				**United States**			
Period	**Number of Patents**	**% Internationally Connected Patents**	**International Dispersion Index**	**Patents/ Million Population***	**Patents**	**% Internationally Connected Patents**	**International Dispersion Index**	**Patents/ Million Population***
1975-1979	5,775	1.18%	0.0050	264.65	202,909	1.39%	0.0042	184.15
1980-1984	5,166	1.10%	0.0040	243.88	183,256	1.74%	0.0056	158.28
1985-1989	6,480	2.38%	0.0090	306.68	217,618	2.69%	0.0087	178.55
1990-1994	9,125	3.21%	0.0126	423.15	296,885	3.70%	0.0136	231.88
1995-1999	11,716	5.22%	0.0204	528.64	447,469	5.31%	0.0206	334.24
2000-2004	14,851	8.18%	0.0327	662.73	512,768	6.99%	0.0276	358.42
2005-2009	7,248	8.54%	0.0336	325.57	236,745	8.04%	0.0314	157.20

* Average patent count and population over five year period.

Table 3.2: A comparison of Core automotive patents (Mechanical, Transport), 1975-2009

Period	Number of Detroit Patents in Sub-categories 53 and 55 of the Mechanical category	% of all Detroit Patents	% of all U.S. Patents in Sub-categories 53 and 55 of the Mechanical category
1975-1979	1,555	26.93%	7.85%
1980-1984	1,302	25.20%	8.46%
1985-1989	1,704	26.30%	9.85%
1990-1994	2,577	28.24%	11.85%
1995-1999	3,627	30.96%	13.92%
2000-2004	5,548	37.36%	18.45%
2005-2009	3,147	43.42%	20.93%

Table 3.3: Detroit Patents, Technical Overview, 1975-2009

	Diversification		% of Patents, by Category					
Period	**Technology Diversification Index (Category)**	**Technology Diversification Index (Subcategory)**	**Chemical**	**Computers & Communication**	**Drugs & Medical**	**Electrical**	**Mechanical**	**Other**
1975-1979	0.727	0.257	15.19%	3.64%	1.38%	13.78%	40.74%	25.27%
1980-1984	0.737	0.254	15.86%	3.59%	2.79%	14.04%	39.85%	23.87%
1985-1989	0.739	0.249	11.66%	5.81%	3.20%	15.46%	40.51%	23.36%
1990-1994	0.742	0.250	11.22%	6.28%	3.61%	15.16%	40.20%	23.53%
1995-1999	0.749	0.261	9.85%	9.58%	3.02%	16.37%	39.81%	21.38%
2000-2004	0.740	0.291	8.20%	13.31%	2.33%	17.38%	42.07%	16.71%
2005-2009	0.715	0.307	5.92%	13.86%	1.66%	18.07%	45.54%	14.94%

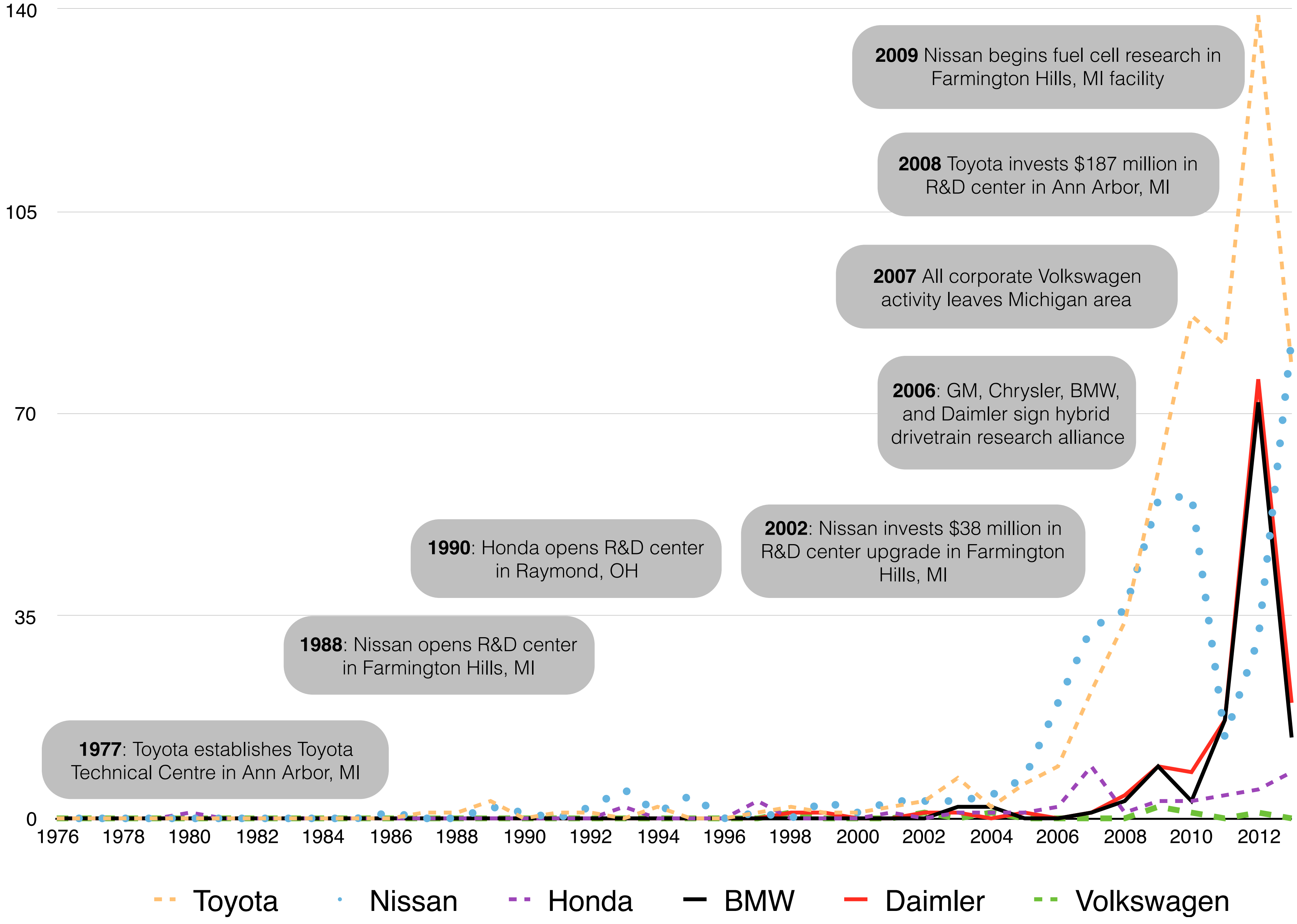
Table 3.4: Detroit Patents, by Assignee (% of Total Detroit Patents), 1975-2009

Period	**1975-1979**	**1980-1984**	**1985-1989**	**1990-1994**	**1995-1999**	**2000-2004**	**2005-2009**
Big Three Automakers	22.63%	22.50%	26.79%	29.73%	28.40%	25.90%	37.69%
Ford	8.90%	9.99%	9.09%	14.63%	15.55%	12.23%	12.94%
General Motors	11.31%	11.52%	12.78%	10.37%	4.83%	10.61%	21.66%
Chrysler	2.42%	0.99%	4.92%	4.73%	8.02%	3.06%	3.09%
Suppliers	2.82%	3.16%	4.04%	5.04%	9.47%	18.11%	10.28%
TRW Automotive	0.40%	0.37%	1.31%	2.55%	3.72%	2.14%	0.80%
Lear Automotive	0.00%	0.00%	0.00%	0.33%	2.61%	3.60%	2.46%
Visteon	0.00%	0.00%	0.00%	0.00%	0.00%	5.62%	1.60%
Eaton Corporation	1.54%	2.11%	2.45%	1.88%	1.39%	0.97%	0.87%
Delphi	0.00%	0.00%	0.00%	0.00%	0.87%	4.31%	2.36%
Borg Warner	0.88%	0.66%	0.23%	0.28%	0.68%	0.82%	0.70%
Magna	0.00%	0.02%	0.05%	0.00%	0.20%	0.65%	1.49%
Foreign Automakers	0.00%	0.00%	0.00%	0.17%	0.05%	0.49%	3.72%
Toyota	0.00%	0.00%	0.00%	0.02%	0.01%	0.09%	1.26%
Nissan	0.00%	0.00%	0.00%	0.13%	0.03%	0.31%	2.14%
Honda	0.00%	0.00%	0.00%	0.02%	0.00%	0.05%	0.04%
BMW	0.00%	0.00%	0.00%	0.00%	0.00%	0.02%	0.17%
Daimler Benz	0.00%	0.00%	0.00%	0.00%	0.00%	0.01%	0.10%
Volkswagen Group	0.00%	0.00%	0.00%	0.00%	0.01%	0.01%	0.01%
Other	3.48%	3.47%	2.01%	2.72%	3.24%	3.41%	1.65%
Siemens	0.00%	0.00%	0.12%	0.44%	0.40%	1.46%	0.25%
BASF	3.48%	3.45%	1.81%	2.19%	2.53%	1.34%	0.94%
Bosch	0.00%	0.02%	0.08%	0.09%	0.31%	0.61%	0.46%

Table 3.5: Michigan Auto Patents, by Assignee (2007-2013)

Period	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
Big Three Automakers	593	474	403	494	487	759	799
Ford	315	295	277	377	396	592	657
General Motors	252	121	64	39	48	63	80
Chrysler	26	58	62	78	43	104	62
Suppliers	384	247	280	237	195	196	206
TRW Automotive	15	12	16	8	4	12	0
Lear Automotive	101	46	49	46	45	45	43
Visteon	67	29	41	30	23	12	15
Eaton Corporation	38	30	32	39	48	40	52
Delphi	131	97	108	62	30	36	32
Borg Warner	0	1	0	0	1	3	0
Magna	32	32	34	52	44	48	64
Foreign Automakers	66	78	138	158	134	324	203
Toyota	22	34	60	87	82	139	78
Nissan	33	36	55	56	14	31	83
Honda	9	1	3	3	4	5	8
BMW	1	3	9	3	17	72	14
Daimler Benz	1	4	9	8	17	76	20
Volkswagen Group	0	0	2	1	0	1	0

Figure 3.1: Patents by German, Japanese Automakers in Michigan, 1975-2013



2009 Nissan begins fuel cell research in Farmington Hills, MI facility

2008 Toyota invests $187 million in R&D center in Ann Arbor, MI

2007 All corporate Volkswagen activity leaves Michigan area

2006: GM, Chrysler, BMW, and Daimler sign hybrid drivetrain research alliance

2002: Nissan invests $38 million in R&D center upgrade in Farmington Hills, MI

1990: Honda opens R&D center in Raymond, OH

1988: Nissan opens R&D center in Farmington Hills, MI

1977: Toyota establishes Toyota Technical Centre in Ann Arbor, MI

Figures 3.2-3.4: Network Maps of Detroit-Based Patents, 1975-2004

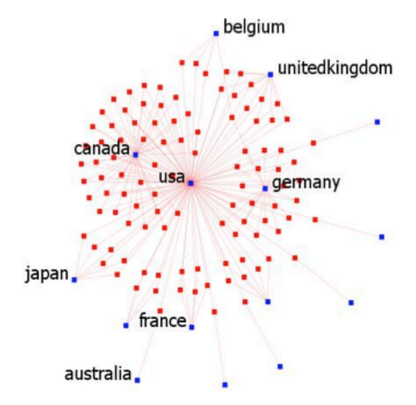


Figure 3.2: 1975-1984

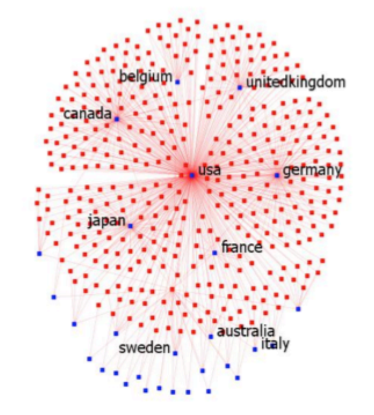


Figure 3.3: 1985-1994

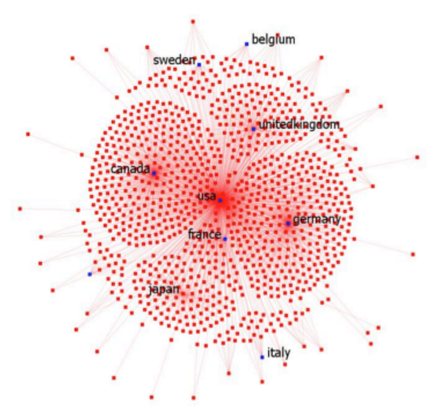


Figure 3.4: 1995-2004

Table 3.6: Network measures of collaborating countries with the Detroit cluster, 1975-2004

	1975-1984		1985-1994		1995-2004	
Country	**Centrality Degree**	**Betweenness**	**Centrality Degree**	**Betweenness**	**Centrality Degree**	**Betweenness**
USA	1.000	0.898	1.000	0.922	1.000	0.902
Canada	0.411	0.065	0.234	0.024	0.296	0.042
Germany	0.206	0.017	0.267	0.031	0.296	0.042
United Kingdom	0.103	0.004	0.118	0.006	0.113	0.006
Japan	0.056	0.001	0.156	0.011	0.090	0.004
France	0.047	0.001	0.035	0.001	0.054	0.001
Australia	0.009	0.000	0.018	0.000	0.024	0.000
Sweden	0.000	0.000	0.150	0.000	0.023	0.000
Netherlands	0.037	0.000	0.010	0.000	0.019	0.000
Italy	0.000	0.000	0.013	0.000	0.014	0.000

Figure 3.5: Locations of Inventors Collaborating With Detroit (Global), 1975-2004

Figure 3.6: Locations of Inventors Collaborating With Detroit (Europe), 1975-2004

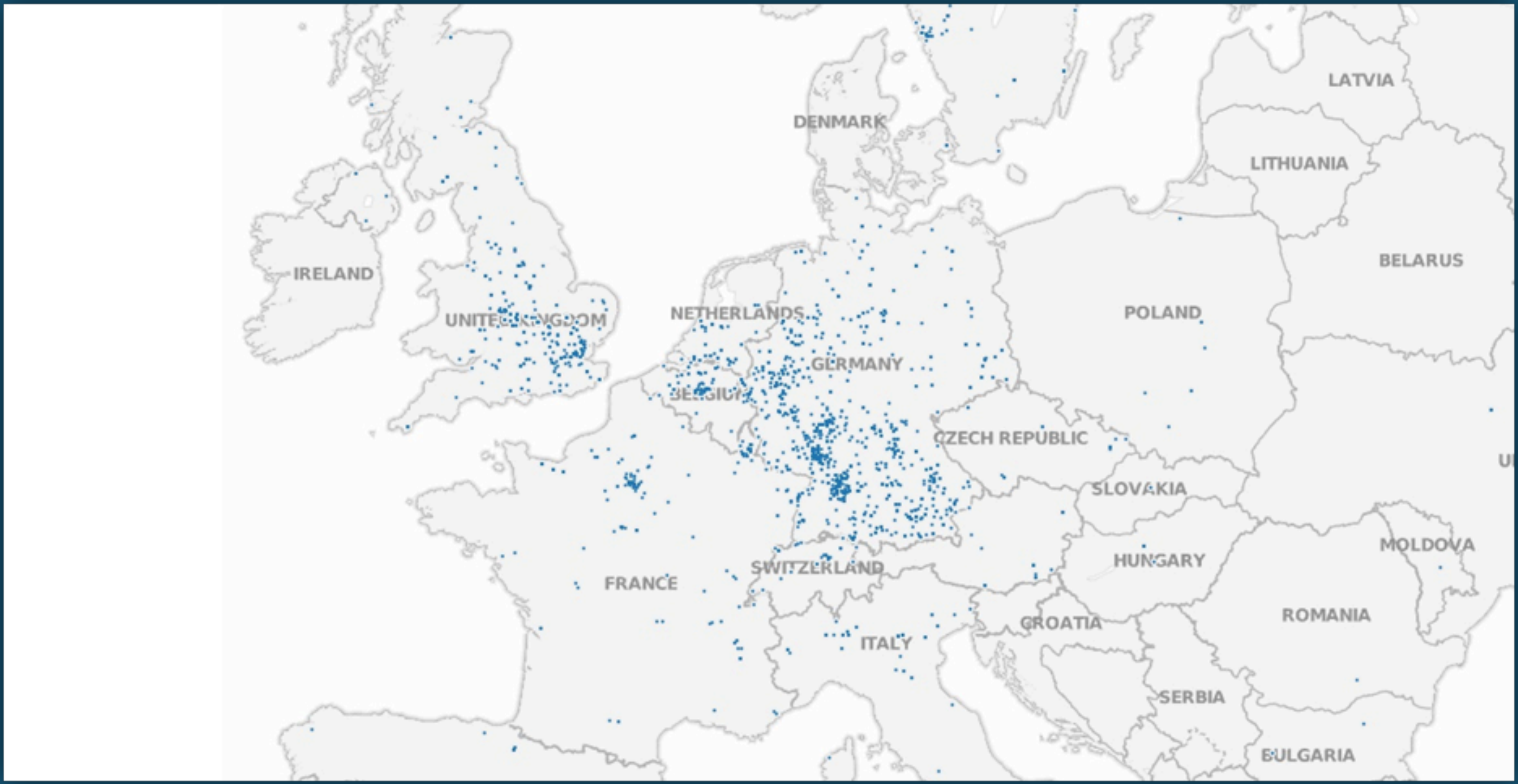


Figure 3.7: Locations of Inventors Collaborating With Detroit (Michigan & Southwestern Ontario), 1975-2004

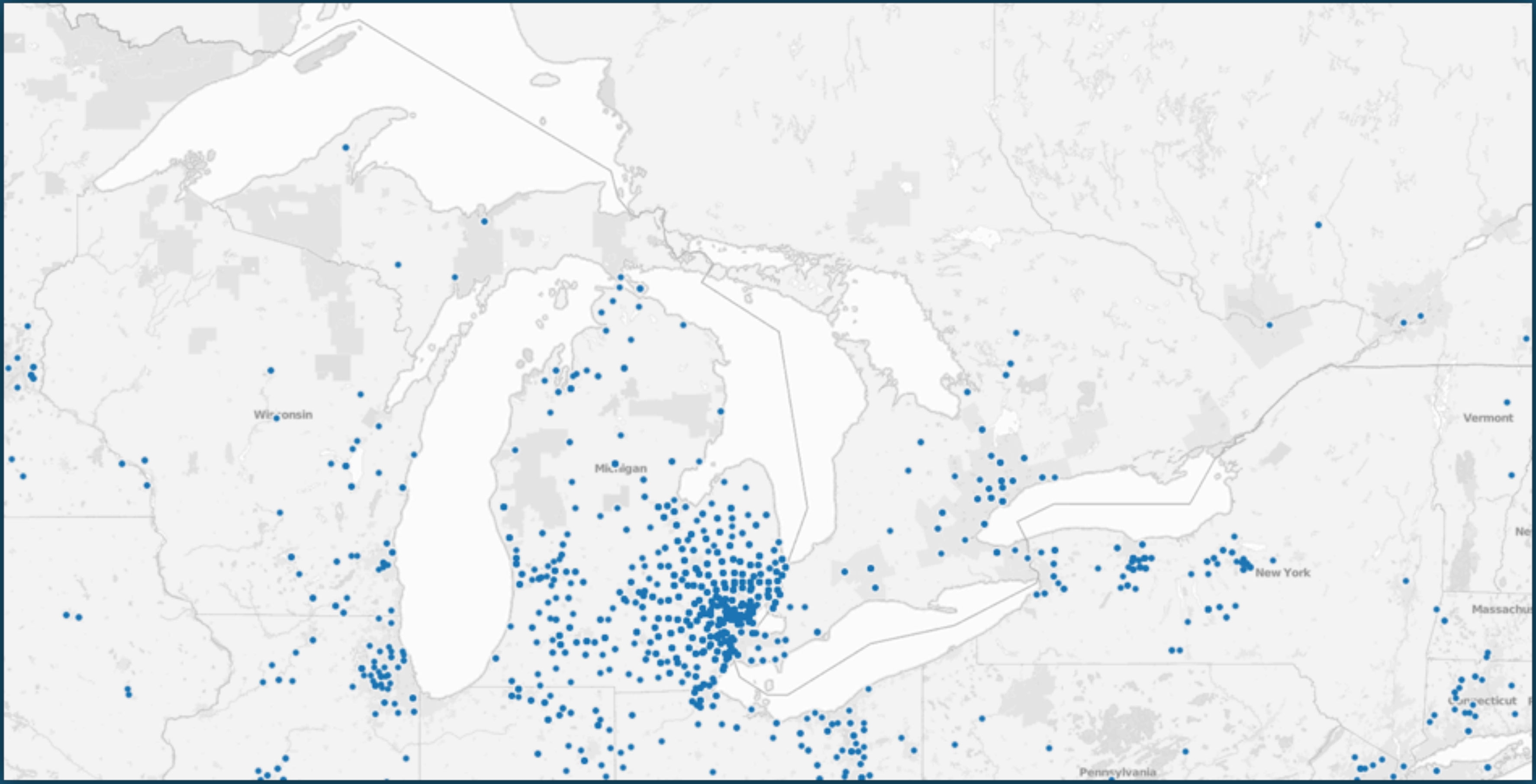


Figure 3.8: Internationally Connected Detroit-based Patents, Domestic vs. Foreign Assignees (1975-2009)

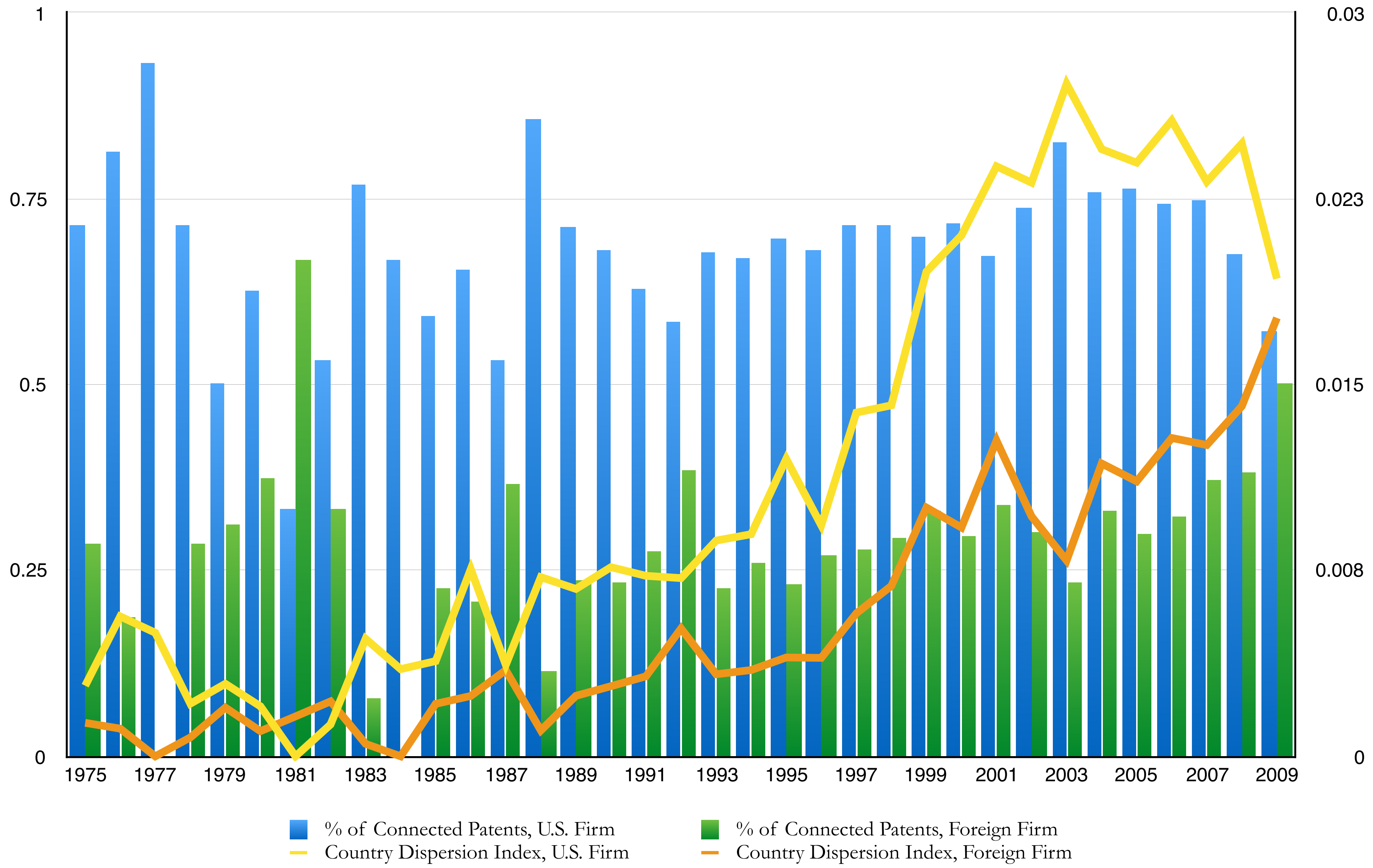


Table 3.7: International Connectedness of Detroit-Based Patents, By Key Assignee: 1975-2009

Period	**1975-1979**	**1980-1984**	**1985-1989**	**1990-1994**	**1995-1999**	**2000-2004**	**2005-2009**
Big Three Automakers	7.35%	12.28%	20.13%	25.60%	22.74%	15.06%	22.78%
Ford	4.41%	5.26%	8.44%	15.02%	13.91%	9.47%	7.43%
General Motors	1.47%	7.02%	7.14%	8.53%	3.76%	3.37%	11.47%
Chrysler	1.47%	0.00%	4.55%	2.05%	5.07%	2.22%	3.88%
Suppliers	2.94%	3.51%	3.25%	4.09%	7.19%	14.01%	8.71%
TRW Automotive	0.00%	0.00%	0.65%	1.02%	1.47%	1.48%	0.48%
Lear Automotive	0.00%	0.00%	0.00%	0.34%	1.80%	3.05%	1.94%
Visteon	0.00%	0.00%	0.00%	0.00%	0.00%	3.46%	0.48%
Eaton Corporation	0.00%	3.51%	2.60%	2.39%	1.96%	0.25%	0.32%
Delphi	0.00%	0.00%	0.00%	0.00%	0.98%	3.05%	1.94%
Borg Warner	2.94%	0.00%	0.00%	0.34%	0.49%	1.81%	0.97%
Magna	0.00%	0.00%	0.00%	0.00%	0.49%	0.91%	2.58%
Foreign Automakers	0.00%	0.00%	0.00%	2.73%	0.32%	1.97%	6.94%
Toyota	0.00%	0.00%	0.00%	0.68%	0.00%	0.25%	2.10%
Nissan	0.00%	0.00%	0.00%	2.05%	0.16%	1.07%	3.23%
Honda	0.00%	0.00%	0.00%	0.00%	0.00%	0.08%	0.16%
BMW	0.00%	0.00%	0.00%	0.00%	0.00%	0.25%	0.97%
Daimler Benz	0.00%	0.00%	0.00%	0.00%	0.00%	0.16%	0.48%
Volkswagen Group	0.00%	0.00%	0.00%	0.00%	0.16%	0.16%	0.00%
Other	2.94%	1.75%	9.74%	12.29%	11.62%	10.53%	4.37%
Siemens	0.00%	0.00%	0.00%	0.68%	2.13%	4.44%	0.97%
BASF	2.94%	1.75%	7.79%	9.56%	7.20%	3.37%	1.78%
Bosch	0.00%	0.00%	1.95%	2.05%	2.29%	2.72%	1.62%

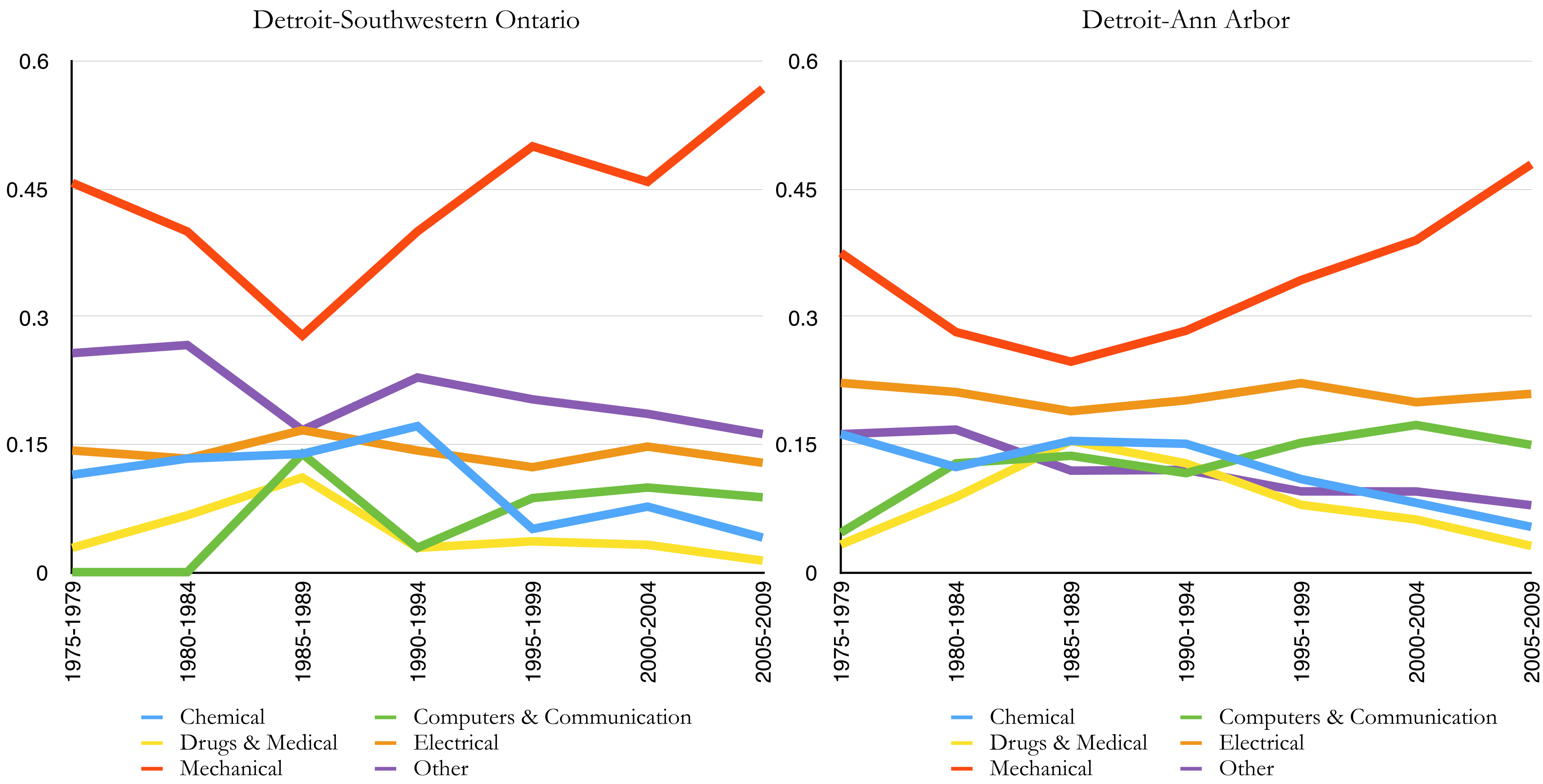
Table 3.8: Share and Technological Diversification Index of Internationally Connected Detroit-based Patents by Country, 1975-2009

Period	Germany	Canada	Japan	United Kingdom	France
% of Detroit Patents					
1975-1979	0.17%	0.54%	0.02%	0.09%	0.00%
1980-1984	0.23%	0.25%	0.10%	0.12%	0.00%
1985-1989	0.43%	0.69%	0.26%	0.17%	0.02%
1990-1994	0.84%	0.53%	0.49%	0.39%	0.00%
1995-1999	1.29%	1.51%	0.61%	0.52%	0.03%
2000-2004	2.42%	2.24%	0.56%	0.88%	0.07%
2005-2009	2.06%	2.28%	1.16%	0.51%	0.25%
Technological Diversification Index					
1975-1979	0.612	0.679	0.000	0.611	0.000
1980-1984	0.750	0.728	0.719	0.656	0.000
1985-1989	0.703	0.783	0.795	0.574	0.000
1990-1994	0.730	0.746	0.702	0.720	0.000
1995-1999	0.759	0.662	0.760	0.756	0.375
2000-2004	0.733	0.691	0.745	0.663	0.595
2005-2009	0.723	0.653	0.707	0.709	0.768

Table 3.9: Technological Composition of Detroit Patents Connected to Canada & Germany. 1975-2009

Period	Chemical	Computers & Communication	Drugs & Medical	Electrical	Mechanical	Other
Detroit-Germany						
1975-1979	54.55%	9.09%	0.00%	9.09%	27.27%	0.00%
1980-1984	31.25%	0.00%	18.75%	6.25%	31.25%	12.50%
1985-1989	43.75%	3.13%	3.13%	9.38%	28.13%	12.50%
1990-1994	38.04%	2.17%	5.43%	9.78%	30.43%	14.13%
1995-1999	21.32%	9.64%	5.08%	12.69%	39.09%	12.18%
2000-2004	17.15%	13.59%	0.67%	14.48%	43.21%	10.91%
2005-2009	12.37%	14.52%	0.00%	16.13%	44.62%	12.37%
Detroit-Canada						
1975-1979	17.95%	0.00%	0.00%	10.26%	46.15%	25.64%
1980-1984	11.11%	0.00%	5.56%	16.67%	38.89%	27.78%
1985-1989	16.98%	11.32%	5.66%	9.43%	32.08%	24.53%
1990-1994	16.39%	1.64%	4.92%	14.75%	37.70%	24.59%
1995-1999	7.52%	4.87%	2.65%	9.29%	50.88%	24.78%
2000-2004	7.35%	9.48%	2.61%	12.32%	49.29%	18.96%
2005-2009	6.19%	7.73%	2.58%	13.92%	54.12%	15.46%

Figure 3.9: Technological Composition of Detroit Patents Connected to Southwestern Ontario & Ann Arbor. 1975-2009



CHAPTER 4: THE DISPERSED MULTINATIONAL: DOES CONNECTEDNESS ACROSS SPATIAL DIMENSIONS LEAD TO BROADER TECHNOLOGICAL SEARCH?

Introduction

Scholarly conceptions of the multinational enterprise (MNE) as a globally dispersed entity have evolved enormously over recent years, incorporating the myriad complexities of firm-location interactions that characterize modern business linkages. The MNE has long been viewed as an arbitrageur of country heterogeneity (Dunning, 1980), although it is becoming more and more clear that globally-informed intangibles, such as R&D and marketing, are core drivers of global value creation (Morck & Yeung, 1991; Mudambi, 2008). To the extent that the MNE is seen as a global network of knowledge-creating entities (Bartlett & Ghoshal, 1990), only recently has the international business literature pursued a greater level of granularity with respect to the knowledge-location nexus of MNE innovation processes (Iammarino & McCann, 2013).

Locations as knowledge repositories have unique and evolving profiles (Boschma, 2005; Boschma, Balland, & Kogler, 2015) that serve unique and evolving roles in global innovation systems (Lorenzen, 2004). As the advance of technology brings about intensification of value chain linkages (Sturgeon, Van Biesebroeck, & Gereffi, 2008), of particular interest is the role of the firm's knowledge connectedness across locations, particularly in the context of generating new ideas and exploring new technologies. At issue with global innovation-location research, which sees the transfer of knowledge into the embedded subsidiaries of MNEs (Meyer, Mudambi, & Narula, 2011) to the broader global firm network (Gupta & Govindarajan, 1991), is the process by which ideas actually travel out of and between locations.

Knowledge spillovers represent the latent process of learning within and across organizations, which heretofore has been presented as a fundamentally local process (Jaffe, Trajtenberg, & Henderson, 1993; Funk, 2013). The mechanisms of knowledge transfer within proximate space are rooted in the basic aspects of human interaction (Arrow, 1962; Romer, 1986) and the agglomerative benefits of co-located firms (Marshall, 1920). Ultimately, the benefits of localization imply a collective momentum of knowledge flows (Storper & Venables, 2004), underwritten by the experiential nature of how tacit knowledge itself is shared (Gertler, 2003). However, the absorption of knowledge by inventive actors from the locations in which they reside is just one element of the broader innovation story: inventors are inherently tied to these locations, but in an increasingly interdependent world, so too is the collaboration process.

This chapter focuses on the role of connectedness in the knowledge generation processes of large innovative firms. Increasingly, scholars have begun to adopt the view that firms and locations co-evolve (Cantwell, 2013; Boschma, 2015; Cano-Kollmann et. al, 2016), and that tacit knowledge is not exclusively tied the notion of "being there" (Gertler, 2003; Amit & Cohendet, 2004; 2005). Similarly, the economic geography literature has explored innovation ties across geographic space, and the role of people and organizations in generating knowledge conduits (Lorenzen & Mudambi, 2013). While there is a competitive disadvantage to a purely local inventive strategy (Un, 2015), the vital conditions to transfer tacit knowledge locally, such as shared practices and language (Maskell & Malmberg, 2006) can be replicated technologically (Grabher & Ibert, 2013). We argue that the knowledge connectedness process that links global centers of excellence (Lorenzen, 2004) sees the coalescing of knowledge that may have otherwise been adhered to locations. Innovation connectedness – which may span international and domestic distance – is crucial to the infusion of new ideas.

In this study, we examine the extent to which large innovative firms are connected across geographic space, and the impact that connectedness has on the exploration into new technological areas. To be clear, the connections studied are at the level of the collaboration, and not those represented by spillovers. This is an important distinction, as the location-inventor infusion of knowledge is an important entry point into the global collaboration process (Cantwell & Santangelo, 1999). It is a direct collaboration, rather than a downstream dissemination of knowledge within a cluster (Tallman, Jenkins, Henry, & Pinch, 2004). However, as Boschma (2005) notes, the role of geography in interactive learning is not the only form of proximity that matters: coordination is key to the movement of knowledge and organizations play role in activating networks (Lorenzen & Mudambi, 2013). To this extent, we argue that the relative footprint of the firm – foreign or domestic – is a crucial amplifier of collaboration across space. As the operational elements of the firm establish organizational linkages between locations (Mudambi, 2008), those ties serve as valuable conduits of knowledge transfer and opportunity recognition.

Within clusters of industrial activity, the balance of local intensity with external infusions of ideas is crucial to the evolution and sustained innovative health of the location (Bathelt, Maskell, & Malmberg, 2004; Hannigan, Cano-Kollmann, & Mudambi, 2015). The same logic has been applied to firms, for whom learning is path dependent and the balance of routinized depth within existing lines of inquiry against the need to refresh and explore (Nelson & Winter 1982, March 1991) is crucial to survival. In other words, both firms and locations rely on the infusion of new ideas to grow and prosper, yet each evolutionary step into new territory is a related technological space (Balland, Boschma, & Frenken, 2015). Collaboration across locations allows for wider – yet targeted – search for new ideas, particularly as local sources are exhausted (Gittelman 2007). To the extent that firms will reach out to find new knowledge, so presents the promise of recombination and exploration (Penrose, 1959; Galunic & Rodan, 1998).

The distribution of economic activity around the world is uneven within countries, owing in large part to many different dimensions of distance (Ghemawat, 2001) and the unique profile of innovation-generating locations (Lorenzen, 2004; Florida, 2005). As much as national borders still matter, the firm can be easily seen as a multi-location enterprise as well (Beugelsdijk & Mudambi, 2013). In this paper, we ask: How do different types of connectedness influence a firm's ability to explore new technological areas? We extend this idea further, asking: does the degree of international (or domestic) focus of the firm's operations impact the relationship between connectedness (international or domestic) with the ability to explore new areas? Our contributions are twofold. First, we elucidate a theory of international and domestic innovation connectedness as distinct (although not necessarily orthogonal) pathways to technological exploration into related space. Second, we argue that the operational footprint of the firm as a positive moderator of connectedness, tilted to the respective type of connection. This chapter contends that operational learning is distinct from that of knowledge generation, and yet establishes the latent conduits between locations that amplifies the transfer of novel ideas.

In this chapter, we employ patent data from the United States Patent and Trademark Office (USPTO), as captured in two well-established databases: the NBER Patent Database (Hall, Jaffe, & Trajtenberg, 2001) and the Harvard Dataverse Patent Database (Li et al, 2014). The use of both databases allows for the complementary characteristics of each, specifically the matching of firm identifiers (NBER) and inventor locations (Harvard DVN). Our sample frame is the population of S&P 500 firms between 1980 and 2006, using only those firms with active innovation profiles. Our patent data is matched to firm characteristics and performance measures from the CompuStat database over the same period. Using a negative binomial random effects estimation, we find that firms with a greater number of patents that are internationally connected in their co-inventor networks tend to patent across technological categories. We find a similar relationship with domestic connections, defined as those that cross U.S. state lines. However, these relationships are positive up to a point, suggesting a limit to which connectedness is helpful. However, the extent to which the firm’s operations are foreign (or domestic) positively moderates the connected relationship with technological exploration. Our results are robust to different specifications of connectedness, technological exploration, and operational footprint.

The remainder of this chapter is organized as follows. The next section will review the relevant literature and develop our theory of connectedness and technological exploration. Testable hypotheses then follow, along with the accompanying theoretical rationalization. We then describe our data and empirical strategy, and follow with an analysis of results. The paper concludes with a discussion of our findings and implications for the field.

Theory and Hypothesis Development

MNEs and the Geography of Innovation

Over the last few decades, deep institutional and technological changes have brought about a substantial reconfiguration of the value chain, along both organizational and geographic dimensions (Sturgeon et al., 2008). Increasingly, heterogeneous companies play diverse roles in global value chains from geographically dispersed locations. Yet, knowledge, technology and intangible assets have maintained and even reinforced their role as crucial generators of value and drivers of firms' competitive advantage (Mudambi, 2008). As orchestrating firms, MNEs are ideally placed to leverage the benefits stemming from the globalization of value chains (Dedrick, Kraemer, & Linden, 2010), as they primarily compete based on an array of internalized knowledge-related assets derived from both internal and external sources (Iammarino & McCann, 2013). MNEs act as knowledge integrators, thanks to their capabilities (or, Ownership advantages) to efficiently and effectively acquire, transfer and recombine knowledge across internal and external geographically distributed networks (Almeida & Kogut, 1997; Cantwell & Mudambi, 2005; Dunning, 1998, 2009).

Leveraging geographically dispersed technology is important because the nature of the local knowledge that accumulates over time in different regions: diverse, perhaps even complementary ideas are (Porter, 1990; Cantwell & Janne, 1999; Singh, 2008). As a robust and diverse knowledge environment allows firms to choose among a wider range of knowledge inputs for recombination, it also provides the opportunity to overcome the constraints of local search (March, 1991; Levinthal & March, 1993; Teece et al., 1997). Thus, diverse inputs enable the pursuit of technology-spanning innovation activities, which have long been recognized as the source of firms' competitive advantage (Mowery et al., 1996; Stuart & Podolny, 1996; Rosenkopf & Nerkar, 2001).

Because of the increasing tendency of firms to be knowledge driven, competition has pushed them to look for distinctive R&D intangible assets in a wider number of locations (Cantwell, 1989). The presence in diverse local contexts enables the MNEs to tap into different knowledge clusters and geographically concentrated repository of knowledge, which they can leverage to both strengthen and, especially, diversify their technical competences (Meyer et al., 2011). However, firms can tap into diverse knowledge pools by directly localizing their activity and indirectly creating knowledge networks and linkages with individuals (inventors) located there.

Owing to the competences that can be sourced directly from the presence in a specific location or indirectly through the personal linkage established with external inventors, MNEs create potential basis for knowledge transfer and learning across firm boundaries, and more importantly across space. Firms establish pipelines, and create and manage the knowledge flows between different actors and distributed locations (Bathelt et al., 2004; Lorenzen & Mudambi, 2013). Therefore, the MNE as an institution that manages, transfers and produces knowledge can be analyzed considering two distinct types of networks, i.e. the knowledge network and the organizational network. However, the act of combining knowledge across distance – geographic, knowledge, or organizational – is fundamentally integrative (Beugelsdijk, McCann, & Mudambi, 2010).

Geographically dispersed innovation is not an exogenous process. Indeed, having geographically distributed R&D operations does not necessarily lead to better innovation (Singh, 2008). Large and differentiated bodies of knowledge need to be integrated and recombined to ultimately give rise to original innovative outcomes (Lahiri, 2010). Accordingly, scholars have recognized the critical importance of cross-regional connections as tools that enable firms to materialize the significant boundary-spanning potential underlying a geographically dispersed R&D network (Frost & Zhou, 2005; Lahiri, 2010). Such connections act as structural bridges that contribute non-redundant technology to the firm's innovation funnel thus overcoming the limits of transferring knowledge across distance (Alnuaimi et al., 2012). Thus, the linkages that bring knowledge out of locations must be inherently integrative.

In fact, over time, MNEs have become key institutions for creating connections between knowledge sources, no matter the geographical, institutional and technological distance that separates them. Their superiority in the mobilization of dispersed knowledge compared to other governance structures, such as markets or alliances (Almeida et al., 2002), is by now very established. The key success factor of the MNE lies in its ability to manage differences and reconcile interdependences across all functional areas (Ghemawat, 2007). As several leading scholars have argued (e.g. Narula, 2003; Rugman, 2003), globalization has not significantly reduced the differences between and within cities, regions, and countries. Indeed, the differences are being explored beyond traditional boundaries and into subnational regions (Beugelsdijk &Mudambi, 2013) and even cities (Goerzen, Asmussen, & Nielsen, 2013). Hence, by managing the acquisition, transfer and recombination of dispersed and heterogeneous knowledge, MNEs operate simultaneously "as conduits and facilitators of global knowledge engagement across space" (Iammarino & McCann, 2013: 284).

The Connectedness of MNE Innovation Networks and Technological Exploration

Locations, which may be characterized as industrial clusters or city regions (Scott, 2000; Storper, 2013), have unique makeups and structures that are inherently tied to firm activities (Storper & Walker, 1989; Markusen, 1996). While it is true that locations are embedded in larger national contexts with key institutional influences, subnational regions remain highly heterogeneous and retain unique characteristics (Beugelsdijk & Mudambi, 2013). Framed in an innovation context, locations are repositories of knowledge unique innovative profiles that evolve in a path dependent manner (Boschma, 2005; Boschma et al, 2015). To this end, locations benefit from both agglomeration externalities (Mashall, 1920; Arrow, 1962; Romer, 1986; Glaeser et al, 1992) and a diversity of ideas that are fungible across industry verticals and operationalized through density (Jacobs, 1969).

Subnational locations such as cities house high knowledge activities that are often at the forefront of value creation and economic growth. Firms that distribute value chain activities to efficient locations around the world look to draw on the beneficial characteristics of locations, either through a direct knowledge transfer (Cantwell & Santangelo, 1999) or simply via lower spatial transaction costs (Goerzen et al, 2013). Simply put, embeddedness within a location helps to establish linkages beneficial to the dispersed firm (Meyer et al., 2011). To this end, physical co-location within a cluster is well established as a mechanism of knowledge transfer (Jaffe et al, 1993; Storper & Venables, 2004; Gertler 2003). However, firms and locations are highly interdependent, and co-evolve over time as knowledge systems become more complex (Cano-Kollmann et al, 2016). As a result, clusters and firms are looking to collaborations across technical and geographic space to fuse new ideas with existing competencies (Hannigan et al, 2015).

To the extent that knowledge spillovers are highly localized (Jaffe et al, 1993), collaborative relationships across space present a more nuanced dynamic. On the one hand, the activities of the firm – including, but not specifically, R&D – are increasingly assigned to specialized (or standardized) locations (Mudambi, 2008). In so doing, the fabric of coordination has intensified in kind (Dedrick et al, 2010). On the other hand, advances in information and communication technologies have cracked – although perhaps not broken – the heretofore tight link between tacit knowledge transfer and the prerequisite of co-location (Amin & Cohendet, 2004; 2005). For instance, parts of the key mechanisms of tacit knowledge transfer within locations - shared languages and practices - may also be replicated virtually (Grabher & Ibert, 2013). Collaborative relationships are non-random, stemming from some mix of personal relationships and organizational linkages (Lorenzen & Mudambi, 2013), and advances in collaboration technologies have enabled broader reaching networks. Furthermore, linkages may form from temporary co-location, which is sufficient to maintain the global pipeline of knowledge (Maskell, Bathelt, and Malmberg, 2006).

Orchestrators are superior knowledge integrators (Dedrick et al, 2010), efficiently and effectively acquiring, transferring, and recombining ideas and driving the full value chain process. As a form of orchestrator, MNEs are add the spatial dimension, working across geographically distributed locations, both inside and outside of the boundary of the firm (Almeida & Kogut, 1997; Cantwell, 2013; Cantwell & Mudambi, 2005). Using insights from the social network theory, we can see firms as managers and creators of linkages between domestic and non-domestic actors. The establishment of these linkages is a necessary condition for the connectedness of the firm to knowledge sources and technology residing either locally or internationally, particularly in the context of collaboration across space, rather than latent spillovers. Knowledge is embedded in individuals and organizational processes (Nelson & Winter, 1982) and then through collaboration it creates new ideas.

Relying on geographically dispersed inventor networks, the firm can access more diversified knowledge, as technology tends to differ across locations depending on location-specific factors (Cantwell, 1989; Chung & Yeaple, 2008). As locations and firms take on specific roles in global value chains (Mudambi, 2008), the evolving profile of locations will also feature prominently in collaboration decisions: the search for knowledge will extend far and wide for new ideas (Gittelman, 2007). Therefore, the extent to which the firm can generate geographically dispersed inventor networks should be linked to its ability to overcome competency traps and lock-in effects, which can reduce the creation of new or more complex knowledge (Boschma, 2005; Levinthal & March, 1993). By recombining technological domains located across different spaces through knowledge connectedness, we expect that the firm is more likely to able to create more complex innovation, that we define as technology-spanning innovation, which is explorative in nature (Lorenzen & Mudambi, 2013).

Despite the fact that the world is increasingly connected, national borders and distance still matter (McCallum, 1995; Ghemawat, 2001). Even with converging characteristics of global cities (Florida, 2005; Goerzen et al, 2013), the fact remains that New York is fundamentally different from Shanghai, Stuttgart from Detroit, San

Francisco from Bangalore, and so on. Thus, the overarching notions of distance and diversity remain quite relevant to collaborative relationships that can be used to overcome the challenges of relying on local innovation sources (Un, 2015). Different typologies of knowledge geographically distributed can be combined with the final aim to develop technical diversity (Cantwell and Janne, 1999). The difference between the knowledge that is embedded in different national contexts can create a potential for "non-overlapping knowledge" bases (Phene et al., 2006). Thus, global linkages orchestrated by the MNEs can enabled the transfer and the creation of different and more complex knowledge.

Yet, firms maintaining too many (international or domestic) connections may experience a reduction in the positive effect of increasing their connectedness further, for a variety of reasons. First, linkages and knowledge networks distributed across space are difficult and costly to create, maintain and exploit. In fact, resources devoted to the management of connections are subtracted to the other types of innovation processes. Second, the greater the firm connectedness, the more complicated it becomes to locate exactly those pieces of knowledge that are needed to span technological boundaries in a specific innovation process (Lahiri, 2010). Third, after a given degree of connectedness, the risk that the next connection brings knowledge that the firms already possess becomes higher. In other words, as the firm becomes closer to cover all the possible set of connections, the opportunity to find yet another original knowledge input becomes increasingly lower, leading to knowledge saturation risks. This sets up our first hypothesis:

Hypothesis 1: There is an inverted U-shaped relationship between a firm's international connectedness and the extent to which it explores new technologies.

The ability to nurture connectedness is crucial to innovation processes. Firms often rely on interactions with other actors operating in close or contiguous environments in order to create and strengthen their knowledge. One of the primary sources of variation among knowledge sources originates from the linkages created across space (Gulati, 1998; Zaheer & McEvily, 1999). However, distance, even in the geographic context, exists in a meaningful way beyond the discontinuities of national borders. The variety of knowledge resources that is required to generate technology-spanning innovation does not only arise from crossing the boundaries of nations.

Firms do not just gain access to the variety of knowledge inputs they need to pursue technology-spanning innovation processes by developing international knowledge linkages. In fact, the economic geography literature has put forward the idea that countries are not internally homogeneous and that instead they can be characterized by high degrees of heterogeneity, in terms of the patterns of technological specialization they follow and hence their knowledge endowment. This idea is rooted in a wide-ranging economic geography and regional studies literature on clusters and regional systems of innovation (e.g. Boschma, 2005; Cooke at al., 1997).

An increasing number of studies suggest that countries are not internally homogeneous, but rather can be characterized by a high degree of sub-national heterogeneity (Beugelsdijk & Mudambi, 2013). Yet, firms' activities overcome borders where spatial transaction costs shift in a discontinuous way (Beugelsdijk et al., 2010), the latter proceed with the distance that separates a firm's activities, and increase in a continuous manner. In traditional IB literature, "border effects" have been mainly identified with national boundaries. However, since spatial discontinuities may and do emerge even within the same country, the investigation of firms' geographical behavior need to account for the influence of both border and distance effects (McCann & Mudambi, 2005). In the context of our analysis, this means accounting for firms' cross-regional knowledge connections, i.e. its innovation connectedness, both within and outside a firm's home country. Ultimately, domestically connected knowledge is a valuable, yet distinct source from those from international locales. Greater institutional and transactional pathways enable the connectedness process and limit the "hassle factor" of establishing connections (Schotter & Beamish, 2013).

Even within the national boundaries, locations may be very heterogeneous along several dimensions that are critical for MNE innovation (Agrawal, Cockburn, Galasso, & Oettl, 2014). This includes the nature and intensity of technological sophistication of co-located agents, the transactional rules governing their interaction, the endowment with knowledge generating factors, and the general socio-institutional infrastructure, to name a few (Iammarino & McCann, 2013). These factors are likely to profoundly affect the dynamics of knowledge evolution within spatial entities.

Within-country heterogeneity is strongly associated with the ability of certain sub-national spatial scales to grow as engines of innovation and new knowledge creation. As an example, recent urban growth dynamics highlight the increasing relevance of cities (Agrawal et al., 2014). Cities facilitate wide-ranging transactions by making advanced infrastructure and diverse resources available. People and organizations are incentivized to agglomerate in urban areas as they expect to gain from wide-ranging human capital interaction and new knowledge generation (Berry & Glaeser, 2005). As such, cities are likely to embed substantial opportunities for accessing advanced knowledge (Goerzen et al., 2013), but, by definition, are limited to the key centers within the same country. Thus, our second hypothesis:

Hypothesis 2: There is an inverted U-shaped relationship between a firm's domestic connectedness and the extent to which it explores new technologies.

The Moderating Role of the MNE's Degree of Foreign or Domestic Operations on Connectedness and Innovation

In the foregoing discussion, we have suggested that knowledge collaborations across both domestic and foreign space are key to develop innovations that span technological areas. However, we also argue that the relationship between the architecture of a firm's knowledge network and its ability to exploit the opportunities for technological exploration can be better understood by accounting for its operational footprint. This idea is rooted into the interactive model of innovation (Kline & Rosenberg, 1986).

While early Schumpeterian views contended the central role of a lone innovating entrepreneur, innovation is now widely understood as an interactive process in which a variety of different actors engage in dynamics of trial and error in order to successfully develop novel ideas (Schumpeter, 1942; Rosenberg, 1982; von Hippel, 1988; Freeman & Soete, 1997; Tidd, Bessant, & Pavitt, 1997). Following this perspective, in the last decades there has been widespread agreement that innovation is rarely achieved by the innovating firm in isolation from its external environment, but rather benefits from the linkages with different actors such as suppliers, user communities and institutions operating in the surrounding innovation system (Lundvall, 1992; Brown & Eisenhardt, 1995; Szulanski, 1996), which serve as conduits that channel feedback information on the innovating firm's initiatives. In this model, successful innovation emerges as a result of processes in which scientific mastery is greatly assisted by other types of knowledge, such as engineering and production expertise (Rosenberg, 1976; Morgan, 1997).

The notion of innovation as an interactive process has spurred reflections on the extent to which geographical proximity can be understood as a sufficient pre-condition for learning. In this regard, Boschma (2005) has put forward the idea that proximity is a multidimensional construct, covering a variety of social, institutional, organization and cognitive aspects, in addition to geographical ones. According with this perspective, geographical proximity – if considered in isolation - does not ensure that the firm is able to source and move locally embedded knowledge. Because innovation is an immensely uncertain undertaking, the effective transfer of complementary pieces of knowledge calls for very powerful coordination mechanisms to be in place (Boschma, 2005). Hence, other forms of proximity are required to facilitate the assimilation and integration of different bodies of knowledge into successful innovation.

Following this view, we argue that while a cross-spatial network of knowledge-based collaborations enhances a firm's opportunities to access diverse and often complementary bodies of technology, such opportunities are amplified when knowledge collaborations across (foreign or domestic) space come along with locally embedded (foreign or domestic) operations. Firms develop pipelines, and create and manage the knowledge flows between different actors and distributed locations (Bathelt et al., 2004; Lorenzen & Mudambi, 2013). Hence, they can be considered as being simultaneously defined by their knowledge network and their operational network. Since the act of combining knowledge across distance – geographic, knowledge, or organizational – is fundamentally integrative (Beugelsdijk, McCann, & Mudambi, 2010), both the knowledge and the operational networks, and the way they align, can be critical.

Coordination is crucial to the movement of knowledge and organizations play a major role in activating networks (Bathelt et al., 2004). To this extent, we argue that the relative footprint of the firm – foreign or domestic – is a crucial amplifier of collaboration across space. A firm's operations embody knowledge that spans activity boundaries to cover design, technical and marketing capabilities (Sturgeon et al, 2008; Dedrick et al, 2010). Cross-activity coordination is critical for the functioning of the firm, such that routines need to be established to ensure the cross-fertilization of heterogeneous bodies of expertise (Nelson & Winter, 1982). As the operational elements of the firm establish organizational linkages between locations, those ties do not only enrich the firm's basic knowledge with more applied expertise arising from the interaction among different intra-firm functions and with the wider institutional environment, but also serve as valuable conduits of knowledge transfer and opportunity recognition. A firm's operational network is a source of experiential learning, as it progressively enables firms to relate to different actors and conditions in the external environment (Barkema & Vermeulen, 1998; Delios & Henisz, 2000; Zahra et al., 2000). Hence, operational learning is distinct from that underlying the generation of technological knowledge, and yet instigates the latent conduits between locations that amplify the assimilation, transfer and integration of ideas across space.

We posit that firms that are provided with a "good match" between their knowledge network and their operational network are more likely to exploit the opportunities for technology-spanning innovation. In other words, firms leveraging a foreign knowledge network are more effective in the recombination of the technological inputs they have access to, the higher their relative foreign operational footprint, as they can better combine their technological knowledge with knowledge of how activities and markets work. On the other hand, as the marginal effect of additional foreign knowledge connections ceases to be positive, the relative foreign operational footprint emphasizes the negative effect, given the complexity of managing simultaneously extremely wide knowledge and operational networks. Following this reasoning, we suggest our third hypothesis:

Hypothesis 3 (HP3): The firm's degree of foreign operational focus has a positive moderating effect on the inverted U-shaped relationship between the firm's international connectedness and the extent to which it explores new technologies.

Data and Methods

Sample

The sample frame of this study was designed to capture the innovation patterns of large firms with active innovation profiles. The basic rationale for this frame is as follows: substantially all large firms with R&D operations are confined completely to a single location (Navaretti, Venables, & Barry, 2004). Thus, we sought a list of firm with distributed operations of *some* type.

In order to build the final sample employed to empirically test our hypotheses we followed a three-stage process. First, for each year t included in the time period 1975-2006 we identified all publicly traded firms that were part of the Standard & Poor's 500 (S&P 500) at least for one week in year t, with a minimum of one patent applied for in that year. Our sample is therefore an unbalanced panel dataset, as it may be that some companies belonged to the S&P 500 for the entire period 1975-2006, but it also may be that some others belonged to the S&P 500 for only some years.

We used CompuStat North America to collect this information. Second, using the CUSIP identifier of the firms identified in the first stage, we collected firm-level data described below from CompuStat. Finally, we drew patent data from the United States Patent and Trademark Office (USPTO) database. Our empirical strategy was to use patent data to represent the technology-spanning innovation generated by each firm in our sample. The advantage of using patent data to analyze knowledge production is related to the detailed information provided by the patent documents. Following previous studies (e.g. Almeida & Phene, 2004; Lahiri, 2010; Phene & Almeida, 2008; Perri & Andersson, 2014), patent data allowed us to determine the location of the inventors, i.e. the locus of the invention, the organization(s) to which the patent was assigned, the grant and application dates, the technological classes of the innovation. Focusing only on utility patents, data on patents granted by the USPTO were gathered from NBER patent citation data file (Hall et al., 2001) and the "*Disambiguation and co-authorship networks of the U.S. patent inventor database (1975 - 2010)*" developed by the Harvard Dataverse Network (see Li et al., 2014).

Our final sample is composed of 506 firms, observed over a 31-year period (allowing for 30 years of data with a single lag). Hence, the unit of analysis is firm-year. As our panel dataset is unbalanced, the total number of observations in our sample results in a final usable observation count of 6850. This is due to mainly three reasons: (1) not all the firms were listed in the S&P 500 for the years of observation, (2) some companies listed in the S&P 500 during our time period may not apply for (and receive) any USPTO patents, (3) missing data related to non-patents data forced us to drop some firm-year observations. The set of patents matched to S&P 500 firms was n=653,246, although these data were aggregated to the firm-year level of analysis.

Variable Operationalization

We describe below the dependent, independent and control variable included in our empirical analysis and their operationalization.

Dependent variable : Technology Spanning Patents (Subcategory). The front page of each patent contains information on the three-digit technological domains and the relative subclass to with the USPTO has assigned the invention. Patents may have more than one class listed: these have been identified in the literature as being fundamentally explorative (Rosenkopf & Nerkar, 2001) and at the firm or regional level, represent an evolution into technological novelty (Strumsky, Lobo, & van der Leeuw, 2012). A more parsimonious approach to delineating patent-based technologies has been the cataloging of patent classes put forward by Hall, Jaffe, & Trajtenberg (2001) in the NBER database. Specifically, we use the NBER subcategories to represent unique technological areas. Thus, for each patent j, a dummy variable was equal to 1 if more than one subcategory was assigned. The variable Technology Spanning Patents (Subcategory) was measured as the total number of technology spanning patents granted to firm i and applied for in year t.

Independent variables: Internationally Connected Patents. Following the approach of Lahiri (2010), we used the addresses of the patent inventors to determined the actual location of the knowledge creation. Frequently, a patent is assigned to a corporate headquarters (Cantwell & Piscitello, 2000), but the underlying innovation may stem from different geographical locations. Thus, we defined a patent as internationally connected, if at least two of its inventors are located in different countries. For each firm *i*, the variable Internationally Connected Patents was measured as the total number of internationally connected patents granted to firm i and applied for in year *t*.

Domestically Connected Patents: Relying to a similar approach used for the previous independent variable, we defined a patent as domestically connected, if at least two of its inventors are located in different U.S. states. For each firm *i*, the variable Domestically Connected Patents was measured as the total number of domestically connected patents granted to firm *i* and applied for in year *t*. In order to test our hypothesis that both forms of connectedness exhibit diminishing returns, we created squares terms to be inserted into our different estimations.

Foreign Focus: To measure the the foreign operational footprint of the firm in the context of international/domestic connectedness respectively, we used the proportion of firm's foreign employees to total employees (Kim et al., 1989). Percentage of Workforce (*foreign*) was measured for year *t-1* when the dependent variable was measured for year *t*. To be more consistent with our idea of "firm as a network of individuals", for the main analyses we decided to use a slightly different approach to measure the firm's foreign focus compared to the one proposed by Tallman & Li (1996) or Daniels & Bracker (1989). However, as robustness check, we used as an alternative more traditional measures of foreign focus, such as the proportion of firm's foreign revenues to total revenues (Rugman, 2003).

Interaction Terms: To test the moderating effect of the foreign footprint of the firm on the international connectedness, we generated an interaction term of the two types of independent variables. Interaction terms ought to fundamentally change the nature of the estimation model (Andersson, Cuervo-Cazurra, & Nielsen, 2014). This interaction term in particular is framed firmly in theory: inasmuch as the firm establishes operations of any kind in locations away from headquarters, this sets up organizational linkages. We argue that the organizational linkages amplify the transmission of R&D knowledge between locations, thus positively moderating the connectedness effect on the exploration into new technologies.

Controls: Percent of Inventors in HQ City. We controlled for the percentage of inventors located in the city where the firm was headquartered (HQ), as a proxy of the concentration of the inventor teams in the firm's HQ, or what may be considered the "liability of localness" (Un, 2015). We created this variable at patent level, and then the variable Percent Inventors in HQ City was calculated as annual mean at firm level. This variable allowed us to control for firms with largely concentrated teams.

Number of Patents: We controlled for the cumulative raw number of patents that the firm grated in the previous years till *t-1*, as a proxy of the firm knowledge base, and a control for the subset of connected patents that are the core explanatory variables. In fact, we expect that the number of technology spanning patents depends on the number of patents the firm owns.

Firm Size (Firm Total Revenue): In the literature there are no homogenous findings on the relationship between firm size and innovation. Empirical results show evidence of the positive effect, proposing that availability of internal funds and economies of scale in R&D favor complementarities between innovation and other firm activities. While, other studies suggest that in larger firms the likelihood of loss of managerial control and reduction of incentives for scientists is higher, determining the deterioration of innovative activities (Phene & Almeida, 2008). The variable is measured as the logarithm of the firm's total revenues in year *t-1* as a measure of firm size.

Firm Return on Assets: In order to control for the relationship between firm and innovation performance, we controlled for the a firm's return of assets in year *t-1*.

Firm Leverage: We controlled for the firm leverage, i.e. financial debt/equity ratio, of the firms in year *t-1*. There may be a negative effect between firm leverage and innovative performance due to the scant capital availability in short term (Kochhar & David, 1996).

Industry Controls: As our sample includes firms operating in different industrial sectors, we controlled for industry-specific effects on innovation. Specifically, we used broad technological categories (Hall et al, 2001), but also overlaid the SIC codes of inventing firms for the purposes of robustness.

Methods

The dependent variables, Technology Spanning Patents (Subcategory), are count dependent variables. Following the approach suggested by Hausman et al. (1984) in their empirical work on patent data and the subsequent approaches by other scholars analyzing event count data (e.g. Almeida & Phene, 2004; Kogut & Chang, 1991; Lahiri, 2010; Phene & Almeida, 2008), we used negative binomial regressions.

As our sample involved repeated observations of our set of firms over time, we needed to take into consideration unaccounted firms effects and year effects that were fixed or varied randomly. Therefore, we considered fixed effects and random effects models, which enable us to control for these effects. In order to identify the most suitable model, we performed a Hausman specification test, and our results show that random effects was the most appropriate choice. This also made intuitive sense, as firms do change over time. So, we decided to employ a negative binomial regression with random effects for all the models. The vector of explanatory variables is as follows:

$$\begin{aligned}\beta_0 &+ \beta_1 \mathit{Internationally\ Connected\ Patents}_{i,t} + \beta_2 \mathit{Internationally\ Connected\ Patents}^2_{i,t} \\ &+ \beta_3 \mathit{Percentage\ of\ Operations, Foreign}\ (\mathit{Workforce})_{i,t-1} \\ &+ \beta_4 \mathit{Domestically\ Connected\ Patents}_{i,t-1} + \beta_5 \mathit{Controls}\end{aligned} \tag{1}$$

$$\begin{aligned}\beta_0 &+ \beta_1 \mathit{Internationally\ Connected\ Patents}_{i,t} + \beta_2 \mathit{Internationally\ Connected\ Patents}^2_{i,t} \\ &+ \beta_3 (\mathit{Internationally\ Connected\ Patents}_{i,t} \\ &\times \mathit{Percentage\ of\ Operations, Foreign}_{i,t-1}) \\ &+ \beta_4 \mathit{Percentage\ of\ Operations, Foreign}\ (\mathit{Workforce})_{i,t-1} \\ &+ \beta_5 \mathit{Domestically\ Connected\ Patents}_{i,t} + \beta_6 \mathit{Controls}\end{aligned} \tag{2}$$

$$\begin{aligned}\beta_0 &+ \beta_1 \mathit{Domestically\ Connected\ Patents}_{i,t} + \beta_2 \mathit{Domestically\ Connected\ Patents}^2_{i,t} \\ &+ \beta_3 \mathit{Percentage\ of\ Operations, Foreign}\ (\mathit{Workforce})_{i,t-1} \\ &+ \beta_4 \mathit{Internationally\ Connected\ Patents}_{i,t} + \beta_5 \mathit{Controls}\end{aligned} \tag{3}$$

in which the level of analysis is firm *i* at time *t*.

Results

In **Table 4.1** and **Table 4.2** we provide the descriptive statistics and correlation matrix for the variables, respectively. The sample means of our dependent variable suggests that firms are twice as likely to have domestically connected patents as they are international ones. Yet, there is correlation between the two, suggesting that the ability to create linkages is a general competency, despite the differences in sources and locations. The high value of the correlation coefficients between the Internationally Connected Patents and the Domestically Connected Patents (0.83) seems to suggest that firms that foster extensive connections across their national boundaries also pursue significant knowledge linkages at home. Consistent with Rugman (2003), firms tend to have more revenue abroad than they do employees, and that headquarters and orchestration is a valuable and specialized activity unto itself (Dedrick et al, 2010). Firms are generally large, and have large patent stocks. Finally, there appears to be reasonably even representation of industries across the sample.

Our main results are presented in **Table 4.3**. All Models report a positive and significant value of the Wald statistic. In Model 1, we test *Hypothesis 1* by including both the linear and the quadratic terms for the Internationally Connected Patents. The coefficients are in line with our expectations, with the linear term being positive and significant ($p<0.01$) and the quadratic term being negative and significant ($p<0.01$). This supports our idea that international connectedness positively influences a firm’s ability to develop technology spanning innovations, but only up to a given point, after which a further increase in international knowledge linkages begins to show diminishing returns. As expected, the controls for Number of Patents and Firm Return on Assets have a positive and very significant effect on the firm’s ability to develop technology spanning innovations, representing the innovation scale and performance aspects of technological exploration. Firms that innovate more and are more profitable are also more likely to be able to span different technological areas in their innovative processes. The effects of these controls remain robust across subsequent specifications. Also Domestically Connected Patents, included to isolate the effects of the two different dimensions of connectedness, has a positive and significant effect on our dependent variable.

In Model 2, we test *Hypothesis 2* by interacting the Percentage of Workforce (foreign) variable with both the linear and the quadratic terms of our independent variable, i.e. Internationally Connected Patents. In so doing, we followed the standard procedure (Aitken & West, 1991) and mean-centered the interacting terms to reduce collinearity. As predicted by *Hypothesis 2*, the findings suggest a positive moderation: the interaction with the linear term is positive and significant ($p<0.01$). This lends support to our idea that a firm's foreign operational footprint amplifies the effects of its international knowledge connections on the exploration of new technologies.

Moving to the firm's domestic profile, in Model 3 we test *Hypothesis 3* by including both the linear and the quadratic terms for Domestically Connected Patents. Also in this case, the results are consistent with our predictions. In fact, the linear term is positive and significant ($p<0.01$) while the quadratic term is negative and significant ($p<0.01$). The control for Internationally Connected Patents as a somewhat orthogonal process has a positive and significant effect on our dependent variable. All controls remain significant.

Across all models, we sought to introduce a series of robustness checks. Specifically, we looked at alternative measures of both the dependent variable. **Table 4.4** displays all three estimations, using the category level of technology class specification from Hall et al. (2001). This is a coarser measure of technological boundaries, thus raising the benchmark level of exploration. Our core results and most controls remain entirely consistent. In unreported results, we also used the direct technology classes from the patents themselves, with little to no change in results.

With respect to the independent variables in our study, we used an alternative measure of the foreign focus of the firm, revenue, rather than employees. As with the other models, all of our hypotheses retain support. In other unreported robustness checks, we used different measures of domestic connectedness (city-spanning, vs. state) as well as the breadth of international connectedness, which was an index of dispersion that can be found in Hannigan et al. (2015). Finally, we introduced alternative industry measures, including SIC codes from *CompuStat* data. In all cases, our core theory was supported.

There was some element of concern regarding the potential for systematic differences between connected and non-connected firms, both in terms of domestic and international linkages. To mitigate against this bias, we conducted subsample tests of firms above the mean level of connectedness (on both dimensions). The results of this analysis can be found in **Table 4.5**. They show in both the international and domestic cases, the magnitude of the impact of connectedness on exploration is somewhat *diminished* relative to the full sample, suggesting that if anything, the a systematic bias is working against highly connected firms.

Discussion and Conclusions

This study sheds light on the importance of knowledge connectedness, intended as the full range of knowledge-based linkages that firms maintain across space to feed their innovation funnel. As global value chains disaggregate involving an increasing number of geographical locations, these specialize in distinct activities and tasks, and co-evolve with local firms (Cantwell et al., 2010), thereby allowing for the accumulation of technological knowledge and expertise (Mudambi 2008). Knowledge is ubiquitous, but its recombination across space requires conduits and collaborative relationships.

Co-location is an effective means to reach out for geographically dispersed tacit knowledge (Audretsch & Feldman, 1996; Jaffe et al., 1993). Yet, as we argue in the paper, it is not the only one. Firms may build and leverage a widespread web of connections in order to create bridges that take tacit knowledge out of space, and allow for the emergence of new ideas that combine geographically dispersed bodies of technological knowledge. Traditionally recognized as the most privileged actors for overcoming the barriers to knowledge transfer across geographical space through their capacity to establish their subsidiaries in worldwide centers of excellence, MNEs do not lose their “primacy” in the renewed scenario of knowledge connectedness that this and other (Hannigan et al 2015; Giuliani et al, 2015) studies depict. Rather, MNEs emerge as the key actors in the orchestration of geographically dispersed linkages (Dedrick et al, 2010) that carry tacit knowledge for the development of technology spanning innovation. This is especially true in light of MNEs’ established experience and capabilities in managing geographical distances to gain access to world-in-class technology (Cantwell and Santangelo, 1999).

In this chapter, we have developed a theory of connectedness in knowledge creation. We argue that connectedness falls along two dimensions – domestic and foreign. In fact, as regions within countries are heterogeneous in their patterns of technological specialization (Beugelsdijk and Mudambi, 2013) and sub-national entities such as cities increasingly play key roles as centers of knowledge creation (Iammarino and McCann, 2013), firms establish their knowledge conduits both within and across their national boundaries to enhance the variety of their knowledge base. Moreover, building on the interactive view of learning and innovation (Rosenberg, 1982; von Hippel, 1988; Lundvall, 1992) and on research highlighting that the transfer of tacit knowledge requires different types of proximity (Boschma 2005; Amin and Cohendet, 2004;2005), we add that the effectiveness of knowledge collaboration across space can be magnified by the other networks that firms establish upon locations, i.e. operational networks. Operational footprint creates the bandwidth for greater knowledge sharing and collaboration, and complement scientific and technological knowledge with more applied information. In other words, places need to be truly connected along different dimensions to make sure that knowledge embedded in different places can be effectively recombined to give rise to complex, technology spanning innovation.

This chapter uses USPTO and CompuStat data to test the relationship between connectedness and the ability to develop complex innovation, which we operationalize as boundary-spanning patents. Testing our hypotheses on data on 506 large firms over the period 1980-2006, we find strong support for all our predictions.

As with all research, this study is not without its shortcomings. One limitation of this paper is that we do not specify the geographical distance between the ties of knowledge connections. In other words, we are not able to account for the differences between knowledge connections between the US and China and knowledge connections between the US and Canada. In future studies, scholars could better investigate the characteristics of cross-spatial connections. Moreover, a better depiction of the geographical spread of firms' operational network could help us to understand what are the effects of a closer overlap with the geographical breadth of knowledge-based connections. In other words, while we have explored the impact of connectedness, and exploration of connectivity, the qualitative characteristics of linkages (Lorenzen & Mudambi, 2013), would add greater insights to the innovative impacts we explore. Furthermore, more insights should be offered on the role of other types of proximity (social, cognitive, institutional) that may expedite the effective integration of geographically separated pieces of knowledge (Boschma 2005). Finally, we acknowledge that further mitigation of the potential endogeneity of connected firms could be achieved using a Heckman model, should an adequate instrument be devised. We leave that to further research in this area. Likewise, international and domestic connections may be either complements or substitutes. Future studies may subsample those groups to examine different effects.

Connectedness is in part a product of our changing world. However, it is increasingly clear that firms are differentially connected with their value chain networks, and the broader environments around them. This chapter is key to point out that international connectedness is not the answer for innovative firms. Indeed, firms must carefully examine their own complementary organizational elements, and scale growth in connectedness appropriately. Ultimately, the pursuit of ideas, wherever they are in the world, is a worthwhile pursuit.

Tables

Table 4.1: Variable Descriptions & Summary Statistics

Variables	**Mean**	**S.D.**
Subcategory-Spanning Patents	20.68	53.66
Internationally Connected Patents	2.273	9.016
Domestically Connected Patents: State	4.782	20.541
Percentage of Inventors in HQ City	0.302	0.333
Percentage of Workforce: Foreign	0.017	0.110
Percentage of Revenue: Foreign	0.152	0.279
Number of Patents (Cumulative)	22,811	9,271
Firm Total Revenue (Millions, USD)	8,090	17,822
Firm Total Workforce (Thousands)	38.988	72.634
Firm Return on Assets	0.048	0.120
Firm Leverage	0.732	7.901
Industry Share: Chemicals	0.236	0.304
Industry Share: Computers and Communications	0.206	0.324
Industry Share: Drugs	0.099	0.246
Industry Share: Electrical	0.189	0.259
Industry Share: Mechanical	0.237	0.288

Table 4.2: Correlation Matrix

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	*Subcategory-Spanning Patents*	1.00															
2	*Internationally Connected Patents*	0.78	1.00														
3	*Domestically Connected Patents: State*	0.75	0.83	1.00													
4	*Percentage of Workforce: Foreign*	0.04	0.02	0.02	1.00												
5	*Percentage of Revenue: Foreign*	0.04	0.10	0.07	0.29	1.00											
6	*Percentage of Inventors in HQ City*	0.01	0.01	0.08	0.01	0.04	1.00										
7	*Number of Patents (Cumulative)*	0.12	0.18	0.13	0.02	0.02	0.02	1.00									
8	*Firm Total Revenue (Millions, USD)*	0.41	0.35	0.30	0.03	0.04	-0.02	0.04	1.00								
9	*Firm Total Workforce (Thousands)*	0.46	0.25	0.26	0.03	0.02	-0.03	-0.02	0.72	1.00							
10	*Firm Return on Assets*	0.02	0.01	0.01	0.00	0.02	0.02	-0.06	0.02	0.00	1.00						
11	*Firm Leverage*	0.02	0.01	0.00	0.01	-0.02	0.00	0.02	0.05	0.03	-0.01	1.00					
12	*Industry Share: Chemicals*	0.01	0.01	0.02	-0.02	0.02	0.02	-0.06	0.03	-0.05	0.00	-0.01	1.00				
13	*Industry Share: Computers and Communications*	0.10	0.08	0.08	0.01	-0.01	0.09	0.16	0.01	0.01	-0.04	0.01	-0.39	1.00			
14	*Industry Share: Drugs*	-0.01	0.04	0.02	0.00	0.02	0.04	-0.05	-0.06	-0.08	0.05	-0.01	0.17	-0.23	1.00		
15	*Industry Share: Electrical*	0.14	0.05	0.04	0.02	0.06	0.01	-0.07	0.01	0.06	-0.01	0.01	-0.29	0.11	-0.21	1.00	
16	*Industry Share: Mechanical*	-0.04	-0.07	-0.06	0.02	-0.03	-0.11	-0.10	0.03	0.08	-0.05	0.01	-0.18	-0.26	-0.23	-0.11	1.00

Table 4.3: Primary Estimations (Random Effects Negative Binomial)

DV: Boundary Spanning Patents (Subcategory)	**(1)**	**(2)**	**(3)**
Internationally Connected Patents	0.035***	0.032***	0.011***
	(12.04)	(15.74)	(8.09)
Internationally Connected Patents (Squared)	-2.72x10^{-4***}	-2.23x10^{-4***}	
	(-7.46)	(-12.55)	
Int Connected Patents x % of SALES: Foreign (lag)		0.004***	
		(2.53)	
Domestically Connected Patents: State	0.007***	0.008***	0.015***
	(13.05)	(13.55)	(19.49)
Domestically Connected Patents: State (Sq)			-2.78x10^{-5***}
			(-15.81)
Percentage of Employees: Foreign (lag)	0.146**	0.136*	0.166**
	(1.97)	(1.83)	(2.25)
Percent Inventors in HQ City	-0.073	-0.074	-0.075
	(-1.52)	(-1.56)	(-1.57)
Number of Patents (Cumulative, lag)	0.410***	0.415***	0.440***
	(17.21)	(17.82)	(19.12)
Firm Size (Firm Total Revenue, lag)	-9.53x10^{-6***}	-9.12x10^{-6***}	-8.32x10^{-6***}
	(-9.95)	(-9.74)	(-9.07)
Firm Return on Assets (lag)	0.417***	0.428***	0.436***
	(4.65)	(4.78)	(4.87)
Firm Leverage (lag)	3.15x10^{-4}	3.13x10^{-4}	2.43x10^{-4}
	(0.32)	(0.32)	(0.24)
Constant	-3.886***	-3.933***	-4.167***
	(-15.84)	(-16.34)	(-17.54)
Industry Controls	Y	Y	Y
Firm-Year Observations	6852	6852	6852
Number of Firms	506	506	506
Wald Chi-Sq	2331.68***	2384.36***	2471.84***

Standard errors in parentheses*** $p<0.01$, ** $p<0.05$, * $p<0.10$

Table 4.4: Robustness Check, Alternate Specification of Boundary Spanning (Category)

DV: Boundary Spanning Patents (Subcategory)	**(1)**	**(2)**	**(3)**
Internationally Connected Patents	0.034***	0.031***	0.010***
	(12.53)	(13.31)	(7.27)
Internationally Connected Patents (Squared)	$-2.79x10^{-4***}$	$-2.40x10^{-4***}$	
	(-8.26)	(-10.24)	
Int Connected Patents x % of Employees: Foreign (lag)		0.003*	
		(1.75)	
Domestically Connected Patents: State	0.008***	0.008***	0.015***
	(13.28)	(13.54)	(18.20)
Domestically Connected Patents: State (Sq)			$-2.88x10^{-5***}$
			(-14.02)
Percentage of Employees: Foreign (lag)	0.119**	0.110	0.150*
	(1.56)	(1.44)	(1.94)
Percent Inventors in HQ City	-0.130**	-0.131**	-0.136***
	(-2.45)	(-2.50)	(-2.59)
Number of Patents (Cumulative, lag)	0.420***	0.423***	0.450***
	(16.67)	(17.20)	(18.64)
Firm Size (Firm Total Revenue, lag)	$-9.17x10^{-6***}$	$-8.83x10^{-6***}$	$-8.06x10^{-6***}$
	(-9.44)	(-9.14)	(-8.58)
Firm Return on Assets (lag)	0.394***	0.407***	0.421***
	(4.01)	(4.14)	(4.29)
Firm Leverage (lag)	$1.62x10^{-4}$	$1.60x10^{-4}$	$7.70x10^{-5}$
	(0.17)	(0.17)	(0.08)
Constant	-4.232***	-4.284***	-4.544***
	(-16.39)	(-16.84)	(-18.15)
Industry Controls	Y	Y	Y
Firm-Year Observations	6852	6852	6852
Number of Firms	506	506	506
Wald Chi-Sq	2335.60	2388.21***	2450.27***

Standard errors in parentheses*** p<0.01, ** p<0.05, * p<0.10

Table 4.5: Robustness Check, High Connected Subsamples

DV: Boundary Spanning Patents (Subcategory)	**Base Model (Int Connected)**	**High Int Connected Subset**	**Base Model (Dom Connected)**	**High Dom Connected Subset**
Internationally Connected Patents	0.032***	0.024***	0.011***	0.008***
	(15.74)	(15.41)	(8.09)	(6.56)
Internationally Connected Patents (Squared)	-2.23x10^{-4***}	-1.23x10^{-4***}		
	(-12.55)	(-10.67)		
Int Connected Patents x % of Employees: Foreign (lag)	0.004***	0.003***		
	(2.53)	(2.90)		
Domestically Connected Patents: State	0.008***	0.005***	0.015***	0.010***
	(13.55)	(7.95)	(19.49)	(15.11)
Domestically Connected Patents: State (Sq)			-2.78x10^{-5***}	-1.49x10^{-5***}
			(-15.81)	(-15.20)
Percentage of Employees: Foreign (lag)	0.136*	0.167**	0.166**	0.084
	(1.83)	(1.98)	(2.25)	(0.91)
Percent Inventors in HQ City	-0.074	-0.110	-0.075	-0.486***
	(-1.56)	(-1.02)	(-1.57)	(-3.96)
Number of Patents (Cumulative, lag)	0.415***	0.094**	0.440***	-0.035
	(17.82)	(2.29)	(19.12)	(-0.71)
Firm Size (Firm Total Revenue, lag)	-9.12x10^{-6***}	-8.02x10^{-6***}	-8.32x10^{-6***}	-5.77x10^{-6***}
	(-9.74)	(-8.20)	(-9.07)	(-6.04)
Firm Return on Assets (lag)	0.428***	0.320***	0.436***	0.384**
	(4.78)	(2.28)	(4.87)	(2.50)
Firm Leverage (lag)	3.13x10^{-4}	0.002	2.43x10^{-4}	0.002
	(0.32)	(1.33)	(0.24)	(1.59)
Constant	-3.933***	-0.192	-4.167***	1.562***
	(-16.34)	(-0.43)	(-17.54)	(3.00)
Industry Controls	Y	Y	Y	Y
Firm-Year Observations	6852	1689	6852	1031
Number of Firms	506	226	506	143
Wald Chi-Sq	2384.36***	958.92***	2471.84***	911.99***

Standard errors in parentheses*** p<0.01, ** p<0.05, * p<0.10

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