Ties that Bind: A Network Perspective on University Spinouts

Patrick McHugh

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Ties that Bind: A Network Perspective on University Spinouts

Dissertation
PhD in Business
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ABSTRACT

Research universities execute technology transfer initiatives to transition university inventions to marketplace innovations. This process requires ties to bridge the gap between two disparate networks: a university’s research community and a licensing corporate entity. One type of licensing corporate entity, and the focus of this research, is a newly formed university spinout. Utilizing a network lens, this study focuses on the ties between university inventors and spinout licensees and on the impact of various inter-organizational relationships on a spinout’s success. This thesis investigates the following research questions: 1. How, if at all, does variation in the nature of the tie between the university inventor(s) and a spinout impact the new firm’s ability to raise venture funding and what are the implications for network theory? 2. How, if at all, does a university inventor’s participation with a university spinout impact his/her research publication and invention productivity and what are the implications for academic productivity models? and 3. How, if at all, do early-stage spinout networks evolve prior to raising venture funding? Our research findings indicate that: 1. Early-stage venture investors view spinout ties to either the inventor or to their research network as “outcome equivalent” when making investment decisions. 2. The impact of inventor-spinout tie strength variation can only be properly interpreted within the context of the spinout’s overall ties to the university inventor’s research network. 3. Faculty involvement with university spinouts does not substantially impact their publishing productivity. 4. The involvement of faculty with physically proximate spinouts has a positive impact on their academic productivity. 5. The involvement of faculty with multiple spinouts simultaneously has a negative impact on their academic productivity. 6. Early-stage university spinout inter-organizational networks are not dense and their network dynamics are highly constrained. 7. Early-stage pre-VC funded networks...
establish strong ties with technical nodes. And 8. Venture capital funders geographically cluster around licensing universities. These findings contribute to network theory in the following ways. This thesis identifies the concept of “outcome equivalence” as a critical construct for comparison of tie impact in heterogeneous networks. It determines that effective tie strength is contingent upon the nature of the networks being bridged. It suggests that in complex networks scale and proximity can change the impact of moderating elements on productivity outcomes. Finally it identifies the highly constrained network dynamics of early-stage networks where change occurs sporadically during periods of punctuated equilibrium driven by node fitness improvements.
CHAPTER 1: INTRODUCTION

The traditional mission of the university is teaching, basic research, and knowledge dissemination (Siegel, Waldman et al. 2003; Markman, Gianiodis et al. 2004). Knowledge dissemination may be operationalized by university researchers in many ways including publishing, speaking engagements and academic entrepreneurship (Louis, Blumenthal et al. 1989). Louis et. al. (1989) suggest the following five types of academic entrepreneurship: engaging in externally funded research, external consulting, obtaining industry support for university research, generating patents/trade secrets and forming or holding equity in spinout companies based on a faculty member’s own research. Spinout companies are start-ups established to exploit a market opportunity enabled by a university’s intellectual property (Steffensen, Rogers et al. 2000; Zhang 2009) and are the focus of this study.

This research investigates the following research questions relative to university spinout success: 1. How, if at all, does variation in the nature of the tie between the university inventor(s) and a spinout impact the new firm’s ability to raise venture funding and what are the implications for network theory? 2. How, if at all, does a university inventor’s participation with a university spinout impact their research publication and invention productivity and what are the implications for academic productivity models? and 3. How, if at all, do early-stage spinout network’s evolve prior to raising venture funding?

Studying these questions via a network theoretic lens advances our theoretical understanding of the contingent nature of a network tie’s impacts. This research focuses on how network structure, tie characteristics, and temporal considerations impact university inventors and spinouts. From a policy perspective increasing our understanding of these issues can enable universities to establish policies to enhance inventor and spinout performance, increasing
revenue and prestige for the university and enhancing the economic impact of university technology transfer efforts.

Start-up firms are critical to the U.S. economy. The National Venture Capital Association notes that venture–backed start-ups employed 11% of private sector workers and had revenues representing 21% of U.S. GDP in 2008 (NVCA 2009). High technology activity, much of it start-up related, is estimated to account for 65% of the difference in economic growth among U.S. metropolitan regions (Cole 2009).

Universities are active participants in this phenomenon. A survey by the Association of University Technology Managers (AUTM) notes that in 2008 595 new companies were established to exploit university research and that 3,381 university start-ups were in operation as of the end of that year (AUTM 2009). The formation of start-up companies by university affiliated entrepreneurs and university licensing to young, unproven firms is a growing trend (Steffensen, Rogers et al. 2000). Certain universities are particularly active start-up “engines”. As examples, an analysis of AUTM’s STATT database for the period 1996 to 2008 shows that MIT and Stanford were involved with 264 and 127 start-ups respectively. Universities with higher levels of industry R&D funding, higher “quality” faculty, and situated in regions with a higher density of venture capitalists were found to be more likely to engage in start-up formation (Powers 2003; Powers and McDougall 2005). University policies on equity investing and inventor’s royalty share were also found material to firm formation levels (De Gregorio and Shane 2003).

Based on a survey of 57 technology transfer offices (TTO) in the UK it was found that universities generating the most spinouts had more favorable attitudes towards surrogate entrepreneurs (professional managers brought in from outside the university to run the spinout firm), superior networks that might be useful to the new firm, and distributed equity ownership
in the new firm more widely (Franklin, Wright et al. 2001; Lockett, Wright et al. 2003). University expenditure on intellectual property protection and the business development capabilities of the TTO were also found to be positively associated with these spinout initiatives (Lockett and Wright 2005).

This study focuses specifically on university spinouts using the definition of a spinout as a start-up firm that involves the transfer of a core technology from an academic institution into a new company whose founding member(s) may include the academic inventor(s) who may or may not be currently affiliated with the academic institution (Nicolaou and Birley 2003). The study utilizes a spinout’s ability to raise venture capital as its firm level success measure and dependent variable in the study of outcome equivalence versus the more common research focus on volume of university spinouts taken in other university focused studies (Lockett and Wright 2005). The study’s analysis of university inventor productivity utilizes productivity measures of invention and publishing commonly applied in other research studies to discern the specific impact of university spinout involvement (Blumenthal, Gluck et al. 1986; Siegel, Waldman et al. 2004; Gurmu, Black et al. 2010). The analysis of the spinout’s inter-organizational network applies network theory to inform our understanding of these early-stage networks.

Spinouts provide a vehicle for the commercialization of early stage university intellectual property (Thursby, Jensen et al. 2001). Much university research is embryonic and requires significant effort to commercialize making it less attractive for licensing by larger firms since these firms may not have the know-how or tacit knowledge to undertake the required technology development activities (Vohora, Wright et al. 2004). More radical, risky technologies in dynamic knowledge-intensive industries require new venture investment to drive their commercialization (Lowe 2002; Shane 2004; Vohora, Wright et al. 2004). Disruptive
technologies that can negatively impact existing business models are also less likely to be commercialized by current industry players (Christensen 1997).

Equity investments in spinout licensees offer universities the potential for significant economic upside and flexibility in deal structure (Bray and Lee 2000). The intrinsic value of equity, even should the university technology be replaced, is an additional consideration (Bray and Lee 2000). Equity holdings may also align university–firm interests and increase external prestige and legitimacy for the university (Feldman, Feller et al. 2002). High-profile spinout successes such as Lycos from Carnegie Mellon University and Silicon Graphics and Genentech from Stanford University are visible reminders of the potential upside in terms of visibility and return from these holdings (Hayter 2010). Employing data from a national survey of Carnegie I and Carnegie II academic institutions, it was found that by 2000 70% of universities that responded had participated in at least one license for equity deal (Feldman, Feller et al. 2002).

While visible, high profile successes such as those referenced above are unusual, university spinouts do demonstrate extremely robust survival rates (Lowe 2002; Pressman 2002; Zhang 2009) and are highly successful at attracting early-stage angel or venture capital (Shane 2004). Relative to levels of capital invested, probability of executing an initial public offering, probability of making a profit and levels of employment, university spinouts have been found to behave similarly to other start-up firms (Zhang 2009).

Innovation involves several distinct stages including idea generation, selection, development, and ultimately diffusion, when an innovation spreads into the marketplace (Hansen and Birkinshaw 2007). With university-based spinouts, technology idea generation is typically performed by university inventors while the selection, development, and diffusion stages are typically addressed by the newly formed spinout network. This study focuses on the ties necessary for technology knowledge transfer between the university inventors and the spinout
licensees and on the establishment of other critical heterogeneous relationships necessary for spinout success. While much research has shown how university spinouts and traditional start-ups are similar in terms of problems encountered (Doutriaux 1987), success rates (Lowe and Ziedonis 2006), and the challenges of achieving financial sustainability (Vohora, Wright et al. 2004) this research focuses on the unique early-stage networking considerations of university spinouts. These networking considerations are driven by the spinout’s need to establish formal relationships with the licensing university, to build ties to access the university inventor’s knowledge, and to access capital, despite the usually embryonic nature of the licensed intellectual property, in order to build out their inter-organizational networks to further develop and commercialize their product offering.

Network perspectives, as used in this paper, have commonly been applied to inter-organizational knowledge transfer research (Hansen 1999; Reagans and Zuckerman 2001; Levin and Cross 2004; Zaheer, Gozubuyuk et al. 2010) and at times directed to university innovation research (Nicolaou and Birley 2003) and start-up analysis (Ferrary and Granovetter 2009). The network perspective is relational and views the world from a structural perspective (Gulati, Nohria et al. 2000). Network theory views the structure, strength and content of ties between interacting nodes as critical to firm performance (Zaheer, Gozubuyuk et al. 2010). Organizations are perceived as both empowered and constrained by the nature of their existing ties (Zaheer and Bell 2005).

This paper draws on the literature analyzing network ties, university technology transfer, start-up network characteristics, and venture capital firm’s investment criteria to address the following research questions: 1. How, if at all, does variation in the nature of the tie between the university inventor(s) and a spinout impact the new firm’s ability to raise venture funding and what are the implications for network theory? 2. How, if at all, does a university inventor’s
participation with a university spinout impact his/her research publication and invention productivity and what are the implications for academic productivity models? and 3. How, if at all, do early-stage spinout network’s evolve prior to raising venture funding?

The examination of these questions is used to inform network theory, contributing to the theoretical network research literature in the following four areas: 1. proposes the concept of “outcome equivalence” as a critical construct for comparison of tie impact in heterogeneous networks; 2. determines that effective tie strength is contingent upon the nature of the networks being bridged; 3. examines issues of node contingency, i.e. how a tie’s impact is contingent upon the connecting node characteristics; and 4. identifies the constrained dynamics of early-stage spinout networks.

This analysis is distinct for several reasons. Most university innovation studies focus on patenting and licensing activities to established firms with few studies directed to university spinout research (Shane 2004), with some exceptions (Nicolaou and Birley 2003; Lockett and Wright 2005; Hayter 2010). Also, many university innovation studies apply a Resource Based View of the firm to their analysis (Lockett and Wright 2005) versus a network perspective. When the extant literature does apply a network lens it is typically conducted at the macro (i.e. entire patent database) level of analysis (Clements 2008) versus collecting and analyzing primary-source data from university spinouts as applied in this study (Shane 2004; Hayter 2010). This research responds to calls for further exploration of the network structure of links between university scientists and firms (Fabrizio 2009) and the need to better understand university spinouts in general and the role of academic entrepreneurs in the context of entrepreneurial networks (Hayter 2010).

Researchers have suggested that participants may find strong ties costly to maintain (Hansen 1999) and that maintaining such ties can lead to opportunity costs (Burt 1992). For
early-stage spinouts with limited resources these costs could potentially have a material impact on their performance. This line of inquiry is unique; only recently have network scholars in general begun to focus on whole networks and few studies consider the trade-offs emanating from the negative consequences of network membership (Zaheer, Gozubuyuk et al. 2010).

From a practical perspective this research notes the importance of careful consideration of a spinout’s development stage in order to optimally manage network tie development and avoid expending effort on ties that will provide limited or no contribution to the firm in the near term. Consideration of the structure of the networks one plans to bridge can also facilitate optimizing the nature of the ties established.

The following section provides a literature review relevant to building an understanding of the establishment and functioning of complex networks in early-stage university spinouts and of the impact of various inventor/spinout network relationships on spinout performance. The first sections introduce theory and prior research on start-up inter-organizational networks and identify a definition of spinout success used as the dependent variable in our initial analysis, the spinout’s closure of a venture capital funding round. As context for this dependent variable, the research literature on venture capital funding criteria is next reviewed. This is followed by an introduction to network theory including considerations of node fitness, structural holes and tie strength. Next the review takes a focused lens to the nature of inventor-spinout ties and to the typology of potential network structures being bridged. The review then proceeds to consider the nature of later-stage, post VC-funded, inter-organizational networks. This literature is applied to derive hypotheses related to the contingent effect of connected node and tie characteristics, the impact of these ties on university inventor performance, and the characteristics of the early-stage spinout’s complete inter-organizational network.
This review is followed by three distinct sections focused on the study of outcome equivalent ties, spinout involvement and academic productivity, and the early-stage spinout’s inter-organizational network. These sections include a description of the data collection and analytic methods used for the analysis of the respective hypotheses. Finally, the results of the research findings are presented followed by discussion and conclusions on the broader implications suggested by these findings and their potential implications for practice.
CHAPTER 2: THEORETICAL FRAMEWORK AND LITERATURE REVIEW

The Oxford English Dictionary defines innovation as “a new method, idea [or] process” and as the “the action or process of innovating.” The former element of this definition focuses on innovation as an output while the latter focuses on innovation as a process. It is this process definition which is the focus of this study.

Innovation research suggests six main stages to the innovation process: 1. need/problem identification, 2. research (basic and applied), 3. development, 4. commercialization, 5. diffusion and adoption and 6. consequences (Rogers 2003). Other research has defined the process as one of idea generation, conversion and diffusion (Hansen and Birkinshaw 2007) while others still have described the process as one of discovery, incubation and acceleration with different competencies required at each phase (O'Connor, Corbett et al. 2009). While these linear innovation process models are simplified representations of a more complex and iterative reality they are useful for framing innovation discussions. For example, university spinout innovation can be conceptualized within these innovation frameworks with university research networks driving technology idea generation; spinouts, leveraging university research, driving conversion; and the spinout’s network driving diffusion as illustrated in figure 1. Innovation involves numerous inter- and intra-organizational relationships and agents (Ferrary and Granovetter 2009).

A number of measures have been identified which enable us to validate process stage advancement and to compare the relative performance of spinouts at any given stage. The following section opens with a review of these start-up success measures identified in the research literature and suggests a success measure, venture capital funding, to use as a dependent variable to support the analysis of our initial research hypotheses. The literature review next
progresses to consider research focused on venture capitalist’s funding criteria. Here we discern what is important to the VC funding decision to help inform our understanding of potential contributions from the spinout’s inter-organizational network. This is followed with sections establishing a research foundation in network theory and providing a review of studies focused specifically on spinouts’ inter-organizational networks. Next, research on the role of venture capital firms in facilitating a start-up’s network development and ultimate success are discussed. This knowledge is used to inform our analysis of early-stage spinout networks. The review then considers the research literature focused on tie strength as a foundation for our consideration of the nature of the inventor-spinout dyad. From this literature review our hypotheses are derived.

**Spinout success**

To enable the study of university spinout performance the research literature has utilized numerous definitions of spinout “success.” Success measures studied include: firm survival (Shane and Stuart 2002; Shane 2004; Leitch and Harrison 2005; Rothaermel and Thursby 2005); financial measures such as profitability or sales growth (Roberts 1991; Samson and Gurdon 1993); academic agenda measures such as improved peer recognition (Samson and Gurdon 1993; Meyer 2003; O’Gorman, Byrne et al. 2008); production measures such as the number of patents or papers produced (Zucker 2002); and achievement of defined milestones such as completing an initial public offering (Goldfarb and Henrekson 2003; Shane 2004), acquiring certain resources
or capabilities to pass through “critical junctures” (Vohora, Wright et al. 2004) and receiving external, especially venture capital, funding (Shane and Stuart 2002; Zucker 2002; Lockett and Wright 2005; Wright, Clarysse et al. 2006).

The focus of this research effort is on the nature and impact of early-stage spinout networks. Given this early-venture focus certain longer term success measures, such as firm survival, sales levels and growth, and completing an initial public offering (IPO), used in other research studies are not applicable to this effort. The firm-level focus of many of our hypotheses similarly precludes using many of the university-inventor-centered success measures such as papers published or patents filed, although these measures will prove useful for a subset of our hypotheses focused on the university inventor as the node of interest. These constraints focus our selection of firm-level success measures to one of the remaining milestone achievements, such as Vohora et al’s “critical junctures” (2004) or the raising of external funds (Shane and Stuart 2002; Zucker 2002; Lockett and Wright 2005; Wright, Clarysse et al. 2006). We examine these measures in the next section.

Venture capital funding as a success measure

Vohora (2004) defined his critical junctures as opportunity recognition, entrepreneurial commitment, credibility and sustainability. Closing a venture capital funding round can signal the passage of several of these critical stages. Raising venture capital demonstrates that a firm has been successfully evaluated by one or several venture capital firms in order to receive its funding. Via a survey of 100 venture capitalists the following criteria were rated as essential characteristics for an entrepreneurial entity to receive funding: that the entrepreneur is capable of sustained intense effort, is thoroughly familiar with the market, has demonstrated leadership in the past, evaluates and reacts well to risk and has a track record relevant to the venture; that the business opportunity suggests significant market growth opportunity, has the potential for a
10X return on capital within 5 to 10 years of investment and that the investment can be made liquid if necessary; and that the opportunity can be easily communicated and that proprietary protection exists for critical firm assets (MacMillan, Siegel et al. 1985).

These venture capital criteria can be mapped to Vohora’s critical junctures, with the closing of the venture funding round demonstrating the VC firm’s belief that the entrepreneur is committed and that the opportunity is both credible and financially promising. Raising venture capital also improves the firm’s sustainability, at least within the limitations of the firm’s capital infusion and burn-rate. The measurable nature of VC funding and its external validation of spinout achievement led to its selection as the dependent variable measurement in the initial study.

It is important to note however that venture capital is not always a necessary step for commercialization. In a recent survey of 117 university spinouts 36% managed to commercialize their technologies with no VC funding (Hayter 2010); however, entrepreneurial finance does serve as a catalyst for firm growth (Wright, Clarysse et al. 2006) and the raising of venture funding increases the likelihood of a firm’s ultimate commercial success (Ferrary and Granovetter 2009; Hayter 2010). As we will see in the following section, commercial viability is only one of several critical considerations to a venture funding evaluation. Venture capitalists consider a broad array of spinout characteristics when considering an investment, a factor leveraged in the design of our initial study. Our studies of academic productivity and early-stage networks consider all university spinouts in their analysis.

**Venture Capitalists’ funding criteria**

Given the definition of our firm-level dependent variable, early stage spinout success, as the firm’s readiness for a venture capital funding round it becomes important to consider the criteria applied by venture capitalists in making these funding decisions. While venture
capitalists can and do get involved in funding opportunities with companies at all stages of
development their average deal size of $2 million to $10 million per transaction make them more
likely sources of capital during a start-up’s second or third funding round when a company’s
funding needs are greater (DeClercq, Fried et al. 2006). In a study of 110 MIT spinouts it was
observed that only 7% of these firms received their initial funding from venture capital sources; a
number which increased to 13% during the firm’s second funding round (Roberts 1991). Second
round funding is quite common for start-ups. The majority of start-ups active in hardware
manufacture or mixed business models (combinations of hardware, software and contract
development) were observed to receive later round financing (Roberts 1991). If venture
capitalists tend to invest more frequently in on-going firms rather than initial start-ups it becomes
important for an early stage company to “invest” wisely to become more attractive to the VC at
these later investment stages.

The research literature notes numerous criteria considered by venture capitalists in
making their investment decisions. These range from high level constructs such as Hisrich and
Jankowicz’s three criteria: concept, management and returns, to very specific recommendations
such as Hall and Hofer’s identification of attorneys as key referral sources (Hisrich and
Jankowicz 1990; Hall and Hofer 1993).

High level constructs vary by study although there is significant overlap between the
various categorizations. Hisrich and Jankowicz suggest a criteria of concept, management and
returns as noted above (Hisrich and Jankowicz 1990). Using factor analysis, Tyebjee and Bruno
compressed venture capitalists’ ratings of funding opportunities based on 23 characteristics into
five underlying dimensions: market attractiveness (size, growth and customer access), product
differentiation (uniqueness, patents, technical edge and potential profitability), managerial
capabilities (skills in marketing, management and finance), environmental threat resistance
(technology life cycle, barriers to entry, business cycle resilience, and down-side risk protection) and cash-out potential (future capital gains via M&A or IPO) (Tyebjee and Bruno 1984). In their review of several earlier research studies on venture capital decision making Zacharakis and Meyer categorized these study findings as: entrepreneurial/team characteristics, product/service characteristics, market characteristics, and financial characteristics (Zacharakis and Meyer 2000). In a similar categorization of prior study findings, venture capital criteria were captured under: VC firm requirements, characteristics of the proposal, characteristics of the entrepreneur/team, nature of the proposed business, economic environment of the proposed industry, and business strategy (Hall and Hofer 1993).

Several studies have leveraged these high level decision criteria to identify specific considerations of the venture capitalists in their funding evaluation. Under market considerations these include: competitive advantage, stable success factors, timing of market entry, level of competition, ability to educate the market on new offering, market size, market growth, and non-competitive industry (Wells 1974; Poindexter 1976; Tyebjee and Bruno 1984; MacMillan, Siegel et al. 1985; MacMillan, Zemann et al. 1987; Robinson 1987; Hall and Hofer 1993; Shepherd 1999; Shepherd 1999).

Product considerations were also prominent in many studies. These included having a working product or prototype, having demonstrated product success, having differentiated product attributes or capabilities, having proprietary elements to the product such as patents, having the ability to establish excellent gross profit margins, having the ability to get the product to market in a reasonable time frame and having a broad product scope (Wells 1974; Tyebjee and Bruno 1984; MacMillan, Siegel et al. 1985; Khan 1987; MacMillan, Zemann et al. 1987; Roberts 1991; Fried and Hisrich 1994; Shepherd 1999; Shepherd 1999).
Numerous management considerations have been prominently identified in the research literature. As noted by Riquelme and Rickards (1992), management experience was the one criteria in their study that all the venture capitalists surveyed agreed upon as critical. Specific issues under management considerations include having a group of two or three founders versus a single individual, having a founder with technical and business experience, having managers with an equity stake in the firm, having managers with an entrepreneurial personality and having a management team with industry competence and experience (Wells 1974; Poindexter 1976; Tyebjee and Bruno 1984; MacMillan, Siegel et al. 1985; Khan 1987; MacMillan, Zemann et al. 1987; Robinson 1987; Roberts 1991; Riquelme and Rickards 1992; Hall and Hofer 1993; Shepherd 1999; Shepherd 1999). In addition specific individual characteristics highlighted included personal integrity, good performance, realistic, hardworking, flexible, thorough understanding of the business, and excellent general management experience (Fried and Hisrich 1994).

Financial and strategic considerations are also important to the venture capital community. These range from having a realistic business plan (Roberts 1991) to earnings growth potential, high rate and absolute rate of returns, exit potential, size of investment, and equity allocation (Wells 1974; Poindexter 1976; Tyebjee and Bruno 1984; MacMillan, Siegel et al. 1985; Hall and Hofer 1993; Fried and Hisrich 1994).

Relative significance of various criteria

As noted, the venture capital research literature has identified a list of important criteria considered by the venture community in their evaluations of start-up funding opportunities. While these criteria have been found significant in these research studies the relative importance of each characteristic is not clear. Fortunately a number of studies have investigated this issue and research has found that venture capitalists’ actual decision criteria explain more variance in
new venture performance than do “espoused” policies (Zacharakis and Meyer 1998) and different venture firms place different weights on potential funding criteria (Riquelme and Rickards 1992). As an example, via a conjoint analysis, Shepherd (1999) determined that the top priority considerations of venture firms when evaluating investment opportunities were the team’s industry competence, competition, timing of market entry, and the ability to educate the market to accept the new company’s product.

In addition, many of the criteria important to venture firms cannot be addressed by the start-up. For example, venture firms have investment criteria that, by definition, make them either a good or bad potential source of capital for the specific start-up firm. These include geographic location considerations (Tyebjee and Bruno 1984; Roberts 1991; DeClercq, Fried et al. 2006), market or technology focus (Tyebjee and Bruno 1984), and size of investment guidelines (Poindexter 1976; Tyebjee and Bruno 1984; Roberts 1991; Hall and Hofer 1993). Different venture funds also apply different hurdles relative to acceptable levels of long term growth and profitability of the industries they invest in (Hall and Hofer 1993).

There are however many venture capital funding decision criteria that the firm seeking financing can impact through their actions. These include issues of product differentiation (Tyebjee and Bruno 1984) and product uniqueness (Wells 1974; MacMillan, Siegel et al. 1985; MacMillan, Zemann et al. 1987). Expected returns for a venture fund have been found to be strongly influenced by their investment’s product market attractiveness (Tyebjee and Bruno 1984) which makes this a key consideration in a venture capitalists’ investment assessment.

Another concern of venture firms is fund risk which has been shown to be influenced by the investment’s management capabilities and the firm’s environmental threats (Tyebjee and Bruno 1984). Addressing the makeup of the start-up’s senior management team can, at a minimum, impact these management concerns.
Venture capital investment models

As suggested above, the path to a venture capital funding round can be quite complex and several researchers have attempted to model this process. These models include a path from deal origination to deal screening, to deal evaluation, and ultimately to deal structuring (Tyebjee and Bruno 1984; DeClercq, Fried et al. 2006). A similar model includes Fried and Hisrich’s (1998) five step process flow from search, to screening, to evaluation, to deal structuring, and to firm funding. A third model proposes a six step process from origination, to firm-specific screening, to generic investment screening, to a first-phase evaluation, to a second-phase evaluation, and finally to a closing (Fried and Hisrich 1994).

DeClercq, Fried and colleagues (2006) also mapped out the specific pre-investment steps of the venture firm to include referral checks, deal screening, entrepreneur’s presentation, VC investment committee meeting, term sheet negotiations, agreement negotiations, due diligence, shareholder agreement negotiations and ultimately agreement. These multi-step processes present many opportunities for a funding deal to potentially fail. In the following section the opportunity for spinouts to leverage network connections, and thus improve the probability of venture funding success, will be considered.

In conclusion, taking steps to have a firm’s management team in place, product ready for market, product pilot validations complete, and a need and intent to apply new capital to marketing and sales activities will significantly improve the spinout’s chances to achieve a successful venture funding agreement (DeClercq, Fried et al. 2006). Each of these issues will be influenced by the networking activities of the spinout, which we will next consider.

Network Theory

This study analyzes university spinouts and their VC funding success through a focus on one of the core areas of study in the organizational social network research literature, the utility
of network connections (Kilduff and Brass 2010). This research stream focuses on how social networks constrain and facilitate outcomes, such as the VC funding dependent variable used in this study (Burt 1992; Nahapiet and Ghoshal 1998; Kilduff and Brass 2010).

**Nodes and hubs**

A critical concept used in this network-centric study is that of network nodes. Network nodes are the actors or agents between whom relationships form in a network (Scott 2000). In the context of this study network nodes may be inter-organizational agents such as legal firms, the university, grant funders, or the network of university researchers that interact with the spinout, as examples. Individual actors such as the university inventor may also serve as nodes in the spinout’s network.

Network nodes manifest different levels of ‘fitness’ which refer to their characteristics that lead to the node’s varying ability to compete for network ties. Nodes with higher fitness demonstrate preferential tie attachment (Bianconi and Barabasi 2001; Bianconi and Barabasi 2001; Barabasi 2002). In the context of this study, spinout nodes with high fitness will demonstrate preferential tie attachment from venture capitalist nodes. The review of the venture capitalists’ assessment criteria suggest several areas of spinout node fitness of interest to VCs including market fitness, product fitness, management fitness, and financial fitness (Zacharakis and Meyer 2000).

The research literature on the issues important to the venture community in their funding assessments suggests a number of critical considerations for early-stage university spinouts. Areas where the spinout may be able to impact these considerations include a focus on the company’s product offering, management capabilities and network connections. This literature suggests that activities that help improve product “fitness” and facilitate building a strong management team and network should improve the firm’s ability to raise venture funding.
Nodes can serve as hubs that, without hierarchical authority, orchestrate network activities to ensure the creation and extraction of value (Dhanaraj and Parkhe 2006). Ferrary and Granovetter (2009) suggest that hubs in a start-up network perform signaling and embedding roles on behalf of the start-up firm. By providing venture funding the venture capitalists signal to others that the start-up node has achieved a level of fitness to warrant this achievement. Via embedding hubs help assure the creation of ties between the start-up and a group of nodes that are preferred (by the hub) suppliers of service (Ferrary and Granovetter 2009).

To facilitate this network-theoretic study we next review the language and basic measurement techniques used for social network analysis, including an introduction to complex network theory that moves beyond the purely structural analysis of networks to a holistic consideration of network nodes, raising the importance of the intrinsic characteristics of these nodes to network performance.

*Social Network Analytics*

Network analysis can be used to study the nodes and relationships critical to a spinout’s success. Network analysis is the exploration of relations between nodes (Clements 2008). These relational ties between nodes make it possible to discern the structures involved in a social system. Network analysis involves the study of connection typologies via graphs spanning a continuum from random to completely regular connections between nodes (Watts and Strogatz 1998).

Relationships between nodes are represented by ties, also known as edges, drawn between two network nodes. The ties between nodes on a graph may be directed or undirected, where directed ties reflect one-way relationships between the two nodes. The degree of a node can be calculated by counting the number of ties that connect to it.
A network’s average degree calculation provides a global measure of a network’s connectivity, indicating, on average, the number of ties between nodes in the network. A network’s density is a measure of the percent of potential ties between nodes that are actually present in the network (Scott 2000).

A node is considered reachable if there is a path between it and any other node in the network. The shortest path between any two nodes is the path with the least number of ties between the two nodes, with the average of these shortest path lengths termed the graph’s average path length. As average path length decreases the reachability for the overall network increases. A graph’s diameter represents the maximum shortest path length in the network (Scott 2000; Clements 2008).

A graph’s clustering coefficient measures the extent to which a node’s links are also connected to each other. Three nodes whose links are also connected to each other will create a triangular graph. The Watts-Strogatz Clustering Coefficient (1998) uses this fact to measure the ratio of the actual triangular node connections in a graph to the total number of possible triangular node connections.

While not exhaustive, these measures represent common methods used to analyze and compare various networks (Scott 2000). Figure 2 provides a summary of these elements.

<table>
<thead>
<tr>
<th>Degree</th>
<th>Number of ties to a node</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>Percent of potential ties actually present</td>
</tr>
<tr>
<td>Average path length</td>
<td>Average of all the shortest path lengths between nodes</td>
</tr>
<tr>
<td>Diameter</td>
<td>Maximum shortest path length in the network</td>
</tr>
<tr>
<td>Cluster coefficient</td>
<td>Ratio of the actual triangular node connections in a graph to the total number of possible triangular node connections.</td>
</tr>
</tbody>
</table>

*Figure 2 Common network measures*

*Complex Network Theory*

Complex network theory (CNT) is a useful theoretical framework for network analysis when there are heterogeneous self-organized nodes with interactions occurring on multiple
dimensions, such as we see in a start-up network (Ferrary and Granovetter 2009). While many studies analyze networks of passive nodes, such as power transmission networks, social networks deal with active nodes that adapt and manipulate the network (Watts 1999). CNT acknowledges that networks are not randomly structured (Newman 2003; Barabasi, Newman et al. 2006) and that their structure results from the behavior of these networking nodes (Granovetter 1973).

The complex network approach emphasizes that structure matters, and suggests a need to holistically analyze networks (Gulati, Nohria et al. 2000; Zaheer, Gozubuyuk et al. 2010). Within this network perspective, considerations of the patterns of ties, tie strength, and node characteristics are critical to consider in an analysis (Zaheer, Gozubuyuk et al. 2010). CNT notes that network complexity is often due to both the heterogeneity of nodes as well as the structure of ties so the impact from a node’s removal depends on both its intrinsic nature and connectivity (Zaheer, Gozubuyuk et al. 2010). CNT highlights the importance of heterogeneity and completeness to explain the weakness or the robustness of a network. Structure still matters however the elements that make up the structure must also be considered.

Network complexity can also be theorized by the large diversity of functions and competences involved. Different nodes may fulfill various functions creating unique network structures. For example, the informal functions of selection, signaling and embedding handled by VC firms in Silicon Valley, as noted by Ferrary and Granovetter (2009), could potentially be carried out by other nodes in a different context.

Clustering density is also an important property of complex networks (Newman 2003). Ferrary & Granovetter (2009) found in their study of Silicon Valley innovation networks that clustering occurred, with numerous ties clustering around member’s educational background, of relevance to building university-centric networks. Clustering is also impacted by node fitness, a concept discussed in the following section.
Node Fitness

CNT provides for certain network agents, such as the VCs serving as hubs for start-up networks, to play a central role in a network’s performance (Ferrary and Granovetter 2009). As noted however, university technologies may be quite early-stage making initial VC funding, and thus VC participation, difficult during the early-stages of a spinout’s development. Most traditional venture capital funds do not consider investments under $1–2 million (Acs and Audretsch 2003). Thus, start-ups typically raise smaller amounts early in their lifecycle via seed funding from friends and family or angel investors (Kerr, Lerner et al. 2010). Angel investors are investors who make early stage investments in companies using their own money, with a recent report noting that angel-funded firms, like VC funded companies, are less likely to fail than those relying on other forms of financing (Kerr, Lerner et al. 2010). The level of angel investments in 2007 nearly matched those placed by traditional VC firms, exceeding $26 billion (Sohl 2008; NVCA 2009). Angel investors are a critical source of early-stage entrepreneurial capital; however, angels do not usually invest in the typically embryonic stage technologies coming from university laboratories (Vohora, Wright et al. 2004). In a study of 87 prospective start-up investments considered by Tech Coast Angels, a large angel investment group based in Southern California, more than 97% of firms considered for investment were funding initial marketing and product development or were already generating revenues (Kerr, Lerner et al. 2010).

While early stage funding of some type typically precedes an influx of venture (or angel) capital Ferrary and Granovetter’s research (2009) shows this does not preclude the venture firms from playing their critical embedding, signaling and cluster networking roles post the venture funding round. In CNT studies it has been observed that some nodes arrive late but still manage to become hubs (Barabasi 2002).
Node fitness is defined as a node’s ability, competence or aptitude (Bianconi and Barabasi 2001; Barabasi 2002) and CNT suggests that nodes with higher fitness should be linked to more frequently. The probability that one will connect to a node with k links and fitness η is $k\eta/\sum k_i\eta_i$ (Barabasi 2002). As a node’s fitness η increases the probability of more future connections increases. Most complex networks display a fit-get-rich behavior with the fittest node eventually gaining the most connections (Barabasi, Newman et al. 2006). Thus, to link to the various funding sources, university spinouts must become fit enough to receive the prospective funding source’s consideration, increasing the likelihood that a tie between the spinout and the source of capital will be established. In the next several sections we will consider the potential characteristics of these prospective ties.

_Bridging structural holes_

Structural holes are gaps between networks characterized by an absence of cohesion (networks are not connected by a strong relationship) and of structural equivalence (networks do not have the same contacts) (Burt, 1992). Structural holes create entrepreneurial opportunities, enable competitive advantage, and increase social capital from enhanced timing and access to information (Burt 1992; Zaheer and Bell 2005). Bridges provide the connection between these two otherwise separate networks to enable this opportunity (Granovetter 1973). Information tends to be redundant within a given group (Burt 1992), thus, only nodes developing cross group ties gain access to new and unique knowledge (Granovetter 1973; Reagans and Zuckerman 2001). According to structural hole theory nodes are not the source of networking activities; node actions are driven by competition for relationships whose value is derived from their social structure (Burt 1992).

Ties represent the relationships that create a bridge across a network’s structural holes (Burt 1992). Optimal benefit requires a high probability that a contact will transmit information
across this bridge and depends on the strength of the connecting node’s relationship. The strength of a tie comes from the amount of time, emotional intensity, intimacy, and reciprocal services with which the connection is characterized (Granovetter 1973; Burt 1992). Tie strength can drive the relative importance of a relationship. An analysis of responses to the 1985 General Sociological Survey demonstrated that the reported importance of respondent’s relations positively correlated with the closeness and contact frequency of their relationship (Burt 1986).

Non-redundant ties bridging structural holes provide optimal information benefits; however, non-redundant ties are more likely to be weak than strong (Burt 1992). In his original paper on the strength of weak ties, Granovetter (1973) actually suggested that strong tie bridges were not even possible.

People are limited in the amount of time they have available for making and maintaining relationships (Mayhew and Levinger 1976). Therefore, individuals are expected to have a few strong ties and many weak ties, and thus it is important to focus resources on the maintenance of strategically important ties to maintain their strength and avoid them falling into their natural weak state (Burt 1992). This is important since agents with strong ties are more highly motivated to be of assistance to each other (Granovetter 1983).

**Tie characteristics**

Research has shown that different ties can enable different forms of knowledge transfer across a structural hole. Tacit knowledge is knowledge that is hard to articulate and that can only be acquired through experience (Polanyi 1966; Von Hippel 1988; Nonaka 1995) and transferring such non-codified knowledge is difficult (Teece 1977; Zander and Kogut 1995). Strong ties have been found helpful for tacit knowledge transfer (Uzzi and Lancaster 2003) due to the greater motivation of nodes to assist in the transfer process and to the existence of relationship specific heuristics that facilitate communication (Uzzi 1999). Similarly, in a study
of the impact of different forms of inter-unit knowledge transfer on project completion times, Hansen (1999) found that strong ties proved most effective when the knowledge being transferred was highly complex and that weak ties were most effective when the knowledge being transferred was less complex.

The functional purpose of a tie was also found to impact optimal tie strength. Where ties are established to facilitate exploration and search weak ties were found to be most effective (Hansen 1999; Rowley, Behrens et al. 2000) while exploitation tasks were found to perform better with strong ties (Rowley, Behrens et al. 2000).

Whether a tie is strong or weak it is always expected to provide information benefits to a node when serving as a bridge over a structural hole (Burt 1992). Timing, assuring you are informed early, and trust, providing confidence in the information provided, are dimensions of relationships that allow one to capitalize upon information provided (Burt 1992). Findings from more than 50 interviews of university-based academic and non-academic staff observed trust and bridge building as critical practices for knowledge transfer (Lockett, Kerr et al. 2008). It has also been noted that strong ties lead to trust (Gulati 1995) and that trust leads to improved performance (Zaheer, McEvily et al. 1998).

Both benevolence- and competence-based trust were found to mediate the link between strong ties and the receipt of useful knowledge (Levin and Cross 2004). Benevolence-based trust impacts the extent to which knowledge seekers will be forthcoming in their need for knowledge and was viewed as more likely to occur among strong ties (Glaeser, Laibson et al. 2000; Levin and Cross 2004). Competence-based trust was seen to impact the perceived usefulness of information received and to also be correlated with stronger ties that provide a basis for a determination of another agent’s capabilities (Levin and Cross 2004). In relationships between the spinout and various network nodes trust plays a critical role (Zaheer, McEvily et al. 1998;
Feldman, Feller et al. 2002; Hayter 2010). Levin & Cross (2004) found that competence-based trust was especially important for the sharing of tacit knowledge. In general, reputation and trust were found critical to network formation in the context of high-growth entrepreneurial firms (Larson 1992).

**Taxonomy of inventor-spinout ties**

The embryonic nature of most university technologies available for license (Jensen and Thursby 2001; Vohora, Wright et al. 2004) drives a need for inventor cooperation in commercialization (Jensen and Thursby 2001). Inventions by definition are novel combinations of existing and/or new components (Kogut and Zander 1992) suggesting a high degree of tacit and highly complex information to be shared by inventors with the spinout firm.

Ties must be established to bridge this gap between the inventor and the spinout (Dasgupta and David 1994; von Hippel 1994). The nature of the knowledge transferred and the intent to exploit this information for commercial activities suggests that strong ties will be critical. The nature of the information to be transmitted also suggests the importance of strong ties to establish trust between the bridging parties in this network (Gulati 1995). Research shows that spinouts benefit from maintaining strong ties to their universities through access to expertise, new research and facilities (Rappert, Webster et al. 1999; Johansson, Jacob et al. 2005).

Connections to university research provide benefits to firms in terms of knowledge access and exploitation (Zucker, Darby et al. 1998; Zucker 2002; Fabrizio 2009). Collaborations between firm researchers and university scientists provide firms with earlier, richer, and more comprehensive access to important university-based science resulting in a firm’s improved search for new inventions (Fabrizio 2009). Collaborations with university scientists may provide access to unpublished research as well as complementary tacit knowledge from both published and unpublished initiatives. Reading published research results may not prove adequate to allow
leverage of many research efforts (Dasgupta and David 1994). Also, research knowledge is often “sticky” and difficult to transfer (von Hippel 1994). Personal interactions with university researchers are often critical for the transfer of technological information and are often the source of information about technologies available for transfer (Thursby and Thursby 2000).

The nature of the ties established to bridge between the spinout and university inventor(s) and their research network vary widely. At one end of the spectrum are spinouts where the university inventor becomes CEO and is thus actively involved in the new firm. Another typical highly embedded role at a spinout firm for a university inventor is chief science officer (CSO) (Hayter 2010). In these extreme instances the inventor leaves the university research network and joins the spinout’s network. Ties back to the university research network are maintained by the inventor’s existing social network, facilitating potential ongoing research and development collaboration.

Alternatively inventors assuming senior management roles at spinouts may be allowed to maintain their university academic positions (at least for a limited time). When this occurs, in the terminology of social network analysis, the inventor is serving as a cut-point joining the two separate networks (termed knots) into one component (Scott 2000). The knots and cut-point are illustrated in figure 3.
At the other end of the spectrum there are some university inventors who play no role in the new venture founded to commercialize their research. In these instances the bridge between the inventor and spinout must be established through ties to the inventor’s university research network. Between these extremes inventors assume varying roles and degrees of separation (Hayter 2010).

Most studies emphasize the importance of active faculty involvement with the spinout firm. Faculty involvement is seen as critical to the continuing development of the new technology, both at the university and at the spinout (Jensen and Thursby 2001; Shane 2004). Access to the university inventor’s detailed understanding of the technology was found to be critical to a spinout’s success (Franklin, Wright et al. 2001). This positive relationship between active faculty involvement and the performance of the technology licensees was also noted in several other studies (Agrawal and Henderson 2002; Zucker 2002). Rappert et. al. (1999) found that spinouts benefit from these relationships on multiple dimensions including access to expertise, entrepreneurial assistance, use of equipment, and via keeping abreast of new university research efforts. Active engagement with academic scientists also enables the spinout firm to embed itself in the scientific community network (Murray 2004).

A significant relationship between the reputation of affiliated university scientists and various measures of firm performance has also been noted. For biotechnology start-ups an affiliated university scientists’ prestige proved a significant predictor of a firm’s IPO performance (Deeds, DeCarolis et al. 1998). Similarly, in another study of biotechnology firms, a significant relationship between the reputation of university scientists affiliated in an identifiable market exchange with the firm was found to correlate with the number of products the firm had in development or on the market, as well as with the employee size of the company (Zucker, Darby et al. 1998).
Researchers have proposed a trichotomous categorization of university spinouts into orthodox, hybrid, and technology forms based on the degree of involvement of the university inventor(s) (Nicolaou and Birley 2003; Nicolaou and Birley 2003). Orthodox spinouts were perceived as those where both the academic inventor(s) (also termed the principal investigator(s)) and the technology spin out of the university. Hybrid spinouts involved the technology spinning out and the academics holding a directorship, membership on a scientific advisory board, or other part-time position within the company while still retaining their university position. Where multiple academics were involved in the invention effort, scenarios where some academics spun out and some retained their university affiliation was subsumed under this category. Finally technology spinouts involve the invention spinning out while the university inventors maintained no substantive connection with the newly established firms other than potentially an equity position or a consulting arrangement. The nature of the interactions between university and firm researchers are not always obvious. In a case study of two new biotech companies the investigators showed the firms engaged in large numbers of collaborative research efforts with university scientists, usually without any formal market contracts in place to govern the knowledge exchange (Liebeskind, Oliver et al. 1996).

The nature of a university inventor’s role with a spinout is likely not determined solely on an economic basis. TTO staff are very sensitive to the desires of their institution’s research staff (Hayter 2010). Active university inventor participation can positively impact a spinout’s performance as noted earlier and university policies can be crafted to encourage this participation. Since many, if not most, university inventors wish to retain their academic positions (Johansson, Jacob et al. 2005) university personnel policies, such as leave of absence regulations, can positively impact the nature of faculty involvement in the spinout entities (Kenney and Goe 2003; Shane 2004). Jensen and Thursby (2001) also find that equity
participation is critical to promote inventor involvement with the spinout. They suggest that for most university inventions to be successfully commercialized the inventor's income must be tied to the licensee's output by payments such as royalties or equity. Sponsored research from the licensee does not provide an adequate incentive for this effort (Jensen and Thursby 2001).

Measuring tie strength

The strength of a tie comes from the amount of time, emotional intensity, intimacy, and reciprocal services with which the connection is characterized (Granovetter 1973; Burt 1992). Relative tie strength distinctions from the empirical research literature have included measures of closeness, frequency and connecting node characteristics (Granovetter 1973; Friedkin 1980; Marsden and Campbell 1984; Hansen 1999; Scott 2000; Levin and Cross 2004). Tie strength can be measured in many ways including frequency of interaction, intensity of interactions, heterogeneity of interaction, and reciprocity of interaction (Hanneman and Riddle 2005).

Granovetter (1973) in his paper, The Strength of Weak Ties, writes that “the strength of a tie is a (probably linear) combination of the amount of time, the emotional intensity, the intimacy (mutual confiding), and the reciprocal services which characterize the tie.” In his study of job changers who found new jobs through the assistance of contacts, tie strength was measured by how often the job changer and contact saw each other around the time that the job information was transferred (Granovetter 1973).

The ties of university biological scientists were analyzed in another study where strong ties were defined as those in which both faculty members shared their current research activities with each other while weak ties were asymmetrical, with only one of the faculty sharing their research information (Friedkin 1980). Treating asymmetrical contact as a weak tie and reciprocal contact as a strong one was also suggested by Granovetter (1973).
In a study of corporate board interlocks tie strength was defined based on the characteristics of the interlocking board members (Bearden, Atwood et al. 2002). If the interlock involved the full-time executive officers of the enterprise the tie was viewed as strong. Those ties involving only the part-time non-executive directors were viewed as weak. This distinction was supported by the increased time commitment and strategic significance of executive officer involvement (Scott 2000; Scott 2002).

From an analysis of survey data on friendship ties by Marsden and Campbell (1984) it was suggested that tie strength is composed of elements of time duration and relationship depth. Closeness, measured as a trichotomy of a friend being an acquaintance, good friend, or very close friend, was found to be the best indicator of tie strength. Difficulties with using frequency and duration of contact as strength indicators were noted due to overestimation biases for ties between neighbors, co-workers, and relatives (Marsden and Campbell 1984).

Hansen (1999) utilized conventional network measures of frequency and closeness in his study of interdivisional ties. Measures of tie strength were the average of these frequency and closeness scores as reported on a 7-point scale by the firm’s R&D managers. Hansen (1999) utilized a work-related definition of closeness versus an affective construct since the ties under study were at a firm level of analysis. Similar measures of tie strength were used by Levin and Cross in their study of firm knowledge transfer (Levin and Cross 2004).

The following section posits that the structural form of the networks being bridged is also an important consideration in determining the effectiveness of a tie of a given strength. This review closes with our initial hypotheses on inventor-spinout tie performance.

Typology of network structures

Different network structures, distinguishable by measurements such as their degree, have been observed in practice. These distinctions may potentially be important to the nature of ties
used for bridging these various networks. Networks that are completely regular or completely random are not common in real world situations; however, between the two extremes of regular and random network connections lie regular networks “rewired” to introduce increasing amounts of disorder (Watts 1999). The addition of some “wiring” disorder to a formerly regular network leads to networks that are highly clustered, like a regular network, but with small average path lengths between nodes, like a random graph (Watts and Strogatz 1998; Newman 2003). These “hybrid” networks, called small-world networks are quite common in real-world situations (Watts and Strogatz 1998; Fleming, King et al. 2007) and provide the network structure behind the popular concept of “six degrees of separation” between individuals popularized by an experiment conducted by Stanley Milgram in 1967 (Barabasi 2002). Watts and Strogatz (1998) demonstrated that the addition of only a small number of non-regular ties to a regular network will transform the network into a "small world". Figure 4 provides a visualization of these networks.

![Figure 4 A visualization of regular, small-world and random networks](image)

Scale-free networks are another common network form observed in such diverse areas as web-page connectivity on the internet, scientific research collaborations on published papers, and networks of Hollywood actors appearing in the same film (Barabasi and Bonabeau 2003). These networks manifest characteristics of preferential attachment and aging in the development of their network type (Barabasi and Albert 1999). In these networks some nodes become very connected and exert significant influence on the behavior of the overall network’s performance.
Degree distributions in these networks have been observed to follow a power law exponent, a scaling constant used in linear equation modeling (Barabasi and Bonabeau 2003; Newman 2003). The power law exponent is derived from a double log scale plot of the network’s degree distribution. After the degree distribution is plotted its linear slope produces the power law exponent for the network. When the exponent, \( \alpha \), is \( >2 \), but \( <3 \), which is typical for networks displaying scale-free characteristics, the graph is considered “scale-free.” Exponents less than 2 suggest that there is even greater inequality present in the network under study than exists in typical scale-free networks (Watts 2004). For scale free networks the probability “P”, of any node having a degree “k” can approximately be represented as: \( P(k) \sim \text{constant}/k^\alpha \). From this formula we see that as the degree for a node becomes large the probability of a node having this degree becomes quite small. Thus only a small number of nodes will have high connectivity levels or degree measures. Given this sharp difference in node degree measures the networks are termed “scale-free”. This is in contrast to a regular network where all nodes have the same degree value. Features of scale-free networks include: a degree distribution that follows a power law curve; small average path lengths compared to random networks; decreasing average node separation and clustering coefficients over time; and increases in the size of the largest cluster and average degree over time (Barabasi 2002).

The structural form a network takes is defined by the characteristics of its’ network ties. For example, for random networks the degree distribution of nodes can be represented by a Poisson distribution (Albert and Barabasi 2002; Newman 2003; Barabasi and Oltvai 2004) while for regular networks the degree distribution can be represented by a straight vertical line. The degree distribution for small world network lies between these two forms while that for a scale free network follows a power law distribution as noted earlier (Albert and Barabasi 2002). Figure 5 provides graphical representations of degree distributions for these various networks.
Figure 5 Degree distributions for regular, small-world, random and scale-free networks

Network structure and effective tie strength

Inventor, scientific and academic collaboration networks have all been observed to display small-world structures (Balconi, Breschi et al. 2004; Fleming and Marx 2006; Fleming, King et al. 2007) where links among the actors are highly clustered and the average path length between any two actors in the network is relatively short (Uzzi, Amaral et al. 2007).

In contrast, start-up networks are complex with numerous heterogeneous interacting agents with different competences and different functions in the network (Barabasi 2002; Ferrary and Granovetter 2009). While the networks of early-stage spinout firms are nascent, they must, at a very early stage in their development, form to address critical functional needs of the firm such as legal, accounting, and banking support (Ferrary and Granovetter 2009). Spinouts must also begin the quest for capital early in their development, requiring access to diverse social networks of prospective funders. Staff and Board members also need to be engaged to enhance node fitness by building industry, market, and technology skills (Hall and Hofer 1993; Kaplan, Sensoy et al. 2009) as well as to enable access to VC social networks (Hall and Hofer 1993) in preparation for future VC support.

Many studies have emphasized the importance of active inventor involvement for university spinout success (Rappert, Webster et al. 1999; Franklin, Wright et al. 2001; Jensen and Thursby 2001; Agrawal and Henderson 2002; Zucker 2002; Shane 2004). However, the small world network characteristics (SWN) of an inventor’s university research network where
agents are tightly clustered suggest that ties to others in the network, while apparently less strong based on the traditional measures of closeness, frequency, and node characteristics, may prove equally “strong” in terms of outcome performance. This analysis suggests the following hypothesis, as visualized in figure 6:

Hypothesis 1a: Spinout ties to a university inventor’s research network are as beneficial as direct ties to the inventor(s) in enabling the spinout’s ability to raise venture funding.

Since World War II much scientific research tends to occur in large multi-purpose scientific laboratories made up of many researchers (Weinberg 1970). Given a university inventors other commitments to teaching and research, it might be easier for spinouts to establish strong ties with other members of the inventor’s research network. Since these small world networks can allow for equivalent knowledge access this possibility could actually make these network ties preferable to direct inventor ties. In addition the signaling benefit from the commitment of other research network members to the inventor’s ideas could also prove compelling to investors.
The research literature has found the impact of tie strength to be contingent on the nature of knowledge to be transferred and on industry characteristics, two topics we will consider in the next sections.

**Knowledge transfer and the nature of the university inventor tie**

The nature of knowledge has been a focus of the organizational learning literature (Zander and Kogut 1995; Cohen and Sproull 1996; Szulanski 1996; Uzzi and Lancaster 2003). Knowledge has been contextualized as either tacit or explicit, varying on a continuum from more difficult to articulate and codify to easier (Polanyi 1966; Nonaka 1995). Hansen (1999) demonstrated that weak ties are optimal for the transfer of explicit knowledge while strong ties are optimal for tacit knowledge transfer. Thus where technologies are less well defined and developed strong ties are preferred.

Our earlier hypotheses suggest that network ties in small world networks can deliver equivalent knowledge transfer to direct ties to a university inventor. These direct ties would be considered stronger in traditional measures of tie strength. As noted earlier, network ties may also provide additional benefits making them preferable in many instances. Given their knowledge transfer equivalence and additional benefits the following hypothesis is suggested:

**Hypothesis 1b:** Ties to a university inventor’s research network are as beneficial as direct ties to the university inventor for the receipt of both tacit and explicit knowledge.

**Industry context and the nature of the university inventor tie**

Very early-stage university spinouts are typically not yet “fit” (Barabasi 2002) enough to receive venture capital funding (Acs and Audretsch 2003); their technologies are typically embryonic and their market opportunity is unproven (Jensen and Thursby 2001; Vohora, Wright et al. 2004). Studies have shown that assuring a prospective investment opportunity has achieved
a certain stage of development is one of the key investment criteria of venture capital firms (Tyebjee and Bruno 1984). Per CNT both nodes and ties are critical to a network (Zaheer, Gozubuyuk et al. 2010) and different nodes fulfill different functions in a network (Barabasi 2002; Barabasi and Bonabeau 2003; Barabasi, Newman et al. 2006; Ferrary and Granovetter 2009). The nature of these nodes can play a crucial role in the perceived fitness of a spinout. Nodes in a spinout’s network can provide functional, signaling and networking benefits.

If a university inventor desires to be CEO of the new spinout, a strong direct tie, the research literature has been mixed on the implications for spinout performance. A study of the entire population of public bio-technology firms from 1980 to 1994 found that those companies in which the CEO was a former university professor performed better than firms utilizing surrogate CEOs (Finkle 1998). However, numerous studies have found that a founding team’s industry experience, management capability, and knowledge are critical factors for a spinout’s success (Shane and Stuart 2002; O'Shea, Allen et al. 2005; Rothaermel, Agung et al. 2007) and that surrogate entrepreneurs are critical to access these capabilities (Franklin, Wright et al. 2001). Hayter (2010) in his study of academic entrepreneurs noted that the presence of outside management was a criterion for the receipt of venture capital unless, in certain instances, the university inventor had previous experience running such a venture. This study also found that hiring an outside CEO within a year of starting up was one of the most significant predictors of future successful commercialization. Roberts (1991) in a study of Boston area entrepreneurs similarly found that those with Ph.D.s (mostly coming from academic roles) did not perform as well as other start-up leaders. Rothaermel and Thursby (2005) however found that having university professors on a spinout’s senior management team reduced the probability of failure although it slowed the firm’s exit from university incubation facilities.
Industry specific characteristics may explain some of the mixed findings in this stream of research. For example, a comparison of university entrepreneurship in the health and physical sciences found that health-science spinouts offer an easy transition for university inventors possibly because many of these entities are, in effect, commercial R&D firms that license their successful technologies to large bio-pharma companies to take to market (Gulbrandsen and Smeby 2005).

Management considerations are one of the four decision-criteria noted as critical in venture capital funding decisions (Zacharakis and Meyer 2000). Venture capitalists are interested in having a founder with technical and industry experience who has an entrepreneurial personality (Wells 1974; Poindexter 1976; Tyebjee and Bruno 1984; MacMillan, Siegel et al. 1985; Khan 1987; MacMillan, Zemann et al. 1987; Robinson 1987; Roberts 1991; Riquelme and Rickards 1992; Hall and Hofer 1993; Shepherd 1999; Shepherd 1999). This industry competence was identified as a top priority consideration of venture firms in their funding evaluations (Shepherd, 1999).

Finally, network tie characteristics could also play a critical role in the mixed research findings. Per the hypotheses above one expects ties to the network to be as or more beneficial to a spinout than direct ties to the university inventor and that such ties can moderate the benefits of direct university inventor ties.

While the research in the bio-science field suggests that having the university inventor as CEO may be an acceptable option for VC investors in this specific industry we hypothesize that network effects will outweigh the benefits of such strong direct inventor ties suggesting the following:
**Hypothesis 2**: Industry will not moderate the impact of spinout-inventor or inventor network ties on the spinout’s ability to raise VC funding.

In summary, these hypotheses extend the theoretical tie strength models noted in figure 7 to incorporate network impacts as noted in the figures 8 and 9.

![Figure 7 Initial tie strength model](image)

These hypotheses suggest that to properly interpret the impact from a given node’s tie one must consider the nature and ties to the nodes broader network. Network and direct node ties are suggested, for small world networks, to be, at a minimum, equifinal and the possibility of network ties proving more effective than direct node ties is suggested. Finally the moderating role of industry is proposed as limited to direct node ties with little impact in situations where the network is engaged.

![Figure 8 Moderating impact of network ties](image)

We will next consider the impact of the university inventor’s involvement with the spinout on their academic productivity. The university-inventor’s involvement with the spinout firm requires time and attention suggesting the potential for impact from this tie on the inventor’s other university responsibilities.
Spinout ties and academic activities – complements or substitutes?

Policy initiatives such as the Bayh-Dole Act in the United States incent universities to encourage their faculty to make and disclose inventions for license and spinoff (Buenstorf 2009) requiring inventor’s involvement in the disclosure, patenting and commercialization efforts (Thursby and Thursby 2004; Agrawal 2006). The impact of these efforts on the university inventor’s traditional research and teaching tasks is the focus of this section.

Faculty engage in six categories of knowledge transfer: publishing, teaching, consulting, patenting, spinout formation and informal knowledge transfer activities (Upstill and Symington 2002; Perkman and Walsh 2007). Researchers have found that these knowledge transfer activities can be complementary, substitutive, or completely independent of each other (Landry, Saihi et al. 2010).

Complementarities can occur when certain knowledge transfer activities provide a positive leverage effect on other such activities. An example is the Triple Helix Model of knowledge exchange between university, industry and government actors for the intended benefit of both academic research and technology transfer (Etzkowitz 2003). A number of research studies have noted complementarities between entrepreneurial and academic activities (Carayol 2003; Owen-Smith 2003; Van Looy, Callaert et al. 2006).

Substitution effects are grounded on the resource constraints of the university inventor where involvement in a technology transfer activity must come at the expense of other efforts...
(Mitchell and Rebne 1995). These effects assume a zero sum game where doing more of one activity creates a negative impact on another. Substitution effects have been noted in the research literature between publishing and patenting and publishing and teaching (Geuna and Nesta 2006; Azoulay, Ding et al. 2007). For substitution effects the university inventor’s output can be conceptualized via a production function. Production functions are one of the pillars of neoclassical economics. Written as \( P = f(L, C, \ldots) \), the production function relates total product output \( P \) to the labor \( L \), capital \( C \), and other inputs that combine to produce it. The function expresses a technological relationship describing the maximum output obtainable from the given amount of factor input (Humphrey 1997). Production functions have been applied to the study of invention networks in prior research studies. As an example, production functions have been used to analyze university patenting, where patent counts were found to relate positively and significantly to the number of PhD students and post-doctorates at an institution (Gurmu, Black et al. 2010). Assuming a university inventor is operating at full production, shifting output to one area must reduce output in another area. However, some research studies have observed that certain academic knowledge transfer activities are independent from each other with no complementarity or substitution effects observed (Meyer 2006).

The production function model suggests that there is a limit to the output that a university investigator can produce, thus, if more of their time is dedicated to the spinout venture it is anticipated that this should impact their output in other areas. The unique challenges of spinouts are anticipated to lead to a “time squeeze” problem for university inventors that will leave less time for academic pursuits and thus negatively impact their traditional academic research efforts (Etzkowitz 1998; Gulbrandsen and Smeby 2005). Academic researchers view publishing as their preferred technology transfer mechanism and an indicator of personal merit (Keith, Layne et al. 2002; Owen-Smith and Powell 2003) suggesting a likely desire to maintain these academic
publishing pursuits. Given these preferences it is anticipated that invention efforts will be the one most impacted by the university inventor’s spinout efforts. This desire to protect the valued publishing activity suggests the following hypothesis:

**Hypothesis 3**: Involvement of university inventors with spinouts will negatively impact their patenting productivity.

Two prior research studies have focused on a spinout’s effect on individual faculty inventor’s publication productivity (Lowe and Gonzalez-Brambila 2007; Buenstorf 2009). These empirical research findings have found some indications of a positive impact from the university inventor’s spinout efforts on their publishing productivity. In a study of 155 technology spinoffs from the Max Planck Institute a positive benefit of spinout involvement on researcher publishing productivity was noted; however, this finding reversed in situations where the inventor was also the founder of the spinout firm. This negative impact of founding occurred even in circumstances where the university inventor was not operationally involved with the firm (Buenstorf 2009). These findings suggest faculty impact may transcend obvious operational involvement and perhaps include characteristics such as emotional affiliation or economic ties. As suggested by Buenstorf (2009) the high level of technical interaction required to facilitate a spinout likely negatively impacts the researcher’s productivity in other areas, cancelling out any benefits typically found with academic-commercial involvement.

In another study analyzing 141 U.S. faculty entrepreneurs Lowe and Gonzalez-Brambila (2007) observed a positive effect on the academic inventor’s publication productivity following their involvement with a spinout firm, although this finding became non-significant once they controlled for faculty seniority. This finding suggests that more senior faculty have established a publishing ecosystem that is not significantly impacted by the benefits of commercial
involvement with the spinout. This moderating effect on publishing productivity of faculty seniority suggests the following hypothesis.

**Hypothesis 4:** Involvement of senior faculty inventors with university spinouts will not impact their publishing productivity.

Numerous studies have noted positive influences from university researcher-firm collaborations. A study revealed that researchers collaborating with or employed by firms were found to have higher citation rates than pure academic faculty (Zucker, Darby et al. 1998) while another survey of over 1200 faculty members at 40 U.S. universities found that biotechnology researchers with industrial support published at higher rates, patented more frequently, participated in more administrative and professional activities and earned more than their colleagues (Blumenthal, Gluck et al. 1986). A study in the technology transfer space suggests that greater faculty involvement with the TTO correlates with an increase in the quantity and quality of the faculty member’s basic research (Siegel, Waldman et al. 2004). Commercial firm contacts can enhance faculty learning, guide research agendas, and suggest novel research approaches. Commercial contacts can also expand a university inventor’s network and provide access to complementary scientific resources and capital (Buenstorf 2009). None of these studies however specifically focused on the impact of a university inventor’s activities in support of spinout companies.

Spinouts present unique organizational and management challenges to faculty inventors potentially causing a more pronounced negative impact on the inventor’s traditional research efforts (Buenstorf 2009). The potential for negative influences from university-spinout ties have been suggested in the research literature. Faculty difficulty in managing their university and spinout responsibilities has been noted. A survey of faculty and administrators at 86 colleges and universities suggests that faculty involved in new ventures may be distracted from their
primary academic duties (Campbell and Slaughter 1999). Another study found that 66 percent of faculty sampled were not able to successfully manage their university responsibilities and off-campus ventures (Samson and Gurdon 1993). A third study surveyed academic entrepreneurs, with respondents noting the near impossible task of balancing time between their spinout and academic obligations (Hayter 2010). Powers and Campbell (Powers and Campbell 2011) in a study on the effects of technology commercialization on university researcher productivity noted negative impacts on research publishing and collaboration. Publication delays due to both legal and economic considerations and shifts from basic to more applied research in support of spinout firms have also been suggested (Nelson 2001; Geuna and Nesta 2006; Stephan, Gurmu et al. 2007). One of the key benefits observed from university-industry collaboration has been the resource access provided by these commercial ties resulting in improved publishing productivity (Blumenthal, Campbell et al. 1996). Given the resource constraints of spinouts this resource spillover benefit seems less likely. Rappert et al’s (1999) study suggests that physical proximity, allowing the shared use of laboratory equipment as an example can benefit spinout firms. Physical proximity may facilitate other inventor-network spinout interactions reducing the resource obstacles to spillover benefits. These findings suggest that closer contact to the spinout can enhance faculty productivity suggesting the following hypothesis:

**Hypothesis 5**: Involvement of senior faculty inventors with physically proximate university spinouts will have a positive impact on their academic productivity.

More generally, expansion of personal networks can have costs, as well as benefits, for university inventors. Burt (1992) notes that, in general, an expanding network size is a mixed blessing since time and energy are limited and not optimizing network connections can lead to opportunity costs. He suggests that network benefits have an upper limit set by the time and energy available to an agent. Agents must trade-off between the structural holes a new contact
provides versus the time and energy required to maintain productive relationships across the entire network (Burt 1992). Burt viewed an agent’s relationships as investments on which structural holes determined the rate of return. Hansen (1999) similarly noted that strong ties are more costly to manage than weak ties and that agents are limited in both the volume and strength of relations that they can productively maintain. As Humphrey (1997) noted a production function describes the maximum output obtainable from a given amount of factor input so as output is increasingly dedicated towards spinouts the output in other areas should suffer. This suggests that an inventor’s simultaneous involvement with multiple spinouts should ultimately have a negative impact on the inventor’s academic productivity, including their ‘protected’ publishing productivity, suggesting the following hypothesis:

**Hypothesis 6**: Involvement of senior faculty inventors with multiple university spinouts simultaneously will have a negative impact on their publishing productivity.

Landry et al. (2010) identified patterns of complementarities, substitution and independence in the relationships between various technology transfer activities. They suggested that spinout formation and granted patents have a complementary relationship and that spinout formation and publications have an independent relationship as noted in the figure below.

![Figure 10: Complementarities and independence between spinout formation, granted patents and publications](image)

Our hypotheses suggest that these relationships, at least for senior faculty, are more complex than this model indicates and a modified model of interaction among knowledge transfer activities is proposed. Hypothesis 3 suggests that the spinout-granted patents interaction is directionally distinct. This hypothesis does not question the complementary nature of the interaction of granted patents to spinout formation however the interaction of spinout formation
on granted patents is conceptualized as substitutive. Hypotheses 4 and 6 address the interaction between spinout formation and publication. Directional distinctiveness is again suggested. The hypothesis does not question the independent nature of the relationship from publication to spinout formation; however, it suggests that the independent nature of this relationship is mediated by the number of active spinouts the inventor is involved with. Multiple spinouts can transform what would be an independent relationship into a substitutive interaction. Finally, hypothesis 5 raises the potential positive moderating effect of physical proximity to both the publishing and patent productivity of the inventor. This modified model of spinout knowledge transfer is visualized below.

![Diagram of knowledge transfer activities](image)

**Figure 11 Directionally distinct patterns of interaction among knowledge transfer activities**

This revised model suggests that the impact of spinout formation on academic productivity is more nuanced than previously proposed. Spinout formation can prove substitutive to patent creation and publication output in some contexts. By considering the concept of outcome equivalent ties proposed earlier, spinouts may be equally served, and inventors and universities better served, by establishing ties between the spinout and the inventor’s university research network as opposed to strong direct ties between the inventor and the new firm.
While the university inventor-spinout tie is a critical consideration it is just one of the new ties the spinout will establish. In the next sections we will consider additional nodes in early-stage spinout networks and the temporal nature of these networks, which, in combination with network theory, will be used to develop our final four research hypotheses.

**Spinout inter-organizational networks**

Establishing a start-up requires involvement from a large number of heterogeneous nodes with a multiplexity of ties (Ferrary and Granovetter 2009). Via a study of Silicon Valley start-ups Ferrary and Granovetter (2009) used complex network theory (Barabasi, Newman et al. 2006) to facilitate the identification and analysis of the nodes and ties of post-venture funded start-up networks.

Researchers have explored the dynamics by which established company ties evolve over time (Gulati and Gargiulo 1999; Ozcan and Eisenhardt 2009). The evolution of established firm ties are constrained by the social mechanisms of tie repetition, tie transitivity and tie similarity resulting in highly stable tie structures in established firms (Podolny 1994; Gulati 1995; Gulati 1995; Gulati and Gargiulo 1999; Powell, White et al. 2005). The period when a spinout begins the formation of its initial network ties however is one of low network determinism (Hallen 2008). These early-stage network dynamics suggest that spinouts can execute and exploit network development strategies to optimize their future network positions. This possibility is now considered in detail.

**Inter-company network participants**

Ferrary and Granovetter (2009) identified twelve distinct nodes involved in start-up formation including: universities, large firms, research laboratories, VC firms, law firms, investment banks, commercial banks, CPAs, consulting groups, HR agencies, PR agencies and media. Formal and informal economic functions of these nodes in the Silicon Valley venture
community were identified. Formal tasks were to: nurture innovation (universities, research laboratories), provide trained workers (universities, HR agencies), develop innovations (large firms, start-ups), finance start-ups (VC firms), handle legal issues (law firm), publicize start-ups (PR firm), circulate information (media channels), provide business expertise (consulting firms), provide accounting support (CPAs), organize exit strategies (investment banks), and enable daily financial activity (commercial banks). Informal functions were also observed and included: incubate start-ups (universities, research laboratories), socialize start-ups (universities, large firms, research laboratories), acquire start-ups (large firms), partner with start-ups (large firms), provide trained workers (large firms, consulting firms), select start-ups (VC firm), share entrepreneurial knowledge (VC firm), embed start-ups (VC firms, law firms), signal start-ups (VC firms, investment banks), network the cluster (VC firms, law firms, HR agencies, PR firms), publicize start-ups and sustain an entrepreneurial culture (media channels). While many of these functions are tightly coupled to the actions of specific nodes, i.e. law firms provide legal services, several informal functions including socialization, embedding, signaling and cluster networking are provided by a more heterogeneous mix of these network nodes.

A key consideration for any social network analysis is the determination of the boundaries of the social relations to be considered (Freeman, White et al. 1989; Scott 2000). Researchers often have difficulty determining the boundaries of relational systems even when “natural” boundaries may exist (Laumann, Marsden et al. 1989; Scott 2000). The comprehensive list of nodes identified by Ferrary and Granovetter (2009) for start-up network analysis addresses this issue, facilitating the determination of inter-organizational boundaries to use in this and other start-up network research efforts. Working with a comprehensive list is important given node inter-dependence and the potential importance of network completeness to a firm’s performance (Ferrary and Granovetter 2009). Figure 12 illustrates the numerous firm-
level agents to be incorporated into a start-up’s complex network (Ferrary and Granovetter 2009).

Ferrary and Granovetter (2009) observed that success resulted not only from the quality of the entrepreneur and innovation embodied within a start-up but also from the firm’s embeddedness within this complex social network. The embedded relationships suggested by Ferrary and Granovetter (2009) represent a very specific form of exchange characterized by personal ties, trust, the incorporation of coordination devices to promote knowledge transfer and satisficing behavior by the embedded nodes (Dore 1983; Larson 1992; Uzzi 1997). These embedded relationships are in contrast to neoclassical exchanges which are characterized by arms-length ties and self-interested action where price distills all information needed for the formulation of an economic relationship (Powell 1990).

Figure 13 provides a temporal mapping of Ferrary and Granovetter’s (2009) node functions along an illustrative spinout lifecycle. Certain formal functions must commence early in a firm’s lifecycle (although the specific nodes involved with these functions might change across time) while others such as exit or acquisition are, by definition, at the lifecycle’s end.
Researchers have noted that spinout success is initially more dependent on the firm’s technological performance than on its marketing, sales or distribution efforts suggesting that activities supporting improved technological performance may be the most important at the early-stages of the spinout’s development (Perez and Sanchez 2003). Informal functions however can take place at any point in time as illustrated by the various “clouds” in figure 13.

![Figure 13 Formal and informal start-up functions](image)

The start-ups in Ferrary and Granovetter’s study (2009) were all post-VC funded firms where VCs played a critical role in embedding the new firm within the start-up network. The start-up’s pre-VC funded inter-organizational networks were not considered and, given the development stage of the firms in their study, the early-stage network’s significance in creating ties between the start-up and potential VC funders was not addressed. By definition, pre-VC funded spinouts are not yet capitalized by venture firms and, thus, venture firms are not a part of their inter-organization network. Understanding the future role VC firms will play, which is the focus of the next section, will contribute to our understanding of a spinout’s early network behavior.
Venture Capitalists as hubs in start-up networks

VC firms are critical to both a start-up’s funding and network embedding efforts (Gorman and Sahlman 1989; Ferrary and Granovetter 2009). A VC firm’s presence in a start-up’s complex network enables interactions between critical nodes and contributes to the network’s completeness (Ferrary and Granovetter 2009). Besides the formal role of providing capital, VC firms also serve informal roles of signaling and embedding their portfolio companies.

A node’s ability to form network ties is constrained by its attractiveness to other nodes (Eisenhardt and Schoonhoven 1996) and existing ties can enhance a node’s attractiveness (Podolny 1994; Gulati 1995). Venture capitalists fund less than 1% of the business plans they review (Perez 1986) so selection for funding by a prominent VC firm, in itself, creates a strong positive signal to other nodes in a start-up network. Social ties between economic agents, or the ease of creating them when needed, strongly impact start-up performance and VC signaling can facilitate this effort (Megginson and Weiss 1991; Stuart, Hoang et al. 1999; Ferrary and Granovetter 2009). Start-up’s value the non-financial contributions of their VC funders, providing equity to high-reputation VCs at a 10-14% discount versus competing funding alternatives (Hsu 2004).

Ferrary and Granovetter (2009) note that venture capitalists play an active strategic role in assuring the network embeddedness of their portfolio companies. VC firms were shown to be the main hub to the other critical nodes, identified in figure 12, in a new firm’s network, illustrating the non-randomness of this network (Barabasi and Bonabeau 2003; Newman 2003). This implies that pre-existing ties to nodes fulfilling functional roles, such as legal and accounting services, may be replaced once relations with a VC firm are established. These nodes occupy the same social position, such as their capacity as a CPA firm, and so can be viewed as
interchangeable for sociological purposes (Scott 2000). The replacement node however may be embedded in the VC firm’s network and thus viewed as the preferred provider post VC funding and of higher status than prior partners in these areas (Hallen 2008).

Inter-organizational nodes well connected to the VC community are not expected to occur with great frequency in early-stage university spinout networks since nodes with strong VC connections typically serve clients at a later stage of development. As noted by Ferrary and Granovetter (2009) the venture capital firm enables the formation of the post-VC funding round start-up network and nodes in these networks await signaling (and financing) by the VC firms before engaging with start-up ventures. Thus, early-stage spinout networks are likely different clusters of nodes than those in later-stage spinout networks orchestrated by venture capital hubs (Ferrary & Grannovetter, 2009).

These findings suggest that the completeness of early-stage pre-VC funded spinout networks may be of little importance to venture capitalists and un-necessary for these early stage firms suggesting the following hypothesis.

**Hypothesis 7:** Early-stage pre-VC funded spinouts will have incomplete inter-organizational networks.

Two paths to the establishment of a start-up’s initial network position have been hypothesized: founder-history logic, where connections are established based on the founder’s existing ties, and organizational-accomplishments logic, where connections result from firm accomplishments (Podolny 1994; Gulati 1995; Gulati and Gargiulo 1999). For early-stage firms accomplishments have been found to play a critical role in the formation of future network ties (Hallen 2008). We will now consider these issues and the relative importance of various nodes and ties to the enhancement of early-stage pre-VC funded spinout accomplishment.
Enhancing technological performance

Node fitness is defined as a node’s ability, competence or aptitude (Bianconi and Barabasi 2001; Barabasi 2002) and CNT suggests that nodes with higher fitness should be linked to more frequently. Start-ups vary based on their stage of development. For example, the early-stage university spinouts studied in this effort are typically not yet “fit” (Barabasi 2002) enough to receive venture capital funding (Acs and Audretsch 2003); their technologies are typically embryonic and their market opportunity is unproven (Jensen and Thursby 2001; Vohora, Wright et al. 2004). Assuring a prospective investment opportunity has achieved a certain stage of development is one of the key investment criteria of venture capital firms (Tyebjee and Bruno 1984). Per CNT both ties and nodes are critical to a network (Zaheer, Gozubuyuk et al. 2010) and different nodes fulfill different functions in a network (Barabasi 2002; Barabasi and Bonabeau 2003; Barabasi, Newman et al. 2006; Ferrary and Granovetter 2009).

In the context of this study, spinout success is defined as the spinout achieving ties to venture capitalists. Therefore, any node or tie changes making the node more attractive to the VC community would be enhancing the nodes fitness. As noted earlier, research studies have identified specific criteria utilized by the venture capital community in their evaluation of potential funding opportunities. These criteria can be categorized as market focused, management focused, financial focused and product focused (Zacharakis and Meyer 2000) as suggested in figure 14.

![Figure 14 Venture capital funding assessment criteria](image-url)
Perez and Sanchez (2003) note that an early-stage spinout’s success is primarily dependent on its product’s technological performance. Much university research is embryonic and risky requiring significant effort to commercialize (Lowe 2002; Shane 2004; Vohora, Wright et al. 2004). This suggests that a university spinout must enhance its’ product performance to make the spinout node more fit and network ties that facilitate this improvement in node fitness can be critical during the firm’s early development stages. Once a node is “fit enough” it can attract additional ties, such as venture capital firms, that will enhance its ability to build-out a successful and complete network.

Venture capitalist’s product assessment criteria for prospective funding opportunities include having a working product or prototype, having demonstrated product success, having differentiated product attributes or capabilities, having proprietary elements to the product such as patents, having the ability to get the product to market in a reasonable time frame and having a broad product scope (Wells 1974; Tyebjee and Bruno 1984; MacMillan, Siegel et al. 1985; Khan 1987; MacMillan, Zemann et al. 1987; Roberts 1991; Fried and Hisrich 1994; Shepherd 1999; Shepherd 1999). Venture capitalists are also concerned about product differentiation (Tyebjee and Bruno 1984) and product uniqueness (Wells 1974; MacMillan, Siegel et al. 1985; MacMillan, Zemann et al. 1987). Venture capitalists are most attracted to funding opportunities where these product concerns are addressed (DeClercq, Fried et al. 2006).

This literature suggests that the benefits of network ties may be related to the state of node development and that, for early-stage spinouts, ties related to improving the node’s product fitness may be most important to the early-stage pre-VC funded spinout. Improving technological fitness can provide an easily observable signal of the progress a firm has made in advancing towards its technological objective indicating the firm’s higher quality and legitimacy (Spence 1974; Hallen 2008).
Early-stage spinouts do require functional services, such as legal, accounting, staffing and banking services; however, ties to these nodes do not need to be strong given their likely transient nature once VC funding is secured (Ferrary & Granovetter, 2009) and their lack of significant contribution to technological fitness. Other formal functional nodes such as public relations and investment banking may be entirely absent at the early spinout stage with no anticipated impact on the firm’s performance. As noted earlier network ties can be costly to maintain and strong ties are more costly to maintain then weak ties (Burt 1992; Hansen 1999). The lack of resources of early-stage pre-VC funding spinouts suggest they will not have the resources to maintain a large network of strong connections however some strong ties are critical as suggested by the following hypothesis.

**Hypothesis 8:** Early-stage pre-VC funded spinouts will establish strong inter-organizational ties with nodes that can enhance their technical performance.

*Temporal evolution of ties*

As suggested by Perez and Sanchez (2003) node fitness is a temporally evolving construct. Spinout firms will, over time, enhance their technological performance and, on a relative basis, ties established to enhance technological performance may decline in importance. Venture capitalists are most attracted to funding opportunities where critical product concerns are already addressed and where the additional funding is to be applied to marketing and sales activities (DeClercq, Fried et al. 2006). The spinout’s closure of a VC funding round is an indicator of the spinout’s likely achievement of certain product capability milestones, such as the development of a working product or prototype (Wells 1974; Tyebjee and Bruno 1984; MacMillan, Siegel et al. 1985; Khan 1987; MacMillan, Zemann et al. 1987; Roberts 1991; Fried and Hisrich 1994; Shepherd 1999; Shepherd 1999). Once such initial financial investment ties
are formed technological accomplishment becomes relatively less important to future tie formation (Hallen 2008).

Researchers have suggested that participants may find strong ties costly to maintain (Hansen 1999) and that maintaining such ties can lead to opportunity costs (Burt 1992). For early-stage spinouts with limited resources these costs can have a material impact on their performance. People are limited in the amount of time they have available for making and maintaining relationships (Mayhew and Levinger 1976). Pre-VC investment spinouts will not have the VC firm serving as a hub to expand their network (Ferrary and Granovetter 2009) nor will they be able to afford the resources to maintain a large network (Hansen 1999). This suggests limited network dynamics for pre-VC funded spinout networks and the following hypotheses:

**Hypothesis 9a:** Once established, a spinout’s inter-organizational network will not change significantly prior to the infusion of venture capital.

**Hypothesis 9b:** Externalities, such as the infusion of venture capital triggered by achievement of node fitness milestones, will trigger periods of rapid network change in early-stage networks.

As spinouts become more fit their ability to attract venture capital increases. To consider this attraction of venture capital nodes we next consider the nature of the university-venture capital cluster.

*Venture clustering and spinout funding*

Leveraging networks to broker contacts to potential investors, such as venture capitalists, can be important for spinout firms (Roberts 1991; Hall and Hofer 1993; Shane and Cable 2002; DeClercq, Fried et al. 2006). Universities generating the most spinouts have been noted to be those with vast social networks to be leveraged (Lockett, Wright et al. 2003).
Researchers have shown that the source of an investment proposal can be important to the proposing firm’s funding outcome (Hall and Hofer 1993; DeClercq, Fried et al. 2006). From the venture research literature we know that knowledge sharing is the primary driver for VC networking. Among venture capitalists sharing information is even more important than the spreading of financial risk as a reason for networking (Bygrave 1987). Studies have observed that network ties, while assisting venture capitalists in their selection of spinouts to evaluate, do not create social obligations that impact the VC’s ultimate funding decision (Shane and Cable 2002). In a study of a specific venture firm, Atlantic Capital, it was noted that the specific referral source was not important; however, the source’s prior experience in referring potential investment opportunities to the fund was a key consideration. If a referent’s prior referrals had been funded the likelihood that a new referral would be funded was higher (Roberts 1991). In conclusion, network ties can facilitate a spinout’s consideration for funding however the funding decision itself is a far more complex process.

Referents also need to attract venture capital that will find the spinout node fit for funding. Venture funds have internal funding guidelines that include criteria such as investment geography, limiting their involvement in given areas (Tyebjee and Bruno 1984; Roberts 1991; DeClercq, Fried et al. 2006). Thus, spinout nodes vary in fitness for linking to specific venture capital nodes based on, at a minimum, the university spinout’s location suggesting the following.

**Hypothesis 10:** Early-stage spinout capital funders will geographically cluster in the region near the university spinouts.

In conclusion, early-stage university spinout inter-organizational networks are anticipated to be incomplete, only establishing strong ties with nodes that can enhance their technological performance. These networks will display limited dynamics for sustained time periods until nodes fitness reaches a point to support the addition of new nodes to the network, such as venture
capital providers, thus driving periods of rapid network growth. These network dynamics display characteristics anticipated by the theory of punctuated equilibrium (Tushman and Romanelli 1985; Gersick 1991; Levinthal 1998) where major change occurs through the introduction of hubs, such as venture capital providers, as illustrated in the following figure.

![Diagram of network growth via punctuated equilibrium](image)

**Figure 15 Early stage network growth via punctuated equilibrium**

This analysis of early-stage network dynamics suggests why venture capital funding (or potentially other early-stage network externalities) is so critical for network growth.

The following three sections outline the methodology applied to analyze these hypotheses, the results of the research effort and the conclusions suggested. Each section addresses a subset of the overall hypotheses. Chapter 3 focuses on the university inventor-spinout ties (hypotheses 1 and 2). Chapter 4 focuses on university inventor productivity considerations (hypotheses 3 through 6). Chapter 5 focuses on the pre-VC funded university spinout network (hypotheses 7 through 10).
CHAPTER 3: OUTCOME EQUIVALENT TIES

Hypotheses 1 and 2 suggest that ties to an inventor’s research network will be as or more effective as direct inventor ties in attracting venture capital interest. To evaluate these hypotheses a survey of early-stage venture capital providers was conducted to discern their relative preferences for various investment options varying on the criteria of interest to this analysis. This data was then analyzed using linear regression techniques.

Methodology

From the research literature on venture capitalists’ funding criteria we know that numerous considerations come into play when venture capitalists evaluate investment opportunities. These criteria become necessary controls for this study and include deal characteristics in broad categories related to the entrepreneurial team, product/service, market and finance (Zacharakis and Meyer 2000). To manage these control variables a survey was created where early-stage investors were presented with investment scenarios that had these control variables fixed. Investment options were varied based on the limited criteria of interest to this study and a linear regression analysis was conducted to evaluate impact.

Data source

To develop the survey vehicle, interviews were conducted with 5 early stage investors to validate the critical investment criteria identified by Zacharakis and Meyer (2000) and to confirm its applicability across a range of early-stage investors. Interviewees included 1 U.S. angel investor, 1 U.S. venture capital investor, 2 European venture capital investors and 1 principal in a U.S. accelerator. This feedback validated the applicability of Zacharakis and Meyer’s (2000) criteria across all the early-stage investors interviewed.
An initial version of a survey vehicle was executed during one of the face-to-face venture capital investor interviews and feedback on survey wording was incorporated into the initial survey instrument. This discussion identified signaling and knowledge transfer as critical dimensions in evaluating the importance of inventor and inventor network participation in the spinout firm. The negative signal from no “inventor” or no “inventor network” participation in the spinout was emphasized over the concern for reduced knowledge access from this lack of participation. Questions on this topic were added to the survey to further probe this observation.

The electronic survey was executed using Survey Monkey and distributed via e-mail to 16 early-stage investors in the Spring of 2012. All investors were known to the principal investigator and included 7 angel investors and 9 venture capitalists. Ten of the investors were from the U.S., four from Europe and two from Asia. Ten completed surveys were received for a response rate of 59%. The final respondents included 7 venture capitals and 3 angel investors with 60% from the U.S. and 20% respectively from Europe and Asia. The survey respondents had, on average, over 12 years experience in early-stage venture investment with tenure varying between 5 and 25 years.

Each respondent rated 9 different information technology and bio-science investment scenarios on their attractiveness as an early-stage investment, providing the data for our dependent variable and a sample of 180 prioritized investments as input for our analysis. The survey vehicle used to gather this data is included in Appendix 1.

*Dependent variable*

The surveyed early-stage investors were asked to prioritize nine different investment opportunities for potential investment. Respondents were asked to rank the investment opportunities on a scale from 1 to 9 with 1 representing the highest recommendation for investment and 9 the lowest. If the potential investor was indifferent between two investment
options they were asked to prioritize them with the same ranking. The relative ranking by the early-stage investors of the investment scenarios presented was used as the scale-level dependent variable for this analysis.

*Independent variables*

The independent variable of interest in this study is the nature of the inventor-spinout ties. Nicolaou & Birley (2003 a,b) studied university spinouts based on a categorization of the university inventor’s involvement with the new firm. They distinguished between university inventors who were uninvolved with the new venture and those who participated on a full- or part-time basis. This categorization was expanded for this study to capture ties involving the inventor’s university research network. This new categorization includes three mutually exclusive tie definitions as follows: university inventor active in firm, university inventor not active in firm however the university inventor’s students/colleagues are active in firm, and neither the inventor or the inventor’s research network are active in the firm.

The mutual exclusivity and complete coverage of these various tie scenarios allows one scenario to serve as the base case in the regression model. All these variables are dichotomous, or dummy variables, receiving a value of 1 if the stated tie scenario is the one in place at the spinout firm. These categorizations and their variable identifiers are listed in figure 16.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Variable description</th>
</tr>
</thead>
<tbody>
<tr>
<td>INV ACTIVE</td>
<td>Only the academic inventor active with the new firm</td>
</tr>
<tr>
<td>NW ONLY</td>
<td>Academic research network members active with no inventor involvement</td>
</tr>
<tr>
<td>NOINVOLVE</td>
<td>No involvement of inventor or academic research network members</td>
</tr>
</tbody>
</table>

*Figure 16 Table of independent variables for the evaluation of hypotheses 1 and 2*

Tie strength for this variable is measured using a technique similar to Bearden et al (1975) in their study of corporate Board interlocks where tie strength was based on the role and full-time nature of the Board members involvement with the firm. Using similar criteria full-
time relationships with the inventor should establish stronger ties and ties directly to inventors should be stronger than ties to others familiar with their work. Thus, the relative strength of the tie categorizations suggested above can be identified and the ties sorted by strength as shown in figure 17.

![Figure 17](image)

However, our hypotheses suggest that tie strength is contextual and specifically dependent on the nature of the networks to which the ties are being established. Thus, in the context of this university spinout study it is posited that ties to members of the inventor’s university research network can prove as strong as ties directly to the university inventor. Based on this hypothesis the relative tie strengths of the proposed connections can be re-sorted as shown in figure 18.

![Figure 18](image)

It is thus anticipated that the $\beta$ values in the regression for the scenarios involving connectivity to the inventor’s university research network will be as large as or larger than the $\beta$ values for the scenarios where only the inventor is actively involved with the spinout.
Control variables

By presenting survey respondents with a fixed scenario for their analysis the large number of control variables identified in the research literature could be fixed for our analysis. The early-stage investors surveyed were informed that the investment options they were being asked to consider only varied based on the two characteristics explicitly identified. They were guided that all other criteria for these investments had been evaluated by them and deemed highly favorable.

As an example, it was suggested that the spinouts had an excellent and extremely large market opportunity, an excellent team, an easy to communicate value proposition and a strong competitive position. It was noted that the firms being considered for investment were physically located in a region where the investor traditionally invested and were at a stage of development the investor deemed appropriate for investment consideration. The key technology that differentiated the investment opportunity was identified as patented and exclusively licensed by the firm from the university under very favorable terms.

A control variable for technical fitness was varied across the investment scenarios presented. This variable was varied to present scenarios where the key technology was only lab proven (with no alpha or beta products available), where the technology was incorporated into a product prototype (alpha version with no client testing) and where the product development was more robust with a prototype of the product commercially launched in beta form to a single client. These scenarios presented variation in the spinout’s technical commercial readiness as outlined in figures 19 and 20.
This technology readiness control variable was varied across scenarios to capture the anticipated variation in knowledge transfer requirements and its potential impact (Hansen 1999; Uzzi and Lancaster 2003). Interaction effects between technology readiness and inventor ties are then evaluated. Given the mutual exclusivity of these various ties, one scenario can serve as the base case in the regression model and does not need to be operationalized as a discrete variable. These variables are dummy variables receiving a value of 1 if the stated tie scenario is the one in place at the spinout firm.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Variable description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BETA PROTOTYPE</td>
<td>Beta version of prototype; one client testing</td>
</tr>
<tr>
<td>ALPHA PROTOTYPE</td>
<td>Alpha version of prototype; no client testing</td>
</tr>
<tr>
<td>LAB ONLY</td>
<td>Lab proven (no alpha or beta product)</td>
</tr>
</tbody>
</table>

The research literature suggests that inventor involvement as CEO of the firm is viewed positively by venture capitalists for firms involved in bio-science (Finkle 1998). To test this industry distinction industry control variables were established. Specifically scenarios were separately presented to the early-stage investors for information technology and bio-science investment prospects. These industry specific scenarios were evaluated independently by the survey respondents and the investors were guided that they should assume investment in the respective industries was consistent with their firm’s investment interests. The survey respondents first rated the information technology firms for their relative attractiveness for investment and then separately were asked to consider a similar mix of firms operating in the
bio-sciences arena. The investor’s responses for these separate investment prospects were pooled to determine the significance of industry to the regression results. Industry was established as a dummy variable with a value of 1 if the investment was in the bio-sciences space. The bio-sciences data was also evaluated independently to compare the impact of direct inventor ties and inventor network ties in this distinct industry space.

Variables were also included to control for the characteristics of the early-stage investor survey participants. Controls included years of early-stage investment experience, nature of the investor (VC or angel) and geographical region of focus (U.S., Europe or Asia).

Analytic technique

Simultaneous multiple linear regression, as used in this analysis, is the best modeling approach when you have a small number of predictor variables and no prior ideas about which predictor variables will produce the best model. The following model was used in this analysis:

\[ \text{Early-stage investor’s prioritization of investment opportunity} = \beta_0 + \beta_1(\text{tech lab proven}) + \beta_2(\text{beta prototype}) + \beta_3(\text{inventor active}) + \beta_4(\text{network active}) \]

All analyses for this study were conducted using the SPSS statistical analysis toolset. With more than 20 data points per variable the data sample meets the minimum sample size of 10 recommended by numerous researchers (Everitt 1975; Kunce, Cook et al. 1975; Nunnally 1978; Arrindell and van der Ende 1985; Garson 2008).

A hierarchical multiple linear regression technique was used in this analysis and additional variables were added to this model to evaluate interaction effects (alpha x inventor active, beta x inventor active, alpha x network active, beta x network active) and control variables for investor characteristics (venture capitalist, Asia, Europe, years of early-stage investment experience) and for industry (bio). In all cases minimum sample size requirements were maintained.
Results

Assumptions

With linear regression modeling it is important that the dependent variable be normally distributed, that the relationship between the dependent and independent variables be linear, and that the error or residual be normally distributed and uncorrelated with the independent variables. Variables must also be tested for multicollinearity, caused by high intercorrelations among predictor variables. These model assumptions are evaluated prior to reporting our findings.

Initial calculations were conducted for the information technology investment scenarios. Statistics for the dependent variable, early-stage investor’s prioritization of the investment opportunity, indicate a skewness statistic of 0.409 with a standard error of 0.255. This measure is well within the acceptable range of +/- 1 (Leech, Barrett et al. 2008) indicating that our assumption of a normally distributed dependent variable holds.

Scatter plots of the dependent variable versus each independent variable visually confirmed that the assumption of linearity for our model is not violated. For dichotomous variables the scatter plot has two columns of data points. Linearity is violated if the data points bunch at the ends or centers of the columns (Leech, Barrett et al. 2008).

Next correlations among the dependent variables were evaluated. Since the variables are nominal a Spearman’s Rho correlation test was utilized. Correlation between nominal pairs is expected, as shown in figure 21, however, as desired, no correlation is noted between the tie and technology readiness variables. Pearson correlations were also run confirming these results. To further test for multicollinearity the model regression was run and Tolerance values and collinearity diagnostics calculated. If Tolerance values are < (1-Adjusted R^2) then there is likely a problem with multicollinearity; however, the Tolerance values for these variables were 0.754, exceeding 0.674 as desired.
Figure 21 Spearman's rho correlations

The collinearity diagnostics, shown in figure 22, were next reviewed. This table provides the proportion of estimated variance accounted for by each principal component. If a component associated with a high condition index has a variance proportion greater than 0.5 in more than one instance collinearity concerns are raised; however that is not the case with this data.

<table>
<thead>
<tr>
<th>Model</th>
<th>Dimension</th>
<th>Eigenvalue</th>
<th>Condition Index</th>
<th>Variance Proportions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>(Constant)</td>
<td>Prototype Alpha</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>2.528</td>
<td>1.000</td>
<td>.03</td>
</tr>
<tr>
<td>2</td>
<td>1.017</td>
<td>1.576</td>
<td>.00</td>
<td>.13</td>
</tr>
<tr>
<td>3</td>
<td>0.983</td>
<td>1.604</td>
<td>.00</td>
<td>.13</td>
</tr>
<tr>
<td>4</td>
<td>0.330</td>
<td>2.751</td>
<td>.00</td>
<td>.36</td>
</tr>
<tr>
<td>5</td>
<td>0.233</td>
<td>4.368</td>
<td>.97</td>
<td>.35</td>
</tr>
</tbody>
</table>

Figure 22 Collinearity diagnostics

Similar results were obtained from an analysis of the assumptions for the bio-sciences data set (Skewness = 0.719, Tolerance values < (1-R²), all Collinearity Diagnostics < 0.5). With the model’s data assumptions confirmed we can now proceed to an analysis of our findings.

Descriptive statistics

Descriptive statistics for the survey responses follow. The dependent variable, early-stage investor’s prioritization of investment opportunity, was prioritized by the early stage
investors on a scale from 1 to 9 where 1 was the most attractive investment option presented. Respondents were first presented with 9 different information technology investment scenarios to prioritize. After they had completed this task they were presented with 9 different bio-sciences investment scenarios to again prioritize. The descriptive results from both these prioritization efforts are presented in figure 23. In addition, the investors were asked to rate the importance of signaling and knowledge transfer considerations to their investment prioritizations. These factors were rated on a scale from 1 to 7 where 1 was identified as “very important” and 7 was identified as “not important.” The investors, as seen in figure 23, noted that both signaling and knowledge transfer considerations were critical factors in their prioritization of the investment opportunities presented.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Std. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Priority of information technology investment</td>
<td>4.47</td>
<td>1</td>
<td>9</td>
<td>2.24</td>
</tr>
<tr>
<td>Priority of bio-sciences investment</td>
<td>4.13</td>
<td>1</td>
<td>9</td>
<td>2.24</td>
</tr>
<tr>
<td>Signaling importance</td>
<td>2.5</td>
<td>1</td>
<td>6</td>
<td>1.592</td>
</tr>
<tr>
<td>Knowledge transfer importance</td>
<td>2.12</td>
<td>1</td>
<td>4</td>
<td>1.061</td>
</tr>
</tbody>
</table>

Figure 23 Information technology investments descriptive statistics

The importance of signaling to investors was identified during preliminary interviews and corroborated in these surveys. Signaling importance was nearly rated as highly as knowledge transfer considerations in the early-stage investor’s investment decision making.

Figures 24 and 25 provide detailed descriptive statistics on the individual investment scenarios presented for prioritization to the early-stage investors. Figure 24 presents data from the information technology (IT) investment scenarios and figure 25 presents the bio-sciences data. Lower means reflect a preferred rating for the given investment. Investment scenarios with higher product readiness were preferred by the early-stage investors. Investment scenarios with no active participation by either the inventor or their network were rated the most negative and,
in most instances, a slight preference for the participation of the inventor’s network, in lieu of inventor participation, was observed. Interestingly, as the technology readiness decreased the preference for network involvement increased.

<table>
<thead>
<tr>
<th>IT investment prioritization</th>
<th>Mean</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Std. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alpha product, inventor active</td>
<td>3.7</td>
<td>1</td>
<td>8</td>
<td>2.1</td>
</tr>
<tr>
<td>Alpha product, network active</td>
<td>3.6</td>
<td>1</td>
<td>5</td>
<td>1.0</td>
</tr>
<tr>
<td>Alpha product, no one active</td>
<td>6.2</td>
<td>2</td>
<td>9</td>
<td>2.2</td>
</tr>
<tr>
<td>Beta product, inventor active</td>
<td>2.7</td>
<td>1</td>
<td>6</td>
<td>2.1</td>
</tr>
<tr>
<td>Beta product, network active</td>
<td>2.7</td>
<td>1</td>
<td>6</td>
<td>1.6</td>
</tr>
<tr>
<td>Beta product, no one active</td>
<td>5.2</td>
<td>3</td>
<td>9</td>
<td>2.2</td>
</tr>
<tr>
<td>Technology only, inventor active</td>
<td>5.0</td>
<td>3</td>
<td>9</td>
<td>1.8</td>
</tr>
<tr>
<td>Technology only, network active</td>
<td>4.6</td>
<td>2</td>
<td>7</td>
<td>1.6</td>
</tr>
<tr>
<td>Technology only, no one active</td>
<td>6.7</td>
<td>3</td>
<td>9</td>
<td>2.3</td>
</tr>
</tbody>
</table>

Figure 24 IT investment prioritization

<table>
<thead>
<tr>
<th>Bio-sciences investment prioritization</th>
<th>Mean</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Std. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alpha product, inventor active</td>
<td>3.6</td>
<td>1</td>
<td>8</td>
<td>2.0</td>
</tr>
<tr>
<td>Alpha product, network active</td>
<td>3.2</td>
<td>1</td>
<td>5</td>
<td>0.9</td>
</tr>
<tr>
<td>Alpha product, no one active</td>
<td>5.8</td>
<td>2</td>
<td>9</td>
<td>2.3</td>
</tr>
<tr>
<td>Beta product, inventor active</td>
<td>1.9</td>
<td>1</td>
<td>6</td>
<td>1.5</td>
</tr>
<tr>
<td>Beta product, network active</td>
<td>2.4</td>
<td>1</td>
<td>6</td>
<td>1.5</td>
</tr>
<tr>
<td>Beta product, no one active</td>
<td>4.7</td>
<td>2</td>
<td>9</td>
<td>2.3</td>
</tr>
<tr>
<td>Technology only, inventor active</td>
<td>5.2</td>
<td>3</td>
<td>9</td>
<td>2.2</td>
</tr>
<tr>
<td>Technology only, network active</td>
<td>4.4</td>
<td>3</td>
<td>6</td>
<td>1.3</td>
</tr>
<tr>
<td>Technology only, no one active</td>
<td>6.1</td>
<td>3</td>
<td>9</td>
<td>2.2</td>
</tr>
</tbody>
</table>

Figure 25 Bio-sciences investment prioritization

Regression results

Figure 26 presents the results of the OLS regression analysis for all the information technology and bio-science investment scenarios. Five regression models used to predict the dependent variable, early-stage investor’s prioritization of investment opportunity, are presented. The first model represents the base case with the independent variables discussed earlier and the industry category as a control. For the additional models the SPSS Hierarchical Multiple Linear Regression function was utilized. For the second and third model various control variables for the survey participants were added. For the fourth model the procedure was again applied to test for interaction effects between the technology readiness and spinout tie independent variables.
Finally the fifth model tests three way interaction effects between the bio-science’s industry control variable, technology readiness and the spinout tie independent variables.

The optimal model for dependent variable predictability is Model 3 with an adjusted $R^2$ of 0.400. The model incorporates the technology readiness and spinout tie independent variables (all of which are significant), the industry control variable (which is not significant) and control variables for the early-stage investors surveyed for this study. The investor control variables that proved significant included the years of experience of the investor, the type of investor (venture capitalist versus angel) and the geographic location of the investor. Venture capitalists and early-stage investors with greater experience tended to rate the investment scenarios more positively. European investors tended to rate the scenarios more negatively than their American peers. While these investor controls are significant their impact on the model’s overall $R^2$ was a modest 6.5% improvement in total. It is not surprising that characteristics of the early-stage investor would impact their prioritization of investment opportunities; however the modest nature of this impact is of note. The addition of these control variables had minimal impact on the $\beta$ coefficients of the independent variables of interest. This suggests that investor differences, while having an impact on the overall ratings of the investment opportunities, were not significantly impacting the relative weights of the variables of interest.
## Table

<table>
<thead>
<tr>
<th>Model 1</th>
<th>Model 2</th>
<th>Model 3</th>
<th>Model 4</th>
<th>Model 5</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tech lab proven</strong></td>
<td>1.036 (334)**</td>
<td>1.027 (333)**</td>
<td>1.024 (320)**</td>
<td>0.592 (558)**</td>
</tr>
<tr>
<td><strong>Prototype beta</strong></td>
<td>-1.076 (332)**</td>
<td>-1.083 (333)**</td>
<td>-1.083 (318)**</td>
<td>-1.016 (551)**</td>
</tr>
<tr>
<td><strong>Bio</strong></td>
<td>0.266 (277)</td>
<td>0.201 (271)</td>
<td>-0.016 (280)</td>
<td>-0.014 (280)</td>
</tr>
<tr>
<td><strong>Venture capitalist</strong></td>
<td>-500 (398)'</td>
<td>-2.042 (341)**</td>
<td>-2.044 (543)**</td>
<td>-2.044 (547)**</td>
</tr>
<tr>
<td><strong>Europe</strong></td>
<td>1.304 (390)**</td>
<td>1.310 (392)**</td>
<td>1.310 (394)**</td>
<td></td>
</tr>
<tr>
<td><strong>Asia</strong></td>
<td>0.104 (395)</td>
<td>0.111 (396)</td>
<td>0.111 (399)</td>
<td></td>
</tr>
<tr>
<td><strong>Years</strong></td>
<td>-0.105 (040)**</td>
<td>-0.104 (040)**</td>
<td>-0.104 (040)**</td>
<td></td>
</tr>
<tr>
<td><strong>Beta x inventor</strong></td>
<td>-0.206 (040)**</td>
<td>0.043 (866)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Tech x inventor</strong></td>
<td>0.952 (789)</td>
<td>0.742 (372)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Beta x network</strong></td>
<td>0.200 (779)</td>
<td>0.287 (860)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Tech x network</strong></td>
<td>0.598 (784)</td>
<td>0.654 (866)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Bio x beta x inventor</strong></td>
<td>-0.842 (378)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Bio x tech x inventor</strong></td>
<td>0.532 (378)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Bio x beta x network</strong></td>
<td>-0.218 (378)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Bio x tech x network</strong></td>
<td>-0.135 (378)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>R²</strong></td>
<td>0.365</td>
<td>0.376</td>
<td>0.431</td>
<td>0.441</td>
</tr>
<tr>
<td><strong>Adj R²</strong></td>
<td>0.347</td>
<td>0.354</td>
<td>0.400</td>
<td>0.397</td>
</tr>
<tr>
<td><strong>F value</strong></td>
<td>19.306</td>
<td>17.148</td>
<td>14.114</td>
<td>9.948</td>
</tr>
<tr>
<td><strong>Significance model</strong></td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td><strong>R² change</strong></td>
<td>0.010</td>
<td>0.055</td>
<td>0.010</td>
<td>0.005</td>
</tr>
<tr>
<td><strong>F change</strong></td>
<td>2.813</td>
<td>5.300</td>
<td>0.758</td>
<td>0.194</td>
</tr>
<tr>
<td><strong>Significance F change</strong></td>
<td>0.095</td>
<td>0.001</td>
<td>0.554</td>
<td>0.813</td>
</tr>
</tbody>
</table>

N = 179, unstandardized coefficients with standard errors in parentheses

*p<0.10, **p<0.05, ***p<0.01, ****p<0.001

Dependent variable: Early-stage investor’s prioritization of investment opportunity

Figure 26 OLS Regression Information Technology and Bio-science investment scenarios
Hypothesis 1a: Outcome equivalent ties

As predicted by hypothesis 1a, spinout ties to a university inventor’s research network are as beneficial as direct ties to the inventor(s) in enabling the spinout’s ability to raise venture funding. If we look across the findings for all 5 models analyzed the β coefficients for the spinout ties (inventor active and network active) are all negative and significant at a ρ<0.001. Relative to the base case of neither the inventor nor their network active with the spinout firm these ties improved the relative rating of an investment option by more than 2 points (on the 9 point investment rating scale). The unstandardized β coefficients for the investment scenarios presented in figure 26 allows for a direct comparison of the β values. The β values and their standard errors are consistent across the various models. Within each model the β values for active networks are consistently more negative, and thus even more beneficial within the model estimates, than those for active inventors.

To confirm these initial OLS results regressions were run separately on the two industry specific portfolios independently prioritized by the investors surveyed. The results of these models for the information technology and bio-science investment scenarios are presented in figure 27 and, as expected, our earlier results are validated; the spinout ties for both models are negative, significant and of a similar scale to each other and to the consolidated models analyzed above.
Power and significant effect detection

The comparison of β values discussed above suggests that network-only and inventor-only ties have similar impact on early stage funder’s evaluation of prospective investments. At a desired power of 0.80 we can calculate the difference in means that would be detectable given the data’s sample size and the descriptive statistics presented in figures 24 and 25. Differences in investor prioritization greater than 20% to 44% between the network-only scenarios and the inventor-only scenarios would be detectable at this power level as noted in the following figure.
<table>
<thead>
<tr>
<th>Investment Scenario</th>
<th>Detectable difference in investment prioritization between inventor-only and network-only scenarios at a power of 0.80</th>
</tr>
</thead>
<tbody>
<tr>
<td>IT investment, alpha product</td>
<td>32%</td>
</tr>
<tr>
<td>IT investment, beta product</td>
<td>44%</td>
</tr>
<tr>
<td>IT investment, technology only</td>
<td>20%</td>
</tr>
<tr>
<td>Bio investment, alpha product</td>
<td>31%</td>
</tr>
<tr>
<td>Bio investment, beta product</td>
<td>44%</td>
</tr>
<tr>
<td>Bio investment, technology only</td>
<td>24%</td>
</tr>
</tbody>
</table>

Figure 28 Difference where, at a power of 0.80 with the data sample size and descriptive statistics, a significant effect is expected to be identified should one exist

Contrast coding for improved power

Contrast coding the inventor-only, network-only, no-one-active variable of interest can potentially improve the Power for this analysis (Davis 2010) and help tease out differences not discerned at the Power levels achieved via the dummy coding technique deployed above. Since there are three groups for the tie types, two contrast codes must be established. The following coding was applied to discern potential differences between the inventor active scenarios and the network active scenarios: Contrast 1 (Inventor active = -1, Network active = +1, No one active = 0). To isolate the “no one active” tie a second contrast code was also established: Contrast 2 (Inventor active = -1, Network active = -1, No one active = 2). These contrast codes allow us to directly compare all the data available (N=59) for the inventor-only and network-only ties.

Descriptive data for the three tie variables of interest follow:

<table>
<thead>
<tr>
<th>Tie type</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>Maximum</th>
<th>Minimum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inventor only</td>
<td>3.68</td>
<td>2.2</td>
<td>9</td>
<td>1</td>
</tr>
<tr>
<td>Is 0.4</td>
<td>3.48</td>
<td>1.52</td>
<td>7</td>
<td>1</td>
</tr>
<tr>
<td>No one active</td>
<td>5.76</td>
<td>2.21</td>
<td>9</td>
<td>2</td>
</tr>
</tbody>
</table>

Figure 29 Descriptive statistics for the three tie scenarios (note lower mean = preferred investment)
For the regression analysis a third and fourth contrast code was used for the technology readiness variable, coded as follows: Contrast 3 (Alpha = -1, Beta = +1, Tech only = 0) and contrast 4 (Alpha = -1, Beta = -1, Tech only = 2). The modified regression was conducted using the other independent and control variables from Model 3 calculated earlier since this model resulted in the best Adjust R² value. The model analyzed follows:

\[
\text{Early-stage investor’s prioritization of investment opportunity} = \beta_0 + \beta_1(\text{Contrast 1}) + \beta_2(\text{Contrast 2}) + \beta_3(\text{Contrast 3}) + \beta_4(\text{Contrast 4}) + \beta_5(\text{Bio}) + \beta_6(\text{VC}) + \beta_7(\text{Europe}) + \beta_8(\text{Asia}) + \beta_9(\text{Years}).
\]

The resulting coefficients from this analysis are provided in figure 30. The overall model adjusted R² is 0.400, the same as model 3 as expected. The β for Contrast 1 remains non-significant, indicating an inability to discern any difference in impact between the inventor-only and the network-only ties however a calculation of Power indicates that at a Power = 0.80 differences in investment prioritization of greater than 14% between the two tie scenarios would be expected to be detected. At a Power = 0.95 a difference of 18.4% or greater would be expected to be detectable. These results suggest that, at most, very minor differences exist between the impact from inventor-only or network-only ties on investment prioritization by the investors.

![Table](image)

Figure 30 OLS Regression Information Technology and Bio-science investment scenarios


**Hypothesis 1b: Network tie transmission of tacit knowledge**

The technology readiness of the investment options presented for investor prioritization varied from having a beta version of the product built and installed in a single client to licensing a less vetted laboratory proven technology. Situations with lower technology readiness are expected to require greater transmission of tacit knowledge from the inventor to the spinout firm, thus requiring stronger ties. Given this variation in need for tacit knowledge transmission across the investment scenarios presented one would expect that interaction effects would be observed between the technology’s readiness and the nature of the spinout tie with a significant and negative $\beta$ coefficient (implying greater preference for the investment) expected for scenarios where the technology has a lower state of readiness but the tie is a traditionally stronger tie directly to the inventor. The interaction terms added to Model 4 in figure 26 however show that none of these interaction terms are significant suggesting no interaction between technology readiness and the nature of the spinout ties in this study. The addition of the technology readiness-spinout tie interaction effect has no impact on the significance of the $\beta$ values for the direct impact of the inventor and network spinout ties in the base model and only results in minor shifts in their unstandardized $\beta$ values. For the model overall the addition of the interaction terms has a modest (1%) and negative impact on Adjusted $R^2$.

Knowledge transfer was rated very highly (2.12 average on a 7 point scale where 1 was most important) as a consideration in the prioritization of investments by the survey respondents. From the results of the analysis of hypothesis 1a we realize that investors find ties to the inventor or their networks extremely valuable as noted by the scale and significance of the $\beta$ values for these ties in the model. The lack of interaction effects on these ties as scenarios shift in their relative need for tacit knowledge transfer suggests that the investors value direct inventor ties and inventor network ties as equally capable for the transfer of either explicit or tacit knowledge.
This null effect is thus supportive of hypothesis 1b that states that network ties will be as beneficial as direct ties to university inventors for the receipt of both tacit and explicit knowledge.

_Hypothesis 2: Industry neutrality_

Hypothesis 2, which suggests industry characteristics will not moderate the beneficial impact of ties to a spinout’s ability to raise VC funding, was also supported by the data. In model 5 variables were added to capture the 3 way interaction effect of investment scenarios in the bio sciences, with varying degrees of technology readiness and varying spinout-investor ties. None of the 3 way interaction variables proved significant to the model nor was the unstandardized value or significance of the $\beta$ values for the spinout tie variables impacted by the addition of these new interaction terms. The overall model impact from the addition of the interaction variables was extremely modest (0.5% impact) and negative to the Adjusted $R^2$.

When investors were directly asked in the survey whether they would prioritize the investments presented differently whether they were in the information technology or bio-sciences space only 40% acknowledged a prioritization shift. In analyzing the data this shift was in a preference towards either information technology or bio-sciences and did not translate into an impact on the significance or value of the spinout tie $\beta$ coefficients as noted in figure 26, which presents the information technology and bio-science models independently.

These null effects suggest that mediation by industry is not appreciably impacting the outcome variables in the model and specifically, in the bio-sciences space, does not demonstrate a preference by investors for stronger direct ties to the university inventor as observed in prior research.

In the following section we will consider these findings, note limitations of this research and suggest additional avenues for investigation.
Discussion and Conclusions

Our initial research question was, “How, if at all, does variation in the nature of the tie between the university inventor(s) and spinout firm impact the new firm’s ability to raise venture funding?” The research findings suggest that early-stage venture investors view spinout ties to either the inventor or their network as “outcome equivalent” when making investment decisions and that the impact of variation in tie strength between university inventors and spinout firms can only be properly interpreted within the context of the spinout’s ties to the overall university inventor’s research network. These findings have important implications for the study of tie strength and structural equivalence.

Measuring tie strength in a small world network context

Ties viewed as distinct based on traditional measures of tie strength may actually perform equivalently when the ties are connecting to nodes within small-world networks. When connecting to small-world networks traditionally more and less strong ties may prove to be “outcome equivalent” due to the bridged network’s structure. In these instances traditionally dissimilar ties may be found to provide similar overall benefits to the bridging networks.

Prior work by Hansen (1999) and Uzzi & Lancaster (2003) suggest when strong versus weak inter-organizational ties are most appropriate to establish; however, a nuanced distinction of actual tie strength based on the structural characteristics of the bridged networks was not considered. Given the nature of the networks being connected, tie strength may need to be considered in the context of the overall network versus the strength of specific ties to certain key individuals. Individuals, such as university inventors, can effectively only support a limited number of strong ties while the capacity of an overall research network for tie support is, in aggregate, far greater. Spinout firms may find ties to the network to prove even more valuable than traditionally defined strong, but less effective, ties to specific key individuals.
Studies distinguishing between tie strength and explicit versus tacit knowledge transfer must consider the impact of the network within which the desired knowledge is embedded. Given the characteristics of small world networks the findings relative to equivalence of tacit knowledge transmission from either the network or the source node are not surprising however they are critical considerations for the study of tie strength impact.

This effort suggests that, when analyzing tie strength, connections to both individuals and their networks must be considered to avoid confounding effects on measures of tie impact.

*Outcome equivalence*

Structural equivalence considers the concept of roles; where structurally equivalent nodes have similar connectivity to the network and play the same part in the network, thus making them interchangeable (Lorrain and White 1971). Structural equivalence, in its strongest sense, suggests that nodes are identical in terms of all their network connections; in practical use nodes regarded as sufficiently similar are termed structurally equivalent in the research literature (Scott 2000). Lorrain and White (1971) allowed for aggregation of structurally equivalent nodes into sets for ease of analysis.

Outcome equivalence, as suggested in this paper, is a related but distinct concept. Outcome equivalence relates to equifinality and path equivalence (George and Bennett 2005). The unit of analysis may compare disparate network elements, such as nodes to networks as done in this study; the focus is on outcomes and the transmission of information across network ties. With outcome equivalence you start with your goal and then trace ties and their relative impact to determine equivalence. Network structure is important, such as the small world networks studied in this paper; however, equivalent network structures are not presumed in the determination of outcome equivalence. The ties of a university professor and a university
student would likely not be considered structurally equivalent in a traditional network analysis but they can be outcome equivalent as displayed in this study.

*Industry moderation*

The research literature has been mixed on the impact of the university inventor’s involvement with the spinout firm, specifically as the spinout’s CEO. Many studies suggest that this does not result in positive outcomes (Franklin, Wright et al. 2001; Hayter 2010) while some, specifically in the bio-sciences space, suggest a positive outcome correlation with the inventor’s involvement (Finkle 1998). To interpret these findings in the context of this study’s results we need to consider network theory, confounding influences and outcomes.

Network theory would suggest that, within the small world networks of university research, knowledge transfer will occur equivalently for direct inventor ties or ties to the inventor’s network as noted in hypotheses 1a and 1b. From our early-stage investor survey we know that both knowledge transfer and signaling are important considerations in prioritizing investments and the knowledge transfer and signaling benefits of direct or network ties were viewed equivalently by the survey participants given their prioritization of the investment scenarios presented. Per this study, strong direct ties to inventors are not viewed more or less negatively by investors than network ties alone and industry (bio versus IT) has no impact on this observation.

Why might our results and the suggestions from network theory differ from some of the findings of prior studies? First, this study evaluates the inventor being active with the spinout; however, the strong tie of the inventor acting as CEO was not explicitly tested. The CEO is a very specific and significant role providing a unique form of strong direct tie that likely has a confounding influence that needs to be explicitly tested.
The outcome variable is also quite different across studies. Finkle (1998) studied public bio-technology firms and found university inventor CEO involvement to be positively correlated with better performance. Causality is a concern in this study. Since university professors generally do not desire to give up their academic position one could argue that professors will only act as CEO for a large upside opportunity, self selecting university CEO’s to these market opportunities (Shane 2004). The outcome variable in our study is “enabling early-stage VC funding.” Venture capitalists may feel comfortable with the inventor’s involvement at this early-stage in development while the need to bring in professional management can become more pressing as the firm progresses towards commercialization (Hayter 2010).

**Study limitations**

There are a number of issues to consider with this study. First the study is contributing to network theory in the explicit context of early-stage investments in university spinout firms limiting its broader external validity. This focus was selected for several reasons. First, the business of early-stage investors is to evaluate firms for investment potential. They consider a large number of issues in making this evaluation including the nature of ties between participants. By creating investment scenarios that fix many of variables the investor’s consider a survey could be created that focuses their evaluation upon the criteria of interest to this study. The investment scenario prioritization approach used made this study more a field experiment than a traditional survey given its similarity to the day-to-day activities of the investor community engaged.

External validity is further limited by decisions made to limit survey complexity, impacting industry and tie structure generalizations. The survey only considers two industry areas, information technology and bio-sciences. The applicability beyond these two industry areas would need to be tested although theory would suggest similar behavior. Similarly, as
discussed earlier the study presented a very strong contrast in tie structure to accentuate the signal of interest however nuanced ties such as having the inventor active as the CEO was thus not explicitly tested.

The data also limits external validity. For the study 180 investment scenarios were evaluated by 10 different early-stage investors. These investors were sourced to provide a representative sample of the early-stage investment community and included venture capitalists and angels active worldwide. The survey respondents were very senior investors with, on average, more than 12 years experience in the early-stage investment field. Control variables for the investors were put in place and differences across investors were noted. While each investor evaluated 18 investment scenarios, our understanding of investor variability was limited to the 10 investor participants. Fortunately the investor control variables had minimum impact (less than 6.5%) on the outcome of interest and their addition to the model did not impact the coefficients for the independent variables that were the focus of this study.

*Future work*

This study suggests several promising areas of future research. The eternal validity of the network theoretic findings could be extended by evaluating this study’s findings in additional contexts. Research also needs to be conducted to determine how best to measure and compare outcome equivalent ties and how this concept can be incorporated into our understanding and measurement of tie strength in general. This study approach could also be replicated in a modified fashion to test more nuanced descriptions of various ties and their impact. This could include the functional nature of ties, such as the university inventor as CTO, CEO or Advisory Board member, or a more granular distinction between the strength of the various ties presented. A review of prior research studies evaluating tie strength impact could also be conducted and
studies involving links to small world networks evaluated to tease out the potential network impact on the study results.

The scenario prioritization survey data collection used for this study was informed by designs for conjoint analysis studies. Conjoint analysis has been used in the past for the analysis of venture capital decision making (Riquelme and Rickards 1992). The results of this study provide a baseline for the evaluation of a related methodological approach, prediction markets, for the gathering of similar data. Prediction markets employ a market mechanism where, through the market, information is shared with participants. How prediction market tools compare to traditional analysis techniques such as used in this study is an area for further research.

*Implications for practice*

In the context of university spinouts this study suggests that active inventor involvement with the spinout is not a necessary condition for the attraction of early stage capital; however, participation by either the inventor or their research network with the spinout is essential. This finding has implications for policies at many universities that limit the ability of students and researchers in inventor labs to work with an inventor’s start-up. While there are good reasons for such policies that extend beyond the focus of this study, these findings can inform a possible reformulation of such policies to better serve the multiple objectives desired.

More generally, these findings have important implications for the management of any knowledge-based business supported by key individual contributors. It suggests that if these firms are structured as small world networks then company stakeholders can be served as effectively (or perhaps more effectively) via connectivity to the network versus direct connectivity to key individual contributors. These findings are useful considerations for organizational design as well as to serve as a communication vehicle to company stakeholders.
who many times insist on direct contact with specific individuals in their quest for a given outcome.
CHAPTER 4 INVENTOR-SPINOUT TIES & ACADEMIC PRODUCTIVITY

Hypotheses 3 through 6 suggest that ties between a university spinout and inventor will impact the inventor’s productivity in their university tasks of invention and publishing. To evaluate these hypotheses archival data on university inventors at the California Institute of Technology (CalTech) was combined with online data on patent applications from the U.S. Patent and Trademark Office and publication data from the Web of Science. This data was analyzed using t-tests and linear regression techniques.

Methodology

Two dependent variables are the focus of this analysis. They are an inventor’s patent application and research publishing productivity pre- and post- the licensing of the inventor’s technology by a university spinout. The inventor’s patent and publishing productivity is measured by the number of patent applications and the number of research articles (where the author is one of the first three authors listed) published in a given period of time. An initial comparison of productivity before and after the spinout license is conducted through a comparison of means via a paired one-sided T-test. This is followed with a linear regression analysis to tease out the impact of specific independent variables on these productivity measures. From the research literature we know that a university inventor’s research and publishing productivity are impacted by numerous factors. Many of these factors are intrinsic to the inventor, such as their experiences in their academic career (Dietz and Bozeman 2005), and are incorporated as controls in this study. For the regression analysis the dependent variables are structured as a percent change in output from before and after the formation of the spinout. The structuring of the dependent variable as a pre- and post- comparison of productivity for a given inventor in a constrained period of time limits the impact of and need for many control variables
utilized in earlier research although they are incorporated into one of our models to test this premise. The study also focuses on spinouts from a single university thus controlling for potential cross-university differences. The independent variables of interest include the inventor’s physical proximity to the spinout firm, the inventor’s level of involvement with the firm, and the number of spinouts the inventor is involved with in the time period of interest.

Data source

The survey data collection effort to support this paper’s research was conducted with the support of the Association of University Technology Managers (AUTM) which provided introductions to the Directors of several university Technology Transfer Offices (TTOs). The data collected includes spinout company names, locations, license dates, and university inventor details. The data collection effort was launched in late 2010. The data collected on spinouts from CalTech is the focus of this research. The initial CalTech data included 104 spinouts licensing technologies between 1993 and 2010. The last two years of spinout data were dropped from the study (spinouts from 2009 and 2010) to enable a two year window for research publishing and patent application filing before and after spinout formation. The initial two years of spinout formation were also dropped (spinouts from 1993 and 1994) to enable capture of inventor involvement with multiple spinouts during the time period of interest before the formation of the spinout of interest. The two year period was selected to provide a reasonable period of time to capture inventor productivity while limiting loss of data from the sample. 57 spinout firms were incorporated into the final analysis.

Patent application data from the online U.S. Patent and Trademark Office database was queried to gather information on invention productivity. The query searched for applications where the university professor was listed as inventor and the university was listed as assignee.
The search was conducted for two years before and after the date of each spinout’s licensing of the university technology.

To gather data on research publishing productivity a query was conducted on the inventor’s name as author on the online Web of Science database. Query results were visually sorted to assure the topic returned was in the proper field of study for the inventor to remove any returns for authors with similar names. Query results where the author’s name was not one of the first three listed were also dropped to address the common practice in the sciences to list large numbers of authors on research publications. This sort was done on the assumption that the most meaningful contributions to a paper are contributed by its lead authors. The search was conducted for two years before and after the date of the spinout’s licensing of the university technology.

To measure whether the university inventor was active in the spinout firm, a dichotomous independent variable in the regression model; a Google query was conducted. The query was done on the inventor and company name and the first page of Google results were reviewed. If the inventor was identified as active with the firm in any of the query returns this variable was listed as a 1.

*Dependent variable*

Two dependent variables are the focus of this analysis. They are an inventor’s patent application and research publishing productivity. For the t-test, the inventor’s number of patent applications and research publications (output) before and after the spinout license date are compared. For the regression analysis the dependent variables are structured as a percent change in output from before and after the formation of the spinout. The percent change is calculated as follows:
Percent change in output = \((output\ post\-spinout\ licensing - output\ pre\-spinout\ licensing)/(output\ post\-spinout\ licensing + output\ pre\-spinout\ licensing)/2\)*100

Utilizing the number of research publications (Dietz and Bozeman 2005; Buenstorf 2009; Manjarres-Henriquez, Gutierrez-Gracia et al. 2009; Powers and Campbell 2011; Ynalvez and Shrum 2011) or patent applications (Buenstorf, 2009; Dietz & Bozeman 2005) as a measure of academic productivity is common in the research literature. Sourcing publishing data via bibliometric techniques through databases such as the Web of Science used in this study is also a common research practice. Similarly the U.S. Patent and Trademark Office online database used in this study is a typical source of patent data for research study (Dietz & Bozeman 2005).

To contrast the productivity data pre- and post- the spinout licensing event the time period for analysis was bounded at 2 years (for a total time period of 4 years per spinout event). This 2 year time period was established to allow for time lags in publication while minimizing attenuation of impact over a longer time period. The incorporation of the second year data is consistent with other studies in the research literature (Buenstorf, 2009).

For the regression analysis the dependent variables are structured as a percent change in productivity, pre- and post- the spinout license event. Defining the dependent variables in this manner, bounding the time period, and focusing on an individual academic inventor at a single university as the unit of analysis presents several benefits in the structuring of control variables for this analysis.

*Control variables*

The sociology of science research literature has identified numerous variables that impact scientist productivity. These variables include characteristics of the scientist, their discipline and their institutional environment.
Scientist demographic characteristics of interest include lifecycle effects that have been found to systematically impact individual productivity (Levin and Stephan 1991). To control for these lifecycle effects studies include both linear and quadratic terms for the scientist’s age, years since PhD, or years on faculty (Buenstorf, 2009). Additional demographic controls included in many studies include gender, citizenship and university position (Levin and Stephan 1991; Bozeman and Corley 2004; Dietz and Bozeman 2005; Fox 2005; Gulbrandsen and Smeby 2005; Carayol and Matt 2006). Since our analysis is a comparison at the individual university inventor level cross demographic differences are not critical controls in this study. Heterogeneity of the unit of analysis is limited to changes in the individual university inventor in the time period of concern. Lifecycle issues are also less critical since the timeframe of analysis is limited to a 4 year horizon; however, given the temporal design of the dependent variable, lifecycle controls for the inventors “years at the university” and “square of years at the university” are incorporated into one of the regression models.

Academic discipline has also been identified as a critical variable in productivity studies. Significant differences across disciplines in terms of publishing (Rinia, van Leeuwen et al. 2002) and patent (Carayol and Matt 2006) output have been noted. The major differences noted in the literature are between technical fields and the humanities/social sciences (Gulbrandsen and Smeby 2005). For this study spinouts are all licensing university technologies and the unit of analysis is the individual inventor so the discipline is constant pre- and post- the event of interest. Given differences noted between the biological and physical sciences in the spinout literature a dummy control variable (1 if biological/medical sciences and 0 otherwise) was established for this characteristic.

Institutional differences have also been noted as important in the productivity research literature. These include research university size and experience and the stock of inventions at
the researcher’s institution as well as more local issues such as laboratory size (Dietz and Bozeman 2005; Buenstorf 2009; Landry, Saihi et al. 2010). Since the data for this analysis is sourced from a single university no control variables are incorporated for these institutional differences.

Independent variables

While the comparison of means test provides a measure of difference between the inventor’s productivity pre- and post- the universities license to the spinout the independent variables in the regression model will be used to better understand the underlying mechanisms that may contribute to this difference. Since we are working with archival data for this analysis we have limited access to critical inventor information such as their personal and professional commitments during the time period of interest. Some of these professional commitments can be captured via the available data however and they are incorporated as independent variables (IV) in our analysis. These IVs include:

- Number of start-ups the inventor is involved with in the two years before the current spinout license of interest.
- Inventor not active with spinout is a dichotomous variable that receives a 1 if the inventor is not identified via an online search as the founder of the spinout firm.
- State of spinout licensee is another dichotomous variable coded as a 1 if the new company is located in California (CA is state where CalTech is located).

Results

A t-test is initially conducted to compare sample productivity means before and after the spinout technology licensing event to determine if evidence suggests the means of the two populations are different. For this analysis we conduct a paired sample t-test since the samples are productivity measures for individual university inventors.

To gain additional insight into the data simultaneous multiple linear regressions were also conducted. As used in this analysis, simultaneous multiple linear regressions are the best
modeling approach when you have a small number of predictor variables and no prior ideas about which predictor variables will produce the best model. The following model was used in this analysis:

$$\text{Percent change in academic productivity} = \beta_0 + \beta_1(\text{CA}?) + \beta_2(\text{not active in firm}) + \beta_3(\text{LN of number of spinouts 2 years prior})$$

All analyses for this study were conducted using the SPSS statistical analysis toolset.

A linear regression was used in this analysis and additional variables were added to the model to evaluate control variables for academic discipline and lifecycle considerations. The base model has 19 data points per variable and the complete model has 9.33 data points per variable approximately meeting the minimum sample size of 10 data points recommended in prior research (Everitt 1975; Kunce, Cook et al. 1975; Nunnally 1978; Arrindell and van der Ende 1985; Garson 2008).

**Assumptions**

With linear regression modeling it is important that the dependent variable be normally distributed, that the relationship between the dependent and independent variables be linear, and that the error or residual be normally distributed and uncorrelated with the independent variables. Variables must also be tested for multicollinearity, caused by high intercorrelations among predictor variables. These model assumptions are evaluated prior to reporting our findings.

Statistics for the dependent variables, percent delta in invention and percent delta in publishing, indicate skewness statistic of -0.162 and 0.175 respectively with a standard error of 0.316, well within the acceptable range of +/- 1 (Leech, Barrett et al. 2008) indicating that our assumption of normally distributed dependent variables holds. Skewness was noted among two of the independent variables, specifically the variables for “location in CA” and “number of active start-ups.” The “location in CA” Skewness and Kurtosis measures were -1.331 and -0.237 respectively. Since this is close to the acceptable range a decision was made to not transform
this variable. The “number of active start-ups” skewness statistic was 3.393 and its Kutosis measure was 12.327. Given the magnitude of these numbers a LN transformation was conducted correcting the skewness measure to 1.927 and the Kutosis statistic to 1.776.

Scatter plots of the dependent variable versus each independent variable visually confirmed that the assumption of linearity for our model is not violated. For dichotomous variables the scatter plot has two columns of data points. Linearity is violated if the data points bunch at the ends or centers of the columns which is not the case with this data (Leech, Barrett et al. 2008).

Next a correlation analysis was conducted. Both a Spearman’s Rho correlation and a Pearson correlation test were run and no correlation among predictor or control variables were noted (except for the “year” and “year²” variables, as expected) as seen in figure 31. To further test for multicollinearity the model regression was run and Tolerance values and collinearity diagnostics calculated. If Tolerance values are < (1-Adjusted R²) then there is likely a problem with multicollinearity which is marginally the case with this data (Tolerance = 0.902) driven by the low Adjusted R² for our model. Fortunately the VIF values are less than 2.5 (VIF = 1.108) suggesting this potential multicollinearity is not a critical concern.

To further investigate this issue the collinearity diagnostics, shown in figure 32, were next reviewed. This table provides the proportion of estimated variance accounted for by each principal component. If a component associated with a high condition index has a variance proportion greater than 0.5 in more than one instance collinearity concerns are raised; however that is not the case with this data.
Residuals were evaluated from a scatter plot of the regression’s standardized predicted value versus standardized residuals and no problems were noted. While some minor multicollinearity concerns remain due to the Tolerance values other measures for multicollinearity are acceptable and all other model data assumptions are confirmed. As a final multicollinearity test the independent model variables were isolated to determine if their $\beta$ shifts significantly. The $\beta$ for the variables of interest shifted less than 15% in this test and the
conclusions were not impacted by these modest changes. Given this we next proceed to the analysis of our models and findings.

Descriptive statistics

A preliminary analysis of spinout data from CalTech provides some insight into the nature of the spinouts and inventors to be surveyed. Some descriptive observations follow. At CalTech there are very few serial inventors. 73% of the university inventors were involved with only one spinout, 22% were involved with two spinouts, 2% with 3 spinouts and the remaining 2% with 5 and 8 spinouts respectively. The majority of the technologies listed a single principal investigator; only 4% of the technologies listed 2 principal investigators and no licenses noted more than 2 principal investigators. The inventors were senior faculty with an average of more than 15 years on staff at the university with times ranging from 4 to 41 years. Only 5 of the faculty inventors had been at CalTech for less than 6 years, a typical timeframe to achieve tenure.

Licensed technologies came from numerous university departments. 15% of technologies were attributed to chemistry (or chemical engineering), 13% to electrical engineering and computer science, 12% to biology, 10% to physics and 50% to various other departments. 18% of licensed technologies were university funded with the remainder funded via government grants. Over three quarters of the spinout licensees were located in California.

Our productivity measures indicate a decline in invention from an average of 4.82 patent applications in the 2 years prior to the spinout license to 3.67 patent applications in the two years following the license event. This finding is consistent with our hypothesis that patent applications would decline in this period. We also see that publications increase slightly post the licensing event from 7.23 publications before to 7.96 publications after. Detailed statistics are included in the following figure.
The following frequency distributions and box plots provides additional information on the inventor’s invention and publishing productivity. Figures 34 provides the frequency distribution for invention in the two years prior to spinout formation. Figure 35 provides boxplots of these invention frequencies both before and after spinout formation.

Figure 33 Inventor Productivity Descriptive Statistics

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Skewness</th>
<th>Kurtosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>CA or not</td>
<td>57</td>
<td>0</td>
<td>1</td>
<td>.17</td>
<td>.423</td>
<td>-1.331</td>
</tr>
<tr>
<td>Invention before</td>
<td>57</td>
<td>0</td>
<td>24</td>
<td>4.82</td>
<td>5.057</td>
<td>1.795</td>
</tr>
<tr>
<td>Invention after</td>
<td>57</td>
<td>0</td>
<td>16</td>
<td>3.67</td>
<td>3.715</td>
<td>1.456</td>
</tr>
<tr>
<td>Percent cota in inv</td>
<td>57</td>
<td>-200.0</td>
<td>200.0</td>
<td>-31.95</td>
<td>92.9068</td>
<td>-1.162</td>
</tr>
<tr>
<td>Pub before</td>
<td>57</td>
<td>0</td>
<td>26</td>
<td>7.23</td>
<td>9.225</td>
<td>.782</td>
</tr>
<tr>
<td>Pub after</td>
<td>57</td>
<td>0</td>
<td>35</td>
<td>7.96</td>
<td>7.831</td>
<td>1.514</td>
</tr>
<tr>
<td>Percent cota in pub</td>
<td>57</td>
<td>-200.0</td>
<td>200.0</td>
<td>15.723</td>
<td>95.6593</td>
<td>.175</td>
</tr>
<tr>
<td>Yrs at Caltech at time of license</td>
<td>57</td>
<td>4.0000</td>
<td>41.0000</td>
<td>15.778275</td>
<td>7.7255705</td>
<td>.788</td>
</tr>
<tr>
<td>Ln number startups 2 years prior</td>
<td>57</td>
<td>0</td>
<td>1</td>
<td>.16</td>
<td>.368</td>
<td>1.927</td>
</tr>
<tr>
<td>Active startups 2 years before plus current</td>
<td>57</td>
<td>1</td>
<td>4</td>
<td>1.23</td>
<td>.627</td>
<td>3.393</td>
</tr>
<tr>
<td>Not active in firm</td>
<td>57</td>
<td>0</td>
<td>1</td>
<td>.61</td>
<td>.491</td>
<td>-1.481</td>
</tr>
<tr>
<td>Valid N (Listwise)</td>
<td>57</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 34 Frequency of invention in 2 years prior to spinout formation
From figure 34 we note that invention frequency is positively skewed. The boxplots of figure 35 show that this skewness is impacted by 5 data points (less than 9% of the data) and that only one of these points (marked with an asterisk) is considered extreme. The skewed nature of the data continues post spinout; however the number of outliers drops to 5% of the data. The outliers are accurate data points and given our interest in understanding invention productivity changes the data is not adjusted for analysis.

Frequency distributions and boxplots are also provided for the inventor’s publishing output as noted in figures 36 and 37 below.
This publishing frequency distribution is less skewed than for invention and except for the higher frequencies around 0 and 7 the distribution is relatively flat suggesting somewhat negative kurtosis. Post spinout the boxplots show a much tighter distribution with 3 outliers (5% of data set), one of which would be considered extreme. Again no adjustments to the data are made for
our analysis based on these observations; however, given the frequency of null observations where the inventor had zero invention or publishing productivity, a sensitivity analysis with the zero invention and publishing productivity records removed is conducted as part of the regression analysis.

In the next sections we will determine the statistical significance of these descriptive observations and test some potentially contributing variables impactful to these productivity outcomes.

**Hypothesis 3 Patent productivity and spinout involvement**

The output for a comparison of means t-test for the university inventor’s invention productivity before and after the issuance of the spinout technology license is shown in figure 38. It shows a mean productivity of 4.82 inventions prior to the spinout license and a mean productivity of 3.67 post this event indicating a reduction of 1.15 inventions or 24% between the two periods. This effect is significant with a $\rho = 0.035$.

![Table 1](image)

**Figure 38 T-test results for invention means**

While significant, the effect size of this difference is small with a $d$ value of 0.26. The 95% confidence interval of the difference in invention means spans 0.083 to 2.233. This significant decline in the university inventor’s mean invention productivity post spinout
formation is supportive of Hypothesis 3 that states involvement of university inventors with university spinouts will negatively impact their patenting productivity.

**Hypothesis 4 Publishing productivity and spinout involvement**

A similar t-test for publication productivity did not detect any statistically significant difference in publication productivity before and after the licensing event. With the means, sample size and standard deviations noted in figure 39 the power for this analysis is a very low 14% so our ability to detect a statistically significant but small impact is quite limited. With this standard deviation and sample size an effect size of 45% could be detected with a power of 0.80. Smaller effect sizes would result in reduced power levels.

<table>
<thead>
<tr>
<th>Paired Samples Statistics</th>
<th>Mean</th>
<th>N</th>
<th>Std. Deviation</th>
<th>Std. Error Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pair 1 Pub before</td>
<td>7.23</td>
<td>57</td>
<td>6.225</td>
<td>0.825</td>
</tr>
<tr>
<td>Pub after</td>
<td>7.96</td>
<td>57</td>
<td>7.831</td>
<td>1.837</td>
</tr>
</tbody>
</table>

Figure 39 Invention productivity analysis

These results are consistent with prior theory and empirical research and the results are supportive of hypothesis 4 that the involvement of senior faculty inventors with university spinouts will not impact their publishing productivity or at least will not impact it substantially.

In the next sections we will utilize linear regression techniques to further inform our understanding of potential contributors to our inventor productivity models and provide insight into the remaining two hypotheses of this section.

**Hypothesis 5 Academic productivity and spinout physical proximity**

Two linear regression models were used for the analysis of the impact of spinout involvement on academic productivity. The first model analyzed the percent change in invention productivity and the results are presented in figure 40. The second model analyzed the percent change in publishing productivity and the results are presented in figure 41.
Three scenarios were evaluated for each model; the first scenario only included the independent variables of interest while the second scenario included all variables, independent and control, in the model. As a sensitivity analysis a third scenario was run including only the significant independent variables for each model: proximity measure (California?) and LN(number of active spinouts). These final revised overall models proved significant for both inventor and publishing productivity.

<table>
<thead>
<tr>
<th></th>
<th>Model 1 – no controls</th>
<th>Model 2 - controls</th>
<th>Model 3 – sig. variable</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Constant</strong></td>
<td>94.399 (29.462)</td>
<td>-81.507 (35.557)</td>
<td>-80.554 (24.905)</td>
</tr>
<tr>
<td>California?</td>
<td>56.697 (29.60)</td>
<td>64.729 (31.407)</td>
<td>63.086 (28.347)</td>
</tr>
<tr>
<td>Not active in firm</td>
<td>30.843 (24.902)</td>
<td>31.705 (25.818)</td>
<td></td>
</tr>
<tr>
<td>LN number of spinouts 2 years prior</td>
<td>-1.267 (33.608)</td>
<td>5.158 (35.602)</td>
<td></td>
</tr>
<tr>
<td>Academic discipline</td>
<td>-25.790 (26.510)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Years at university</td>
<td>-0.536 (5.364)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sq of years at university</td>
<td>-0.004 (0.136)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>R²</strong></td>
<td>0.108</td>
<td>0.125</td>
<td>0.082</td>
</tr>
<tr>
<td>Adj. R²</td>
<td>0.058</td>
<td>0.021</td>
<td>0.066</td>
</tr>
<tr>
<td>F-Value</td>
<td>2.147</td>
<td>1.196</td>
<td>4.945</td>
</tr>
<tr>
<td><strong>Sig</strong></td>
<td>0.105</td>
<td>0.324</td>
<td>0.03*</td>
</tr>
</tbody>
</table>

N = 57, unstandardized β coefficients with standard errors in parentheses

*p<0.10,  **p<0.05,  ***p<0.01
Dependent variable: Percent change in invention productivity

**Figure 40 Invention productivity regression models**

<table>
<thead>
<tr>
<th></th>
<th>Model 1 – no controls</th>
<th>Model 2 - controls</th>
<th>Model 3 – sig. variable</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Constant</strong></td>
<td>17.344 (30.824)</td>
<td>-48.944 (55.126)</td>
<td>29.324 (14.086)</td>
</tr>
<tr>
<td>California?</td>
<td>23.907 (30.968)</td>
<td>22.907 (32.327)</td>
<td></td>
</tr>
<tr>
<td>Not active in firm</td>
<td>-17.049 (26.053)</td>
<td>-23.881 (26.574)</td>
<td></td>
</tr>
<tr>
<td>LN number of spinouts 2 years prior</td>
<td>-60.842 (35.162)</td>
<td>-73.595 (36.645)</td>
<td>-51.686 (25.792)</td>
</tr>
<tr>
<td>Academic discipline</td>
<td>13.913 (27.287)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Years at university</td>
<td>6.034 (5.521)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sq of years at university</td>
<td>-0.095 (0.140)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>R squared</strong></td>
<td>0.079</td>
<td>0.126</td>
<td>0.068</td>
</tr>
<tr>
<td>Adj. R squared</td>
<td>0.027</td>
<td>0.021</td>
<td>0.051</td>
</tr>
<tr>
<td>F-Value</td>
<td>1.523</td>
<td>1.202</td>
<td>4.016</td>
</tr>
<tr>
<td><strong>Sig</strong></td>
<td>0.219</td>
<td>0.321</td>
<td>0.05*</td>
</tr>
</tbody>
</table>

N = 57, unstandardized β coefficients with standard errors in parentheses

*p<0.10,  **p<0.05,  ***p<0.01
Dependent variable: Percent change in publishing productivity

**Figure 41 Publishing productivity regression model**
In both models the inclusion of the control variables caused a drop in the overall Adjusted $R^2$ values. The best overall models were those that only included the significant independent variables with Adjusted $R^2$s of 0.066 for the invention productivity model and 0.051 for the publishing productivity model. These figures are consistent with prior academic productivity studies with similarly defined dependent variables such as Buenstorf’s (2009) study of the variable, “Log fractional publication count.” Buenstorf’s (2009) study, like ours, focuses on within inventor productivity changes and the Adjusted $R^2$ values for his study was 0.098. Between inventor productivity studies have much larger Adjusted $R^2$ values (Landry, Saihi et al. 2010), such as 0.300; however, in these cases the model’s major contributors are well known between academic controls for discipline and research unit size which are not meaningful given the definition of our within inventor productivity change dependent variable. Since individual productivity models are impacted by considerations such as an inventor’s available slack time and personal commitments a low $R^2$ for the overall models specified in this study, which do not include such variables, is not surprising.

As noted in figure 40, the proximity variable, “California?” was found to be positive and significant in the regression model for the “percent change in invention productivity.” This proximity variable was also found to be positive and significantly correlated with the dependent variable “percent change in inventor productivity” in the Pearson bi-variate correlation shown in figure 33. Proximity is a dichotomous variable represented by a 1 if the spinout company is located in California. The model indicates that being located “proximate” to the university improves the “percent change in invention productivity” by 63% within a standard error band of 35% and 91%.

This regression was also run with all null invention records removed (no additional inventions in the four year period around the date of spinout formation). Five records were
removed from the data. The proximity variable “California?” remains significant at the 0.10 level (Unstandardized $\beta = 63.278$, Std. Error = 33.584, Sig = 0.066).

A decision tree analysis was also conducted to potentially contribute to our understanding of the overall productivity model. The decision tree was run using the CHAID technique, Chi-squared Automatic Interaction Detection. At each branch CHAID chooses the independent variable that has the strongest association with the dependent variable (Borgatti, S.P., Everett, M.G. & Freeman, L.C. 2002). The parent node and child node parameters were set at 5 and 2 respectively for this analysis. The resulting tree has only one branch, occurring for the “California?” independent variable as illustrated in the figure below. This result was repeated for the dataset with the null invention records removed. These results are confirmatory of the findings from our regression analysis.

![Decision tree for invention productivity analysis](image)

**Figure 42** Decision tree for invention productivity analysis

These overall findings are supportive of hypothesis 6 that the involvement of university inventors with physically proximate spinouts will have a positive impact on their academic productivity.
Hypothesis 6 Academic productivity and multiple spinout involvement

Figure 41 shows that the variable LN (number of spinouts inventor is involved with in the 2 years prior to the current spinout’s formation) is significant to the model for publishing productivity. This regression was also run with all null publishing records removed (no publishing in the four year period around the date of spinout formation). Five records were again removed from the data. The variable LN (number of spinouts inventor is involved with in the 2 years prior to the current spinout’s formation) remains significant at the 0.10 level (Unstandardized β = -74.335, Std. Error = 38.167, Sig = 0.057).

A decision tree analysis was also conducted to potentially contribute to our understanding of the overall productivity model. The decision tree was run using the CHAID technique, Chi-squared Automatic Interaction Detection; however no branching occurred on any of the independent variables, including the variable LN (number of spinouts inventor is involved with in the 2 years prior to the current spinout’s formation) where branching was anticipated. An alternative branching technique, CRT (Classification and Regression Tree), was also tested. CRT branches on the independent variables that result in segments that are as homogeneous as possible with respect to the dependent variable (Borgatti, S.P., Everett, M.G. & Freeman, L.C. 2002). The parent node and child node parameters were set at 5 and 2 respectively for this analysis. The resulting tree has numerous branches, with the second branch occurring on the “number of spinouts” independent variable, as expected. The various other branches are occurring based on faculty tenure, as noted in the following figure. This result was repeated for the dataset with the null publishing records removed; however branching for this reduced dataset only occurred on faculty tenure. While the tree based on the complete dataset is confirmatory of the findings from our regression analysis the decision tree based on the dataset reduced for the null publishing records did not replicate the regression findings.
To determine the effect size of the “number of spinouts” variable a graph of the “% change in publishing productivity” versus the number of active spinouts created is provided in figure 44. The graph includes plots of the standard errors as well. Initially, with a single start-up, the standard error includes a spectrum of potential changes from positive to negative. As the number of active spinouts increases the “% change in publishing productivity” becomes rapidly more negative. This finding is supportive of hypothesis 6 that the involvement of university inventors with multiple spinouts simultaneously will have a negative impact on their academic productivity.

As noted in the descriptive statistics, 97% of the CalTech inventors were involved with 3 or fewer spinouts in their careers so the high spinout involvement data is quite sparse and driven by a few highly productive start-up university inventors. To test the models sensitivity to faculty
highly active in the spinout arena the data for the top four highest spinout involvement faculty were removed from the data set and the model re-run. Without these highly active inventors in the data set the variable LN (number of spinouts 2 years prior) was no longer significant. This suggests that being active with a large number of spinouts can have a major negative impact on academic productivity as theory would suggest; however, the significance of the impact at lower levels of active spinout involvement is less certain. This sensitivity analysis also raises external validity concerns discussed below.

![Figure 44 % Δ in publishing productivity vs. # of active spinouts](image)

In the next section we will discuss the implications of these findings and suggest potential future steps to enhance this research effort.

**Discussion and Conclusions**

Academic output occurs in the context of complex networks and, as shown in this study, it is impacted by feedback loops, directed impacts, and moderating mechanisms. The empirical results of this study are supportive of these complex network interactions and a more robust model of academic technology transfer as initially visualized in figure 11 and modified in the figure below based upon our research findings. These findings respond to the challenge of Lowe
and Gonzalez-Brambila (2007) for more research to unpack correlation versus causation in the models of faculty entrepreneur’s research productivity.

Specifically, university spinout ties appear to negatively impact faculty patent productivity. Publishing productivity seems unaffected by faculty spinout involvement; however, a faculty member’s simultaneous involvement with numerous spinouts ultimately negatively impacts publishing productivity as well. Finally, working with proximate spinouts does appear to provide some positive benefits to academic productivity, moderating the negative impact of spinout involvement on academic patenting outcomes.

The positive effect of university-industry relations on research productivity noted in earlier studies comes primarily from the capacity of industry to provide complementary resources (cognitive, technical and/or financial) to these academic research efforts (Manjarres-Henriquez, Gutierrez-Gracia et al. 2009). This study indicates that some of the benefits to academia from industry interaction can still be realized in the context of early-stage spinout involvement; however, spinouts represent a unique class of interaction that requires focused consideration. Our empirical results suggest that a spinout’s limited resources and greater need for assistance change the impact of these industry ties on the university inventor.

As an example of such spinout assistance, in a survey of university inventor’s conducted for an analysis of spinout networks reviewed in the next section, the need to provide significant
time to support the spinout’s fundraising initiatives was identified. Specifically, in the year prior to a fund-raising event, more than 50% of academic inventor respondents stated they dedicated more than 20% of their time to this fund raising initiative. Such involvement is unlikely to occur in more traditional university-industry interactions and the nature of a spillover research benefit from such efforts is far less certain. Fortunately, the concept of outcome equivalence identified in our study of university inventor-research network-spinout ties provides a potential area for policy focus to optimize university-spinout interactions for the benefit of all parties.

Study limitations

This study has a number of limitations that provide opportunities for future research. The study is at an individual versus organizational level and the translation of such studies to their organizational impact can be complex. As an example, some research studies have noted that a decrease in patents can lead to an increase in university royalties, an unexpected outcome (Murray and Stern 2007). Working at the individual university inventor level however does allow the evaluation of conditions that impact individual academic research productivity, a key input to university technology transfer and prestige.

External validity is also a concern with this study. While the study evaluates data from 100% of the spinouts from a major U.S. research university the results are specific to this university and its academic inventor network. This focus allows for the control of many university specific variables; however, the results may not translate to universities more broadly. For example, a specific university may have a policy of licensing technologies exclusively to singular firms which research has shown has a dampening effect on research publishing (Powers and Campbell 2011). Other universities, without such a policy, would be expected to demonstrate different publishing productivity impacts from spinout licensing events. Also, California, the proximate state in this study, is a very resource rich setting in the technology
start-up arena and thus the benefits of proximity observed in this study may not hold for less rich proximate areas.

The focus on a single university’s spinouts also constrains the studies available sample size impacting the studies power. This is not a concern for effects where a statistically significant signal was detected (with 95% confidence) such as the impact on invention productivity and the effects of multiple spinouts and of proximity. However, for effects where no significant impact was detected, such as the spinout’s impact on publishing productivity we can only acknowledge that any such impact, if it exists at all, cannot be very large (in our case greater than 45% at a power of 80%).

The focus on a single university also creates some data constraints that limit the effects that can be evaluated. For example, at CalTech the majority of university inventors are senior faculty with 6+ years experience at the university. From prior research studies we know faculty seniority can have an impact on productivity; however, this moderating effect could not be confirmed in this study. Also, while a significant number of spinouts were in the bio-medical arena CalTech does not have a medical school which may bias the nature of these bio-medical businesses. Finally, with a single university sample there are only a small number of university inventors active with large numbers of spinouts, possibly creating a bias in results due to individual inventor effects.

Finally, in this study we focused on academic productivity as defined by the production of patent applications and research publications. No effort was made to evaluate the quality of these outputs via citation measures, as an example.

*Future work*

Given the structure of the dependent variable proposed in this study data from university inventors at additional universities can easily be aggregated with a minimal increase in control
variables (dichotomous variable per university data added). Adding additional inventors to the study will improve both the studies external validity and power. Adding data from additional university settings could also potentially improve coverage of certain inventor classes, such as lower seniority inventors or inventors extremely active with spinouts, two classes of academic inventors with limited coverage at the university evaluated in this study. TTO policy effects could also be evaluated with the variability a cross university study would present.

Implications for practice

This study proposes a revised theoretical model of academic productivity in the context of university spinouts, outlined in figure 45. A key finding is that spinout involvement creates a negative impact on university invention productivity; however, licensing to spinouts physically closer to the university can result in moderation of this negative effect. Thus, this suggests that licensing locally can have beneficial impact on university technology transfer productivity by reducing any negative effects on academic invention, a key input to the technology transfer process.

Simultaneous university inventor involvement with multiple spinouts can extend negative effects to an academic inventor’s publishing productivity although no major impact on publishing productivity was detected for inventor’s only involved with a single spinout. Where inventors are active in multiple spinouts organizational policies, such as allowing for a conscious leverage of the university inventor’s research network, can be put in place to minimize these negative effects. In both these instances, as suggested by the study on outcome equivalent ties, facilitating spinout-academic inventor network tie formation can potentially reduce the burden of spinout ties on the academic inventor and thus reduce any negative impacts on their research productivity.
CHAPTER 5 PRE-VC FUNDING UNIVERSITY SPINOUT NETWORKS

Hypotheses 7 through 10 consider issues related to early-stage pre-VC funded spinout network dynamics. These considerations include network completeness, tie strength, temporal tie changes, and spinout-venture capital network bridging. The social network analysis techniques, applied in this study, are appropriate for the study of such relational data (Scott 2000). This relational data is composed of numerous nodes and ties which are analyzed via qualitative measures of network structure (Scott 2000) as well as statistical quantitative analysis.

Methodology

Social network analysis (SNA) is the study of relational data between nodes. Social network analysis leverages graph theory and graphical visualizations of network nodes and ties, called sociograms, to help identify and visualize relationships in networks. This form of analysis embodies a theoretical orientation towards the importance of a social world’s structure (Scott 2000). Social network analysis and visualization software from Analytic Technologies\(^1\) was used to create sociograms and to conduct the statistical analyses to evaluate our hypotheses.

Data source

An initial survey data collection effort to support this paper’s research was conducted with the support of the Association of University Technology Managers (AUTM) which provided introductions to the Directors of several university Technology Transfer Offices (TTOs) resulting in an initial data set that included spinout company names, locations, license dates, and university inventor details. This initial data collection effort was launched in late 2010 and resulted in the identification of spinouts at numerous U.S. research universities.

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With the university spinouts and university inventors identified a second survey vehicle was created to gather the spinout-level relational data of interest to this study. This survey vehicle was tested with nine inventors at two research universities (not including the university of final focus) during the summer and fall of 2011. Surveys were created via Survey Monkey and distributed via email. The same process used for survey vehicle testing was applied for the final survey release, a copy of which is provided in Appendix 2. Survey methods, as applied in this research, are common data collection techniques in network analysis studies (Granovetter 1973; Friedkin 1980; Marsden and Campbell 1984; Hansen 1999; Levin and Cross 2004). In ego-centric social network analysis it is typical to survey individuals to determine their network ties (Scott 2000); however, in this study, the unit of analysis is the spinout firm. Hansen (1999) in his study of ties across organizational subunits surveyed R&D management to gain insight into the nature of organizational sub-unit ties. A similar approach is being taken in this effort where we survey the university inventor to gain insight into the nature of the spinout’s ties.

To obtain high survey response rates a decision was made to focus the data collection effort on a single university where the principal investigator had established good initial connections. Thus, data for this study was gathered from university inventors at North Carolina State University. A number of steps were taken to improve response rates. An email which included the electronic survey was sent from the principal investigator to each university inventor in early 2012 and the principal investigator telephoned each survey recipient to bring their attention to the survey and to assure them that the survey link was from a legitimate source. Survey respondents were also entered in a raffle for an Amazon Kindle Fire. The survey had been re-designed to allow completion in under 10 minutes, which was referenced in both the email and telephone call for the final survey. The final survey response rate was 47% providing coverage of 29% of all spinouts from the university.
The AUTM survey data identified 52 spinouts from North Carolina State University. Circumstances reduced our ability to gather information on a number of these firms. The university had seven inventors who were involved with multiple spinouts. It seemed too intrusive to ask these inventors to provide feedback on each spinout so they were only queried on one of their spinouts, which was randomly selected by the principal investigator. In addition, 11 of the inventors were not faculty members or had left the university further reducing the addressable sample size to 32. The remaining 32 spinout inventor’s were surveyed resulting in a survey response rate of 47% and coverage of 29% of all North Carolina State University spinouts. The survey resulted in feedback on 15 spinout firms, 60 inventor network – spinout ties, and 165 spinout inter-organizational ties.

An analysis was conducted to determine potential bias in the respondent sample. Both respondents and non-respondents were found to be senior faculty with similar tenure at the university (7.1 years for respondents and 8.6 years for non-respondents). The departmental mix of survey respondent and non-respondents was also quite similar as seen in figure 46.

Bias caused by not being able to survey the 11 students/faculty inventors who were no longer at the university was also considered. A critical consideration was whether they had departed to join their respective spinout firms. To evaluate this, a Google search was conducted for the inventor and firm names and the responses on the first search return page were reviewed. In addition a search of the inventor, spinout and university names was conducted on the business
social networking site, Linkedin. No connection between these departed inventors and their respective spinout firms were detected. These inventors also came from several faculty departments at the university, indicating no departmental or industry bias in this sample.

To evaluate hypotheses 7, 9a and 9b survey feedback was collected on the nature of the spinout’s inter-organizational ties over time. The respondents were asked to identify in what year post technology licensing the spinout’s relationship with other universities, investment banks, law firms, media companies, PR firms, research labs, large corporate firms, HR firms, commercial banks, consulting groups and CPA firms began.

To evaluate hypothesis 8 the survey requested information on the strength of both the university-inventor spinout tie and the strength of ties between members of the inventor’s university research network and the spinout. Information was gathered on the ties of the inventor, other university professors, students/research assistants and post-doctoral fellows. The frequency and closeness of the relationship was rated on a 7 point Likert scale. For the frequency of interaction measure a 1 represented full-time involvement and a 7 represented interactions of 6 times or less per year. For closeness a measure of 1 was identified as very close and a 7 was represented as distant. The responses for the frequency and closeness survey measures were averaged to create the strength of tie measure used in this study. This measure is the same one used by Hansen (1999) in his study of the strength of ties in organizational networks.

Hypothesis 10 was evaluated through the use of archival data. A web search was conducted in the Spring of 2012 for each spinout’s name with the terms “venture capital”, “Series A”, and “angel funding” included in the search. Funding firms identified in the first Google search screen were noted. In addition a web search was also done to identify the company website. Where websites were found news releases and Board members were reviewed
to identify any ties to the venture capital community. The VentureSource database from Dow Jones was also leveraged to determine/confirm a spinout’s source of venture funding. Funding firms were identified for 14 of the 52 university spinouts; however, since two of the spinout licensees were located outside NC (one on Colorado and one in Massachusetts) they were removed from the samples leaving us with 12 funded spinouts for analysis. For these 12 funded spinouts 38 distinct funding firms were identified (since multiple firms were involved with several of the spinouts). Only two firms were found to make investments in multiple spinouts and only 12 of these spinout funders (32%) were members of the National Venture Capital association (NVCA).

Once funding firms were identified a Google query was then conducted on these funding firms to determine the nature and location of the funding entity. 19 of the 38 funding firms were found to be located in North Carolina. This data on the geographic-focus of the North Carolina State University spinout funders was then compared to the average geographic distribution of such funders in the United States venture community. To gather this baseline, archival data from the NVCA\(^2\) and the Gaebler.com\(^3\) online databases was utilized. The NVCA notes on their website that in 2010 there were 462 active U.S. venture capital firms, defined as firm’s investing at least $5 million in companies. The Gaebler.com data indicated that only 7 venture capital firms had a physical location in North Carolina. Since our earlier web search had identified 19 North Carolina based spinout funders this larger figure was utilized as the numerator to estimate the number of U.S. venture funders located in North Carolina, creating a baseline of 4.1%.

The survey data discussed earlier was utilized to create sociograms and conduct statistical analyses. SNA sample data, such as collected via this survey, can present difficulties relative to

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\(^2\) [http://www.nvca.org/](http://www.nvca.org/)
\(^3\) [http://www.gaebler.com/venture-capital-firms.htm](http://www.gaebler.com/venture-capital-firms.htm)
their representativeness for the entire data set. For relational data a representative sample of agents may not provide a similarly representative sample of the agent’s ties (Alba 1982). A focus on nodes as roles, such as used in this study, can address this concern (Burt and Minor 1983). Survey data on the relations between nodes can thus be used to determine what structural locations exist in a network (Scott 2000). In the next sections we will consider the format and results of these analyses in more detail.

**Analytic techniques**

The hypotheses in this study are analyzed via both sociograms and statistical analysis techniques. The statistical analyses in this study are focused on determining the probability that the parameters of interest (tie density, tie strength, and node geographic distribution) differ from a given baseline (tie density post VC funding, tie density 3 years after firm formation, tie strength of the spinout to the university inventor and average geographic distribution of venture capital investors). This form of analysis is typical of network studies where the focus is on the probability of parameters relative to theoretical baselines versus their probability of representing the population of all networks (Hanneman & Riddle 2005). T-tests are utilized for these comparisons.

A critical assumption of common statistical techniques, such as mean comparisons via t-tests, is that observations are drawn from independent, random samples. This assumption is typically violated in the study of relational data which, using standard statistical analysis tools, will result in under-estimates of sample variability and too high a confidence in the analytical results (Hanneman & Riddle 2005). To address this concern probabilities in this study are determined via simulation. Boot-strapping and permutation approaches are used to estimate sampling statistics directly from our observed networks through 5,000 boot-strap trials for our
density comparisons and 10,000 permutations for network attribute analyses (tie strength and
geographic distribution of nodes). These simulation techniques, while helpful, are not able to
fully compensate for the difficulties presented by the relational nature of social network data. A
statistical bias remains and is expected to vary as a function of the data’s auto correlation
(Krackhardt 1988; Carpenter, Li et al. 2012). Quadratic Assignment Procedures (QAP) have
been found superior to traditional OLS Monte Carlo simulations in a direct comparison of
techniques (Krackhardt 1988); thus QAP output is provided as part of this analysis.

A conditional probability analysis is also conducted to determine the propensity to form
future ties given pre-existing tie formation. This technique is particularly useful for such
sequential hypothesis testing. We now proceed to the results of this analysis and how they
inform the understanding of our hypotheses.

Results

In this study we initially consider the completeness of the pre-VC funded spinout’s inter-
organizational network. We next proceed to evaluate the spinout’s ties to technical nodes within
the university inventor’s research network. The study then considers the stability of these early
stage inter-organizational networks over time. The study concludes with an analysis of the
venture funding network supporting these university spinouts.

Hypothesis 7: early-stage spinout inter-organizational networks

The spinout’s early-stage inter-organizational network is visualized via the sociogram in
figure 47 where the square nodes are the various agents identified as important in Ferrary and
Granovetter’s (2009) study of start-up networks and the circles represent the various spinouts.
The Ferrary and Granovetter (2009) study establishes the boundaries defining what are the
significant inter-organizational relationships in start-up networks. The theoretical density of
these complete post-VC-funded start-up networks are the baseline against which the early-stage pre-VC funded spinout networks analyzed in this study are compared. To assure time for network development the spinout network 3 years post technology licensing was used for this comparison.

Ties in this sociogram illustrate the existence of connections between the various nodes. Measuring tie intensity via the multiplicity of its connections is one of the most widely used measures of tie weight in the research literature (Scott 2000). Node size in the sociogram is scaled to reflect the number of ties connecting to it. All spinout nodes have, by definition, ties back to the technology licensing university so this is the largest node in the network. Inter-organizational ties in this network drop off dramatically. The second most connected inter-organizational node is law firms with 9 connections followed by CPA firms with 5 ties. Several inter-organizational nodes, as can be seen in the sociogram, have 1 or fewer ties, such as consulting groups and HR companies.

The largest tie density for the spinouts is a degree of 6 for spinout 2 versus a potential degree of 12 for a fully connected inter-organizational network. Even after 3 years post the technology licensing event we see that 6 of these spinouts only have a degree of 1, having not established relationships with any additional inter-organizational firms.

While these spinout networks are 39.66% less dense then a fully connected post-venture funding spinout it is critical to consider the significance of this difference. To do this we ran a bootstrap simulation to conduct a paired sample t-test. 5,000 bootstrap samples were used resulting in a standard error for the difference of the paired samples of 0.0316, compared to a standard error of 0.0208 using classical analysis techniques. The resulting $\rho = 0.0002$ (t-statistic: -12.5649) allows us to conclude that the density of ties among organizations is much greater in the post-VC funded networks than in the early-stage networks of these pre-VC funded
spinouts. Note the QAP analysis comparing the year 3 spinout inter-organizational network to the theoretical post-VC funding network had a correlation value of 0.349 at a significance of 0.0002 showing significant correlation between these two networks which is not unexpected.

Figure 47 Year 3 inter-organizational spinout network

(Node size varies based on the density of ties connecting to the node; circles represent Spinouts and squares represent the Inter-organizational network nodes identified in Ferrary & Granovetter’s (2009) study. The sociogram includes 28 nodes and 86 ties.)

These findings are supportive of Hypothesis 7 that suggests early-stage pre-VC funded spinouts would have incomplete inter-organizational networks. In the next section we will consider the nature of the ties to the largest inter-organizational node, the licensing university, and the characteristics of the ties connected to technical resources of the inventor’s university research network.
Hypothesis 8: spinout ties to the inventor’s research network

By definition the university spinout has ties to the university and potentially has ties to the university inventor’s research network. Many nodes make up the inventor’s research network including the inventor, other professors, students/research assistants and post-doctoral fellows. In this analysis we consider the extent and strength of ties to these technical nodes.

Two measures of tie strength were used for this analysis. The first measure was the frequency of node connections identified in the sample data. In addition, conventional network measures of frequency and closeness are also used in a separate measure of tie strength (Burt 1992; Hansen 1999).

In the sociogram in figure 48 the inventor’s university research network members are identified via squares and the spinouts via circles. The size of the nodes again reflect the number of ties connecting to it. We see from the sociogram that the majority of spinouts have established multiple connections to the inventor’s technical network members; only 3 spinouts are only connected to a single node. A total of 24 ties to non-inventors were established by these 15 spinouts. In only one instance was a tie between the spinout and the inventor not established. While the spinouts are clearly establishing ties to the inventor’s technical research network we still need to determine the strength of such ties.

The number next to each tie reflects the tie’s strength (smaller is stronger). Existing ties between the spinout and the inventor had a mean tie strength of 3.4329 with a standard deviation of 1.791. Ties between the spinout and other members of the inventor’s research network averaged 3.729 with a standard deviation of 2.638. The difference in mean tie strength between these two groups was 0.301

To evaluate hypothesis 8, that early-stage pre-VC funded spinouts will establish strong inter-organizational ties with technical nodes, we need to determine if the ties to these additional
technical nodes are at an equivalent strength to the ties established directly with the university inventor, presuming that such ties would represent a strong connection. To do this a t-test is conducted to compare the mean tie strength of the spinout’s ties directly to the inventor and the ties to the inventor’s technical research network. This t-test was supported by a simulation of 10,000 permutations resulting in a $\rho = 0.7326$ for the two tailed test ($0.654$ and $0.374$ for the one tailed tests) indicating that no difference in strength could be detected between the spinout’s ties to the university inventor and to the members of their technical network. This finding is supportive of hypothesis 8.

Figure 48 Inventor’s network - spinout ties
(Node size varies based on the density of ties connecting to the node; circles represent Spinouts and squares represent the nodes in the inventor’s research network. The sociogram includes 19 nodes and 38 ties. Tie strength is included next to each tie and is an average of closeness and frequency measured on a 9 point scale where lower values represent stronger ties.)

In the next analysis we consider issues of network dynamics and the temporal evolution of these spinout inter-organizational networks.
Hypothesis 9a and 9b: constrained network dynamics

Hypothesis 9a suggests that, once established, a spinout’s inter-organizational network will not change significantly prior to the infusion of venture capital. To evaluate this hypothesis the spinout’s inter-organizational networks are compared at the end of the first year post the technology licensing event and again at the end of the third year following this event. The year 1 inter-organizational spinout networks are illustrated in the sociogram of figure 49 while the year 3 inter-organizational spinout networks were used in our earlier analysis of hypothesis 7 and are illustrated in figure 47. As before, the square nodes represent the various agents in the inter-organizational network, the circles represent the spinouts and node size is scaled to reflect the number of connecting ties.

The first year spinout inter-organizational network has a density of 0.0952 while the third year spinout inter-organizational network has a density of 0.1138, for a temporal density difference of 0.0185. To determine the significance of this difference a paired samples t-test was constructed using a bootstrap simulation of 5,000 samples. The bootstrapped standard error for the difference was 0.0083 (compared to 0.0157 for the classical t-test) and the $\rho = 0.0242$ (t-statistic: -2.2351) indicating a significant difference in network densities across the 3 year time frame. This change in network density is significant relative to the density of the first year network, representing an increase of 19%; however, the overall network density remains small at 0.1138. In the first year network there were 9 spinouts with only one tie and the largest spinout network had a degree of 6. By the third year the number of spinouts with only 1 tie had reduced to 6 however the largest spinout network remain unchanged. Note the QAP analysis comparing the year 3 spinout inter-organizational network to the year 1 spinout inter-organizational network had a correlation value of 0.905 at a significance of 0.0002 showing significant correlation between these two networks which, again, is not unexpected.
A conditional probability analysis was also conducted and the resulting tree diagram is represented in the following figure. The likelihood of tie formation is represented in this figure across the three year horizon analyzed in this study. The static nature of these networks is clearly demonstrated. If a spinout does not establish inter-organizational network connections within its first year then there is a 66% likelihood that no additional ties will be established before the end of year three. If a spinout does establish spinout ties in its first year then there is a 84% likelihood that no additional ties will be established in the subsequent two years.
These findings are, in total, not supportive of hypothesis 9a. The growth in the spinout’s network across the 3 year time horizon was significant; however, this finding must be cautioned given the modesty of the ties in the networks in both years and the paucity of tie formation. Network dynamics are significant however constrained for these early stage networks.

The network density for a fully connected spinout inter-organizational network for this sociogram, would be 0.5123. This fully connected network reflects the fully embedded post venture funding networks identified in Ferrary and Granovetter’s (2009) study. From our analysis of hypothesis 7 we know these early stage networks are nearly 40% less dense then these later stage post VC funded networks and that this large difference is significant. This significant network size difference pre- and post- a venture funding event is supportive of hypothesis 9b that venture funding can set the stage for rapid network growth.

In the next section we consider the nature of the venture capital networks that the spinouts connect to.
Hypothesis 10: venture capital clusters

The sociogram in figure 51 identifies the ties from various organized early-stage capital funding sources (angel or venture capital) to the spinout with tie strength measured via frequency of occurrence. The early stage capital providers are clustered by geography with one group representing funders from North Carolina (where NC State is located) and the other group representing funders located elsewhere. Measuring tie intensity via the multiplicity of its connections, as done here, is one of the most widely used measures of tie weight in the research literature (Scott 2000). The width of the tie is scaled to reflect the tie strength. The sociogram illustrates that 75% of the spinouts were funded by investors where at least one of the investment firms was located in the local state.

![Figure 51 Geographic mix of funding sources](image)

The data for this study indicated that 50% of the 38 spinout funders identified were North Carolina based versus the U.S. average of 4.1% of such providers having locations in the state. A t-test was conducted to confirm the statistical significance of this large observed difference in geographic mix. A simulation of 10,000 permutations was used for the test resulting in a $p = 0.000$ for the one-tailed test ($0.0001$ for the two-tailed test). These findings are supportive of hypothesis 10 that early-stage capital funders will geographically cluster in the region of the funded firms.
Discussion and Conclusions

This study supports the hypotheses that early-stage pre-VC funded spinouts will have incomplete inter-organizational networks and that these networks will expand slowly. These findings build upon and are supportive of Hallen’s (2008) work on the initial network positions of new organizations. Per Hallen (2009) new organizations form their early ties through the personal connections of their early stage human capital while later-stage connections are driven through organizational accomplishments.

This study suggests that these early-stage networks will have limited ties and that temporal network dynamics will be quite constrained. These networks will expand over time; however their growth will be modest, at least within the 3 year horizon evaluated in this study.

Perhaps driven by the need for organizational accomplishment to accelerate later-stage network growth this study indicates that one area early stage start-ups establish strong ties is to the inventor’s technology research network. These ties assist the firm in achieving critical product/service development accomplishments. During a spinout’s early-stages (pre VC funding) having more and stronger ties to nodes that enhance the spinout’s technical fitness facilitate development of the spinout’s technical fitness and ultimately attractiveness to VC funders.

The impact of ties on the spinout’s technological commercial readiness can take time however. The inventors in our survey were asked to judge the commercial readiness of the licensed technology at the point of license and one year post licensing. The results, displayed in figure 52, demonstrate a level of technological accomplishment however the majority of technologies continue to remain short of commercial readiness. This slow advancement towards commercial readiness likely plays a role in the constrained temporal network dynamics observed
in this study by limiting the attractiveness of these spinouts to venture capital investors who, as hubs, play a key role in network development (Ferrary & Granovetter, 2009).

![Figure 52 Technology commercial readiness](image)

Networking to and aligning the interests of inter-organizational nodes and spinouts is facilitated via the actions of network hubs, such as venture capital firms, that act in the interest of both the spinout and the various early-stage inter-organizational nodes. Network hubs orchestrate networking activities to ensure the creation and extraction of value (Dhanaraj and Parkhe 2006). A network hub manages knowledge mobility, assures innovation appropriability, and maintains network stability. Knowledge mobility is the ease with which knowledge is shared and deployed within the network (Dhanaraj and Parkhe 2006) while innovation appropriability is an environmental property that enables stakeholders to realize economic benefit from an innovation (Teece 1986). Network stability enables sustainable positive performance of the network over time (Dhanaraj and Parkhe 2006). Hubs are frequently found in networks driving the benefits noted above; however, hubs are not a required network element (Thompson 2004). Prior to a venture capitalist serving as a hub in a spinout’s network other entities could potentially assume this role.

TTO’s business development, IP protection, and royalty distribution responsibilities make them prospective hubs for pre-VC university spinout firms (Lockett and Wright 2005); however, not all TTOs perform this role. Hayter (2010) observed university TTOs assuming one
of three distinct service categories: serving as a primary provider of entrepreneurship services, serving a networking function to entrepreneurship services, or playing no role in the sourcing of entrepreneurship services. Typically university scientists without their own entrepreneurship network look to the TTO to serve as a network hub to facilitate their commercialization efforts (Audretsch, Lehmann et al. 2005). The TTO, like the VC firm in later stage networks observed by Ferrary and Granovetter (2009), can effectively introduce inter-organizational nodes, such as early stage-funders, to a continuous flow of prospective spinouts. By serving as a hub the TTO can potentially accelerate networking the spinout to early-stage funding networks via signaling and embedding functions the TTO can conduct on behalf of the spinout. A hub’s informal roles of socializing, signaling, embedding, and networking (Ferrary & Granovetter, 2009) can impact node fitness through alignment of inter-organizational node-spinout interests.

The study’s survey provided information on how the firm first got in contact with the venture capitalists they interacted with most. Respondents were asked to select from the following list: cold call, inventor’s contacts, CEO contacts, TTO contacts, other university network contacts, firm’s business partners (lawyers, accountants), or via venture capitalist approaching the firm. These observations are captured in the sociogram in figure 53. To capture the venture capitalist approaching the firm directed ties where relationship directions are indicated via arrows were incorporated into this sociogram. Tie strength was again measured via frequency of occurrence.

* 8 survey respondents to this question

Figure 53  Path to venture capital providers
This sociogram, which is descriptive and based on only 8 responses to this survey question, suggests a quite limited path from spinouts to the venture community. This is not entirely surprising since the early-stage spinouts network is quite limited. We see that business partners, such as lawyers do play an important role; however, since they are one of the few nodes in these early stage networks this is not entirely surprising. Just being there can make one valuable in this context. The lack of TTO involvement in bridging to the venture community is likely driven by the role assumed by the TTO at this specific university.

The benefits of ties in an early-stage spinout network may be either intrinsic to the tie via its’ bridging to the new node’s network, i.e. by providing links to the VC community, or it may be driven by the tie’s instrumental contribution to the node’s fitness, i.e. via its infusion of capital or performance of some service. This conceptualization is similar to two ideal types of actions suggested more than 40 years ago in a study of interpersonal networks (Mitchell 1969). Mitchell viewed interpersonal networks as built from the action of communication involving the transfer of information between individuals and purposive type action, or instrumental action, involving the transfer of goods and services between agents (Mitchell 1969; Scott 2000). Which type of contribution is most important from a tie at any given time likely depends upon the fitness of the node being investigated. This suggests that intrinsic tie benefits should not be assumed; network nodes may be unable to provide useful connections or may be incented to not share connections should they exist.

Spinouts in this study did not appear to focus on the networking capabilities of their potential inter-organizational ties when selecting potential connections. Our survey results indicate that references and reputation were the primary selection criteria used by spinouts in selecting inter-organization network connections. The network of contacts these nodes can provide was noted as the lead secondary selection criteria.
Who are these early-stage funders that spinouts need to network to? This study indicates that local funding firms are critical players in the spinout ecosystem. While the potential universe of funding firms is quite large the actual mix of funding firms active with a specific university’s spinouts is far more local and limited. Many of these early-stage funding firms are also not large, brand name venture funding players. As an indicator of this, only 12 of the 38 funders identified in this university spinout network were members of the National Venture Capital Association. This local characteristic suggests the opportunity for the TTO to play a more significant role as a hub bridging these local spinout-early stage funding networks.

This research contributes to the existing research literature by raising node fitness as a critical consideration in the evaluation of a potential tie’s benefits. As a complement to Ferrary and Granovetter’s (2009) study of Silicon Valley start-ups this work suggests that for early-stage spinouts, unlike for the later stage start-ups, strong embeddedness in the potential start-up network is unlikely. This study also extends Ferrary and Granovetter’s (2009) analysis of post-VC funded start-ups temporally so that the evolution of a start-up’s network can be analyzed from its’ founding through its’ VC funding milestone. The network dynamics of these early-stage spinouts was found to be highly constrained suggesting limited options for strategic action.

This study suggests that certain ties in a network, while functionally necessary, should not be considered strategic nor should they be supported via strong ties. Increasing tie strength to such nodes does not improve one’s performance and conceivably could lead to poorer overall firm performance. Maintaining strong ties with these nodes is unlikely to provide the firm with additional benefits and can prove costly to the firm’s overall production function. Consideration of the instrumental versus intrinsic benefits achievable from a given tie can facilitate decisions on the time and energy to devote to such relationships.
Study limitations

This study was based on data from a single large research university located in the Southern United States. A benefit of this focus is the ability to control for cross-university differences; however the external validity of this study is thus more limited. Our data collection was also limited to the size of this university’s spinout network. While our survey response rate was quite good additional data would have been beneficial. Fortunately the signals from the data were strong and thus significant. Finally, the identification of the importance of location to early-stage spinout funding networks suggests a need to validate this finding in additional geographic regions.

Future work

A number of avenues are suggested for further analysis based on this study. Replication of this study at other universities in other geographic regions will enhance the external validity of these findings. Qualitative case studies should also be conducted to unpack some the underlying mechanisms constraining these early stage networks and their network dynamics. These findings could also be interpreted through alternative theoretical lenses such as the more typical resource dependency theory or the theory of strategic action where contributions to these theories could be made from these findings. Finally, a more detailed analysis could be undertaken to more thoroughly understand the nature of the ties in these limited early-stage networks and their specific contribution to future network outcomes.

Implications for practice

This study has a number of implications for practice. The local nature of the early-stage spinout-funding networks suggests the opportunity for the university TTO to play an active role as a hub bridging the spinout-funding networks. In the survey more than 50% of the university inventors identified spending more than 20% of their time supporting fund raising efforts in the
year prior to closing or discontinuing the quest for a venture funding round. It is difficult to imagine how these fund raising efforts benefit the inventor’s academic productivity. The actions of a hub could prove highly beneficial in reducing the inventor’s level of support for such efforts.

The venture capitalist survey identified the importance of a technology’s commercial readiness to a venture’s prioritization by prospective venture funders. Strong ties to technical resources are one mechanism to advance this commercial readiness. Facilitating connections to the inventor’s research network to enable this technological development could prove beneficial to all parties.
CHAPTER 6 CONCLUSIONS

The three studies discussed in this paper have dealt with consideration of the impact of network ties and of the dynamics of complex network development. In the following sections we will consider the overall contribution to network theory, the implications for theories of knowledge and the potential for application of these findings in the university spinout domain.

Network theory contributions

In our initial study of early stage capital decision making the concept of outcome equivalent ties was identified. These ties exist when nodes are embedded within a small world network. Small world networks allow ties to numerous network members to enable similar outcomes. This finding raised the importance of network considerations to the “calculus” of tie strength determination and analysis. This study suggested the beneficial impact on knowledge transfer from connections to any members of the knowledge source’s small world network.

The second study focused on academic inventor productivity through a complex network theory lens. Multiple variables in an inventor’s network were evaluated for potential impact on productivity outcomes uncovering that moderating contextual elements, such as the number of active spinouts an inventor is involved with or spinout proximity, can potentially change the anticipated outcomes of an inventor-network tie.

The final study considered the spinout’s inter-organizational network. The findings demonstrate that these early-stage networks have highly constrained network dynamics broken by periods of punctuated equilibrium. These periods of change are triggered by the introduction of hubs such as venture capital providers to the network. The introduction of these hubs relate to considerations of node fitness driven, in this case, by both temporal and technological fitness considerations. This study, in the context of early-stage spinout funding networks, also
identified physical proximity as a critical consideration to network development. This finding further supports the importance of physical proximity observed in our earlier study on academic productivity. Despite technological advancements enabling geographically distributed networking both these studies suggest that geography remains a critical element in network development.

These final two studies also suggest that ties to an inventor’s research network can provide benefits to both the inventor and the spinout. Network ties can benefit the technological progress of the spinout while potentially enhancing overall academic productivity – a potential win-win for both the spinout and the university.

...to theories of knowledge

Our study of early-stage capital decision making identified the enablement of knowledge transfer between the spinout and the university as a critical criteria considered by early stage funders when prioritizing their potential investments. Their indifference to whether strong direct ties were to the inventors or their networks suggested the concept of “outcome equivalent ties.” This finding has implications for knowledge transfer across networks, raising network structure as a key consideration in knowledge transfer research. Figure 54 visualizes these findings in a potential knowledge transfer context. This study provides the foundation for future research applying a knowledge lens to these network observations.
Implications of findings for university technology transfer

For Technology Transfer Offices there was much good news from these university spinout network studies as well as considerations for policy execution to maximize technology transfer/new venture performance. Study 2 suggests that working with a single spinout does not impact faculty publishing productivity. While spinout involvement does impact invention productivity, a key input to the TTO, the studies finding noted a moderating influence from the license to physically proximate spinouts. The identification of outcome equivalent ties in study 1 further suggests that facilitating tie formation to the academic inventor’s research network to reduce direct inventor involvement could further reduce this negative impact on invention productivity.

The study of academic productivity noted potential negative consequences to an inventor’s publishing productivity from involvement with numerous spinouts. The identification of outcome equivalent ties suggests that a TTO could facilitate the establishment of more and stronger inventor research network ties to the university spinouts of these prolific faculty to
reduce the impact on the inventor directly. By managing the network, spinouts could be equally served and the academic inventors overall productivity improved.

Finally, the analysis of spinout inter-organizational networks suggests the potential benefit from TTOs serving as a hub in these early-stage networks. A hub could accelerate tie formation and potentially early-stage funding for these spinouts. The local nature of early-stage funding networks identified in this research suggests these funding-TTO network ties should either already exist given previous funding events or could be readily established. The TTO’s assumption of this role could, at a minimum, increase the speed and efficiency of spinout-prospective funder interaction.

Methods

Methodologically, this study leverages two unique circumstances. First, this study analyzes university spinouts to develop network theory. University spinouts present a unique opportunity for network study. The initial technical founders of a university spinout, in most instances, do not leave the university to join the spinout firm. Thus, in most instances, a critical external network tie is established between the university and spinout at the time of technology license. University inventors are also members of small-world research networks allowing for the analysis supporting our outcome equivalence observation. A universities fixed geographic nature also allows for the analysis of proximity explored in our analysis.

Second, in the study of outcome equivalent ties the early-stage funder survey has the characteristics of an experiment. In the survey the funders were asked to prioritize various investment opportunities, a task they conduct regularly as part of their day-to-day business activities. This technique allows for the management of the large number of control variables required for studies in this area, which force the majority of such studies to limit their analysis to
large archival datasets, limiting their ability to tease out more subtle nuances which were the focus of this analysis.

*Future work*

Spinouts specifically, and early-stage start-ups generally, remain a fruitful arena for analysis and extension of this work. This study should be extended via detailed case study analyses. As examples, the “TTO as hub” recommendation can be evaluated via an analysis of the Imperial College London Technology Transfer effort which has been established as a publically traded entity by the university. This recommendation can be further analyzed via a case study analysis of Boston University’s TTO. Recently the BU TTO assumed the role of a spinout network hub bridging spinouts to early-stage funding networks. Issues of proximity and outcome can thus be investigated.

Outside the context of university spinouts the “proximity” observation can also be analyzed through angel investment data available from the leading, in-the-cloud, angel investment management platform, Angelsoft. This platform is used by the majority of U.S. Angel investor groups and its use has been growing rapidly worldwide. The software was designed to facilitate deal flow and to enable syndication of investment opportunities across angel groups. The extent to which syndication occurs and its geographic characteristics would be the focus of this analysis.

Finally, accelerators have become popular vehicles for the development of early-stage ventures. Their focused approach (usually an intense 12-20 week incubation of numerous co-located start-up companies) and emphasis on start-up networking provide a unique case for the analysis of very early-stage start-up networks. The role focus of analysis of this study could be extended to an ego focused analysis to gain a more granular understanding of the “role-level” constrained network dynamics observed in this study. Approximately a third of accelerator
participants raise additional early-stage funding post the incubation period presenting the opportunity to evaluate outcomes in the context of this network research.

This paper investigates the following research questions: 1. How, if at all, does variation in the nature of the tie between the university inventor(s) and a spinout impact the new firm’s ability to raise venture funding and what are the implications for network theory? 2. How, if at all, does a university inventor’s participation with a university spinout impact his/her research publication and invention productivity and what are the implications for academic productivity models? and 3. How, if at all, do early-stage spinout network’s evolve prior to raising venture funding? Our research findings indicate that: 1. Early-stage venture investors view spinout ties to either the inventor or to their research network as “outcome equivalent” when making investment decisions. 2. The impact of inventor-spinout tie strength variation can only be properly interpreted within the context of the spinout’s overall ties to the university inventor’s research network. 3. Faculty involvement with university spinouts does not substantially impact their publishing productivity. 4. The involvement of faculty with physically proximate spinouts has a positive impact on their academic productivity. 5. The involvement of faculty with multiple spinouts simultaneously has a negative impact on their academic productivity. 6. Early-stage university spinout inter-organizational networks are not dense and their network dynamics are highly constrained. 7. Early-stage pre-VC funded networks establish strong ties with technical nodes. And 8. Venture capital funders geographically cluster around licensing universities.

In conclusion, this study has advanced our understanding in the general area of network theory and specifically contributed to the research literature on university spinouts. These findings also provide a rich platform for future research, as noted above.
REFERENCES


APPENDIX 1 – EARLY STAGE INVESTOR SURVEY

1. You have been presented with the 9 investment opportunities listed below and you have been asked to prioritize them for potential investment. The opportunities should be ranked from 1 to 9 where 1 represents your highest recommendation for investment and 9 your lowest. If you are indifferent between two investment options you can give them the same ranking. The investment options only vary based on the two characteristics noted. You have evaluated all other criteria for these investments and deemed them highly favorable (excellent and extremely large market opportunity, excellent team, easy to communicate value proposition, and a strong competitive position as examples). These firms are all physically located in a region where you traditionally invest and they are all at a stage of development you deem appropriate for investment. They are all active in the same industry, information technology, which is an investment focus for your firm. The key technology that differentiates the new firm’s product has been patented by and exclusively licensed from a university under very favorable financial terms.

### Investment options - please prioritize in terms of investment interest

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<th>1 (highly attractive)</th>
<th>2</th>
<th>3</th>
<th>4</th>
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<th>9 (not attractive)</th>
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2. Would you have prioritized these investments differently if they had been in the bio-sciences arena?

- Yes
- No

3. Investment options for a bio-sciences investment - please prioritize in terms of investment interest

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4. How important was signaling, through the involvement with the new firm of the inventor or their network, to your investment prioritization?

- [ ] 0 (very important)
- [ ] 1
- [ ] 2
- [ ] 3
- [ ] 4
- [ ] 5
- [ ] 6
- [ ] 7 (not important)

5. How important was knowledge access, from the involvement with the new firm of the inventor or their network, to your investment prioritization?

- [ ] 0 (very important)
- [ ] 1
- [ ] 2
- [ ] 3
- [ ] 4
- [ ] 5
- [ ] 6
- [ ] 7 (not important)

6. How many years experience do you have in early-stage venture investment?

7. How were/are you involved in early-stage venture investment?

- [ ] Accelerator
- [ ] Angel
- [ ] Venture capitalist
- [ ] Other

8. Where are you located?

- [ ] United States
- [ ] Europe
- [ ] Asia
APPENDIX 2 – UNIVERSITY INVENTOR SURVEY QUESTIONNAIRE

Please enter the name of the new firm you were involved with in the space provided.

Did this firm plan to raise venture capital funding either per its original business plan or at some later stage?

- Yes
- No
- Unknown

Did this firm raise capital from a formal venture capital firm?

- Yes
- No
- Unknown

What percent of your time was dedicated to fund raising in the year prior to closing the venture round or discontinuing the quest for the VC funding?

- 0%
- 10%
- 20%
- 30%
- 40%
- 50%
- 60%
- >60%

Approximately how many venture capital firms did this firm contact?

- 0
- <5
- 5-10
- >10
- Unknown

Approximately how many venture capital firms did this company get to present its’ funding proposal to?

- 0
- <5
- 5-10
- >10
- Unknown

How did this firm get in contact with the venture capitalists they interacted with most?

- Cold call
- My contacts
- CEO contacts
- University Technology Transfer Office contacts
- Other university network contacts
- Firm’s business partner (lawyers, accountants) contacts
- Venture capitalist approached the firm
- Not applicable
- Unknown
- Other (please specify)
Were (or are you) this firm’s CEO?
- Yes
- No

Did the CEO have a PRIOR relationship with your university or research institution?
- Licensee
- Student
- Employee
- Friend of yours
- Professional colleague of yours
- No relationship
- Unknown
- Other (please specify)

Who first identified the firm’s initial CEO?
- CEO was in place prior to licensing
- I identified the first CEO
- Technology transfer office identified the first CEO
- Initial capital providers identified the first CEO

How would you describe the commercial readiness of the licensed technology when first licensed by this firm? As an example of criteria to rate commercial readiness, in the ICT/software space the Defense Department has developed a technology readiness scale where 1 = Basic scientific principles observed and reported, 2. Technology concept and/or application formulated via applied research, 3. Analytical and experimental critical function and/or characteristic proof-of-concept, 4. Component/subsystem validation in laboratory environment, 5. System/subsystem/component validation in relevant environment, 6. System/subsystem model or prototyping demonstration in a relevant end-to-end environment, 7. System prototyping demonstration in an operational environment, 8. Actual system completed and qualified through test and demonstration in an operational environment, and 9. Actual system proven through success in operation.

How would you describe the commercial readiness of the licensed technology ONE YEAR AFTER LICENSING by this firm?

How were you involved with this firm in the first year?

How did your involvement with this firm change during the second year (relative to your involvement during this firm’s first year)?
- Decreased significantly
- Decreased somewhat
- Stayed the same
- Increased somewhat
- Increased significantly

How were members of your university research network (either current or former) involved with this firm in the first year?

Which of the following statements do you most agree with?
- I am personally involved with the firm at least part-time early on to facilitate a successful initial funding round.
- I do not need to be involved with the firm however it is important that graduate students, post-docs or other faculty from my department are involved at least part-time to facilitate a successful initial funding round.
- My involvement with my department colleagues or lab needed to facilitate the firm’s completion of an initial funding round.

Were you negatively impacted in any of the following areas by the time you needed to spend with this firm (check all that apply)?
- No impact
- Teaching
- Research
- Technology licensing
- Publishing
- Personal life
Did this firm establish relations with any of the following (prior to obtaining venture funding)?

<table>
<thead>
<tr>
<th>Category</th>
<th>Year pre licensing relationship began</th>
<th>Primary selection criteria</th>
<th>Secondary selection criteria</th>
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<td>Other university</td>
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<td>Investment bank</td>
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<td>Law firm</td>
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<td>Media company</td>
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<td>Commercial bank</td>
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<td>Consulting group</td>
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<td>CPA firm</td>
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What is the current status of this firm?

- Ongoing private business
- Ongoing public business
- Acquired
- Out of business
- Unknown