PARRISH, CHRISTOPHER LEE, Ph.D. Firm Social Capital and the Innovation Process. (2019)
Directed by Dr. Albert N. Link. 177 pp.

This dissertation conceptualizes, measures, and evaluates social capital as a productive input for innovative firms. First, a theoretical production function is conceptualized that considers social capital as an input into the production of three important innovation outputs: receipt of developmental (i.e., late-stage) funding; commercialization of an innovation realized through sales of a new product, service, or process; and growth-related activity of the firm developing the innovation, such as an initial public offering, formation of a spin-off firm, a firm sale or merger, a joint venture, or a product licensing agreement. Second, measures of social capital for innovative firms are developed based on the structural and content dimensions of relationships cultivated internally by and externally to the firm. Through internal collaboration and engagements with external parties, social trust and reciprocity are built that promote the sharing of ideas and innovation. Third, social capital as an input into the production of innovation outputs is evaluated using a unique dataset comprising survey responses to a Federal small business award program—the U.S. Small Business Innovation Research (SBIR) Program—that supports early-stage funding needs of firms developing an innovation. The dataset contains questions that provide insight into a firm's innovation output and its social capital, such as the nature and degree of engagements with third parties, as well as the accomplishments associated with the firm's internal collaborative activities. The empirical results presented in this dissertation suggest that social capital may have significant importance in the production of innovative outcomes. The key contributions of this dissertation include development of a theoretical production model that includes social capital, the measurement of a firm's social capital as an input into production, and the quantification, empirically, of social capital as a productive input for innovative firms.

FIRM SOCIAL CAPITAL AND THE INNOVATION PROCESS

by

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A Dissertation Submitted to
the Faculty of The Graduate School at
The University of North Carolina at Greensboro
in Partial Fulfillment
of the Requirements for the Degree
Doctor of Philosophy

Greensboro
2019

Approved by

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APPROVAL PAGE

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ACKNOWLEDGEMENTS

I thank my advisor, Al Link, and my dissertation committee of Martin Andersen, Dora Gicheva, and Chris Swann for their input, guidance, and general growth throughout the dissertation process. Their diverse perspectives and suggestions have only made this dissertation a better product. I also would not have had the opportunity to pursue my studies without the unwavering support of my wife Melissa and my sons Samuel and Seth. The completion of this dissertation has truly been a group effort of my family and the faculty and students in the UNCG economics department.

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CHAPTER I

INTRODUCTION

In a traditional economic production function, output is characterized as a function of some combination of physical capital and labor capital. Physical capital inputs, such as machines, equipment, and laboratories, are typically tangible fixed assets used in the manufacturing of goods and services. Labor is arguably a more complex input in production than are physical assets since it includes intangible dimensions of a firm's employees, such as skills, abilities, and social norms, that must be managed and balanced to optimize production efficiency. The intangible dimensions of labor are important factors in the production process as they provide the know-how, experiences, and richness of social interactions that propel a firm toward desired outcomes.

Becker (1993) characterizes the intangible dimensions of labor, such as education, training, and experience as knowledge wealth human capital, but also acknowledges the existence of "other knowledge" (p. 53) when considering the accumulation of human capital. This "other knowledge" within a firm includes the knowledge wealth of social relationships cultivated among its employees through collaborative activities, exchanging of ideas, and shared values and ideals as well as the leveraging of best practices and knowledge transfers realized through the engagement with external parties. These intangible "other knowledge" dimensions of labor contribute to the social capital of the firm, which is characterized by norms of trust and reciprocity within a firm's social network. By exploring of the productive nature of the "other knowledge" social dimensions of labor capital, a more informative view of the benefits of social capital for firms can be developed.

Exploring the role of social capital in firm production is important for several reasons. First, given the broad skills and multi-dimensional nature of firms, distinguishing between the two labor inputs of human capital and social capital allows for a delineation and differentiation between the intangible labor dimensions of firms. Second, as the dimensions of social capital are further enumerated, it may be possible to theorize more clearly the implications of greater or lesser degrees of such dimensions on firm activities, including producing innovations. Third, theorized relationships between certain social capital dimensions and firm activities can be tested empirically, potentially advancing the literature on the intangible labor dimensions that drive innovation in an increasingly knowledge-based environment.

The contribution of this dissertation is therefore threefold. First, by explicitly distinguishing labor inputs into two core components, human capital and social capital, a theoretical framework that includes a firm's social capital as a factor of production is developed to provide the necessary structure to evaluate social capital as a potential contributing input to various forms of output, including innovations.

Second, the social capital of a firm is described and measured based on the structural and content dimensions of relationships cultivated through trust-building interactions and the formation of expectations of reciprocity among the firm's employees as well as with external parties to the firm.

Third, measures of a firm's social capital are included as factors of production to explain empirically key outputs of the innovation process for firms as described by the following research questions:

1. Are there dimensions of social capital that benefit innovative firms in the pursuit of developmental (i.e., late-stage) funding?

2. Are there social capital characteristics of innovative firms that are associated with realizing sales resulting from the commercializable technology? and
3. Are there certain types of social capital associated with the probability than an innovative firm experiences growth-related activities resulting from its innovations, such as through the execution of an initial public offering (IPO), as a spin-off into a financially independent organization, a firm sale, a firm merger, a joint venture agreement, or a product licensing agreement?

Using a unique dataset based on responses to a Federal survey of small businesses funded through the U.S. Small Business Innovation Research (SBIR) program, the relationship between social capital and the three aforementioned outputs in the innovation process are empirically tested. The SBIR dataset consists of responses to firm- and project-level surveys of Phase II projects. The survey was administered by the National Research Council (NRC) of the National Academies in 2005, and it relates specifically to the National Institutes of Health (NIH)-funded Phase II SBIR projects.

Acknowledging the exploratory nature of the analysis herein due to the limitations of the direct measurements of the social capital within the SBIR dataset and the use of contemporaneous data to evaluate multiple outputs, the reported empirical results related to each of the above questions suggest that social capital is an important input in the production of innovation outputs. Specifically, social capital, as measured as strong social ties through the collaborative production of intellectual property as well as the shared values and cultural vision necessary to create and build a business by its founders, is positively and significantly associated with the output of the SBIR project receiving additional developmental funding. Social capital, as measured as weak social ties cultivated through strategic agreements with U.S. and/or foreign companies and investors, is positively and significantly related to the output of commercializing an innovation.

Additionally, weak social ties, including engagements with private investors, such as venture capitalists, are shown to be positively and significantly related to a firm's execution of growth-related activities, potentially underscoring the benefits of social capital in the attainment of strategic growth and equity funding sources for a firm.

An implication of the findings in this dissertation is that firms investing in activities that support the cultivation of intra- and inter-firm social relationships may benefit from those investments through the realization of positive innovation outputs. Such activities could be advanced by focusing on collaborations that build trust and reciprocity among its employees and by fostering relationships with external parties where mentoring and guidance can be facilitated. Additionally, given the relationship between social capital and innovation, entities or organizations that provide financial assistance to innovative firms for research and development (R&D), such as the SBIR program, may be well served to consider the dimensions of a firm's social capital as an additional criterion for providing financial support.

The remainder of this dissertation is structured to discuss each of its three contributions. With respect to the first contribution, Chapters II, III, IV, and V define and conceptualize social capital as a form of capital in the innovation process. Chapter II defines social capital and how it is different than human capital as an intangible input in production. Chapter III reviews the literature relating human capital to innovation outputs given the relatively larger body of economic research on this type of intangible capital input in production. Next, Chapter IV reviews the more limited economic literature relating social capital to innovation outputs, which highlights the gap in the research to pursue the theoretical and empirical economic analysis developed in this dissertation. Lastly, Chapter V outlines the theoretical framework to include social capital as an input into the innovation process.

Once social capital is conceptualized in an innovation production framework, Chapter VI discusses the role unique role of financial capital in innovation production and how it can lead to a higher levels of a firm's social capital. Additionally, Chapter VII describes the financial support to innovating firms provided by the SBIR program, which is the source of data for the empirical analysis.

With respect to the second contribution of this dissertation, the measurement of a firm's social capital, Chapter VIII lays out the dimensions of firm social capital, an approach to measure each dimension, and how to operationalize social capital measures.

Finally, the third contribution of this dissertation is detailed in Chapter IX, which uses the social capital measures to empirically test the relationship between a firm's social capital and three key innovation outputs to answer the research questions outlined in this chapter. A concluding summary and discussion of potential implications pertaining to this dissertation are presented in Chapter X.

CHAPTER II

HUMAN CAPITAL AND SOCIAL CAPITAL

It is necessary to delineate and differentiate the two key forms of intangible labor capital inputs for innovative firms: human capital and social capital (i.e., Becker's "other knowledge"). Making this distinction allows for the exploration of how investment in each type of capital can be productive. Further, human capital and social capital are generally analyzed separately in the economics literature. This separation is partly due to the evolutionary view of the component parts of human capital, which tend to be more objective in nature, and the subjective and less quantifiable types of interpersonal connectivity associated with social capital. Additionally, while human capital has historically been viewed within an economic context of a return on investment in education and training, the early research on social capital emerged in a sociological context and is related to the generation of knowledge resulting from social experiences. To understand the economics literature with respect to innovation outputs from both human capital and social capital, a brief overview of the history of each is presented below.

What is Human Capital?

The concept of human capital has existed for centuries (Smith, 1776/1976). It was not until Mincer (1958) and Becker (1964) wrote more extensively about the value of and return from human capital in the 1950's and 1960's that an expanded definition emerged. Their analyses focused primarily on the educational and training dimensions of human capital and their respective impact on wages and productivity. Since the publication of the Mincer and Becker

foundational studies, a thread of economic thought has been explored to evaluate the impact of various dimensions of human capital on the productivity of economic units.

Smith (1776/1976) noted the abilities of individuals in society and how those traits can translate into productivity. In reference to the application of division of labor, Smith (1776/1976) implied that just as returns on physical capital are expected to recover its cost, there is also an equal or greater return on investment in human capital,

> When any expensive machine is erected, the extraordinary work to be performed by it before it is worn out, it must be expected, will replace the capital laid out upon it, with at least the ordinary profits. A man educated at the expense of much labour and time to any of those employments which require extraordinary dexterity and skill, may be compared to one of those expensive machines. The work which he learns to perform, it must be expected, over and above the usual wages of common labour, will replace to him the whole expense of his education, with at least the ordinary profits of an equally valuable capital (Book I, Chapter X, Part I, p.42).

Marx (1858) used the term *human capital* in his writings, and Marx (1906) also described the potential influence of education and skills in increasing productivity,

> In order to modify the human organism, so that it may acquire skill and handiness in a given branch of industry, and become labour-power of a special kind, a special education or training is requisite, and this, on its part, costs an equivalent in commodities of a greater or less amount. This amount varies according to the more or less complicated character of the labour-power. The expenses of this education (excessively small in the case of ordinary labour-power), enter pro tanto into the total value spent in its production (Part II, Chapter 10, Paragraph 12).

Schultz (1961) provided a theoretical argument for the increase in wages as a result of investment in human capital; he noted,

> While any capability produced by human investment becomes a part of the human agent and hence cannot be sold; it is nevertheless ‘in touch with the marketplace’ by affecting the wages and salaries the human agent can earn. The resulting increase in earnings is the yield on the investment (Part III, p. 8).

In a deeper interpretation and extension of the human capital concept, Mincer (1958) and Becker (1964) provided key foundational work in the development of economic theory and models to attempt to explain the outcomes related to human capital accumulation through education, experience, and training. There were also some alternative views of human capital theory put forth by Spence (1973) and Stiglitz (1975). Spence (1973) and Stiglitz (1975) purport that information asymmetries, such as signaling and screening, may account for certain outcomes more so than education or other observable talent-building experiences.

However, Becker's (1993) exposition on human capital provided an extensive theoretical and empirical analysis on investment in human capital, and in particular, investment in education. He asserted the most important contributions to human capital accumulation are education and training, which includes both "general" and "specific" on-the-job training, and "the most important single determinant of the amount invested in human capital may well be its profitability or rate of return…" (p. 45). These suppositions underpin the notion that investment in human capital is deliberate with measurable outcomes of increased earnings and productivity.

Becker (1993) also outlined other means by which individuals can acquire human capital, such as through the observation of market forces, information gathering, and the accumulation of social, emotional, and physical health assets. For example, consumers can observe prices and make low-cost consumption decisions, job market participants can glean information about wage levels to seek their best employment opportunities, and individuals can invest in good health and diet in an effort to increase productivity. While the latter leverages the research area of health capital (Grossman 1972), Becker (1993) argued that all these types of "other knowledge" can be considered in a model of investment of human capital and productivity.

As a more general definition, human capital is the embodiment of an individual's cumulative talents through investments in education, training, skills, and other experiences that

improve the individual's capacity to be productive. Thus, human capital represents a form a wealth for the individual with the potential to generate returns on investment. Additionally, key in this interpretation is the degree of creativity and innovativeness that one possesses. However, the ability to quantify any one component much less the total level of human capital is difficult, and accordingly, the literature often compartmentalizes distinct elements of human capital in an effort to perform empirical testing of hypotheses.

What is Social Capital?

In this dissertation, social capital is assumed to be a separate form of Becker's "other knowledge" as it encapsulates the intangible social experiences and interactions that are interpreted to be embedded in Becker's definition. The distinction is intended to compartmentalize the intangible dimensions of "other knowledge" related to capital accumulated through the development of social interactions and to evaluate the productive qualities of social capital. However, in contrast to human capital, social capital is more difficult to define precisely given the often unobserved frequency and intensity of its accumulation. Additionally, the lack of a consistent definition lies in the diversity of the context in which social capital is discussed. Robison, Schmid, and Siles (2002) noted,

> While there is some commonality in the meaning given to social capital in the literature, there are considerable and confusing differences. Perhaps one reason that researchers have not generally agreed on a definition of social capital is that the definitions are not limited to answering the question: what is social capital? Past definitions have included answers to such questions as: where does social capital reside? How can social capital be used? And how can social capital be changed (p. 2)?

In a more structured context, Halpern (2005) stated that social capital consists of three basic components: a network, norms, and sanctions to maintain the network and norms. Coleman (1988) asserted that social capital should be defined by its function, and he theorized that social

capital is the result of the type of structural relationship between the engaged "actors." Burt (2005) characterized social capital as a location in a relationship in which the development of social interactions that share information and experiences creates for individuals and for groups of individuals an "advantage in pursuing their ends" (p. 5).

Synthesizing the various definitions of social capital into a one within an economic context, social capital is defined in this dissertation as the stock of wealth created from the ability to create, foster, and leverage social interactions into economic action. Social capital is accumulated through the cultivation of relationships with others (the network) and the development of social content, which includes the norms of trust and reciprocity. Social capital is further refined through feedback from others (e.g., positive and negative reaction to social behavior) that guide enforcement of the norms of trust and reciprocity.

There is not a clear genesis of the term *social capital*. Putnam (2002) discussed the evolution of the term *social capital*, noting the term was observed early in the 20th century in an article by Hanifan (1916) with reference to the social connections necessary to improve conditions in rural communities.[1] However, according to Scopus (2016), which analyzes the frequency of the use of terms in publications, it was not until the beginning of the 1970's that the sociological literature began to publish extensively about social capital. This post-1970's trend in the social capital literature is perhaps due in part to the increasing recognition of the potential incremental benefits associated with increasing the number of one's social acquaintances and connections (Putnam, 1995). During this post-1970's period, Bourdieu (1972, 1977) explored social capital in a sociological context in an effort to characterize the cultural capital related to

[1] Claridge (2004) provides a review of the various definitions of social capital through history by author.

social interactions, but he did not expound upon or delineate the types of social relationships embodied within social capital.

Recognizing the multi-dimensional facets of social capital, Granovetter (1973) decomposed and analyzed the different strength of social interpersonal ties. With respect to the construct of social ties, Granovetter (1973) contended the strength of a social tie is often defined by generalizing interpersonal relationships,

> …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 (p. 1361).

Granovetter (1973) further asserts that social capital consists of "strong", "weak," or "absent" social ties.[2] He suggested strong social ties are characterized by tight friendships and family connections, and dense social networks with those individuals sharing a common or institutional (homogeneous) knowledge. Alternatively, weak social ties are characterized by acquaintances, less dense social networks, and a heterogeneous information set across social ties. An absent social tie is one where no connections exist or if they do they are negligible or insignificant.

Granovetter (1973) argued that weak ties can be quite powerful, and he noted "those to whom we are weakly tied are more likely to move in circles different from our own and will thus have access to information different from that which we receive " (p.1371). In fact, Granovetter (1973) stressed that weak social ties provide a powerful social mechanism to share experiences and ideas, potentially leading to large-scale outcomes. His research supports the concept of weak

[2] "Strong" and "Bonding" ties as well as "Weak" and "Bridging" ties are used in the social capital literature interchangeably.

ties bridging social distances more easily, resulting in more social connections. It is the existence of these weak ties that reveals heterogeneous information, providing an opportunity for key information flows and idea exchanges even though individuals are not consistently in touch with each other. In reference to the impact of weak ties in an economic outcome, Granovetter (1973) documented in his findings from his job search research, "it is remarkable that people receive crucial [job] information from individuals whose very existence they have forgotten" and "weak ties are an important resource in making possible mobility opportunity" (p. 1372).

While Granovetter's (1973) research focused on the importance of weak social ties, and in particular, "weak ties are more likely to link members of different small groups than are strong ones, which tend to be concentrated within particular groups" (p. 1376), Krackhardt (1992) posited that strong social ties are equally important, especially in situations of change and uncertainty. Krackhardt (1992) suggested the measurement of the strength of a tie can be ambiguous, and he used the term *philos* to designate a type of interpersonal tie that is more characteristic of a strong relationship. It is through the *philos* network that change is realized because strong connections have frequent interactions, a sense of caring, and a shared history. The contribution by Krackhardt (1992) to more specifically define strong social ties and to demonstrate the importance of trust inherent in *philos* supports the notion that frequent interpersonal interactions, positive treatment of others, and a relationship history create opportunities to motivate and share information to mutual benefit.

Thus, Granovetter (1973) provided foundational theory and supporting research on the strength of weak social ties. Krackhardt (1992) argued strong social ties can also be very important in the identification of opportunities and information sharing. It follows from the argument from these two scholars that strong and weak ties can be both advantageous and effective forms of social capital in achieving desired outcomes.

Leyden and Link (2014) theorized that entrepreneurs develop strong and weak ties in their search to optimize social capital in the innovation process. This theory is explored more extensively in Chapter V as strong and weak social ties are expected to be important inputs in the outcome of innovation outputs.

What is the Role of Human Capital and Social Capital in Innovation?

It has been argued that innovation comes from both an innate ability to innovate as well as from environmental influences (Bell et al., 2018; Aghion et al., 2017). There are also many research papers suggesting that innovation is born out of necessity and/or opportunity (Baptista, Karaöz & Mend, 2014; van der Zwan et al., 2016; Williams & Williams, 2014). These theories frequently focus on the human capital dimensions of the potential innovators, including education, measurements of intelligence or experience, and other demographic characteristics. However, demographics are often assumed to encapsulate an underlying set of behaviors or preferences, which makes these measures imprecise or incomplete when considering them as drivers of innovation.

In is asserted in this dissertation that innovation requires collaboration. Leenders & Dolfsma (2016) summarized this concept succinctly and stated, "(i)nnovation is a 'team sport,' where individuals work together in teams, teams work together in projects, organizations work together in alliances, and countries work together in international technology agendas (p. 125)." The core argument in this dissertation is that innovation (and its associated output) is a function of both human capital and social capital inputs. This dissertation focuses more intensely on the 'team sport' dimension associated with innovation as it provides an added depth to the measurement of the intangible inputs driving innovation output by conceptualizing, measuring, and evaluating social capital of innovative firms.

Summary

This dissertation posits an important distinction between the intangible dimensions of labor capital inputs: human capital and social capital. Human capital includes the stock of knowledge wealth generated through investments in education and training while social capital is the stock of knowledge wealth created through the cultivation of strong and weak ties. These ties are built on the norms of trust and reciprocity that provide valuable opportunities to share information, collaborate, generate ideas, and build cultural ideals of shared purpose. Thus, social capital, similar to human capital, is a separate stock of knowledge wealth as investments in both human capital and social capital must be intentional and purposeful to be productive and useful. These two forms of intangible capital are theorized to be key drivers of innovation output.

The next two chapters provide a more detailed literature review of human capital and social capital, respectively, within the context of the three innovation outputs that are central to this dissertation: receipt of external funding to support the innovation, commercialization of an innovation, and whether the innovative firm experienced growth-related activity resulting from the innovation.

CHAPTER III

LITERATURE REVIEW OF HUMAN CAPITAL AND INNOVATION OUTPUTS

Although human capital and social capital are distinct types of intangible labor capital, the economic analysis that has been performed relating human capital and innovation is much deeper. Therefore, the literature review in this dissertation first starts with a discussion of the extant literature relating human capital with innovation outputs. Specifically, this chapter reviews the economic research that has been performed that relates human capital to the three research questions associated with the following innovation outputs: 1) the ability of a firm to obtain external funding for a new technology, 2) the commercialization of a new product or service, and 3) whether the innovative firm experienced growth-related activity as a result of the innovation, such as an initial public offering, a spin-off firm, a firm sale or merger, a joint venture, or a product licensing agreement. Following this chapter, a review of the literature relating social capital to the same innovation outputs is provided to highlight the current gaps that are addressed in this dissertation. Table 1 lists by author(s) each empirical paper mentioned in both the human capital and social capital literature review chapters, its data sources used in the paper, the outcome of interest, and the explanatory variables, including the human capital and social capital variables as specified by the author(s).

Table 1. Literature Review Empirical Papers

Authors	Data	Outcome	Human/Social Capital Explanatory Variables	Other Explanatory Variables
Human Capital & Innovation				
Hsu, Haynie, Simmons and McKelvie (2014)	Mixed sample of venture capitalists and angel investors sourced from Angel Capital Association and National Venture Capital Association	Indicator of positive decision to invest in the given opportunity	Human Capital: entrepreneur has more than 10 years of experience working with young firms	firm economic potential to breakeven, existence of strong relationships with key stakeholders (firm "readiness") and the entrepreneur's passion around the venture
Gimmon and Levie (2010)	Random sample of founders in high-tech export targeted start-ups whose ventures were established in an incubator in Israel	Two binary variables: 1) firm survived or did not 2) firm raised funds or did not	Human Capital: industry/managerial experience, academic education/status	age, location, and sector of the firm; gender, ethnicity, and age of the founder; and sales and technology strategy
Audretsch and Lehmann (2005)	Balance sheet, IPO, and public data on sample of German publicly-listed companies	Firm survival in the stock market (not delisted)	Human Capital: executives with academic titles, executive owners with academic titles, board members with advanced academic degrees	firm patents, executive patents, firm age, employee growth rate, ownership concentrations (executive, board, friends/family, venture capitalists)
Bonardo, Paleari, and Vismara (2011)	Control and treatment sample of small to medium-sized enterprises that went public during 1995-2003 in Europe that were university-backed (treatment) and independent (control)	Operating performance of stock after IPO	Human Capital: affiliation with a university, academics present in top management at time of IPO, venture capital-backed firm, academic titles of top management, experience of top management, education of top management	leverage, profitability, firm age, firm size, industry, country, IPO year, innovation (patents and R&D investments)

Gallie and Legros (2012)	Time-series data of French industrial firms from 1986-1992 with sampling based on number of employees	Patent count	Human Capital: on-the-job training and R&D expenditure per employee	firm market share, firm size, number of competitors, and occupational categories (executives, engineers, clerks, technicians, skilled, unskilled)
Giménez, López-Pueyo, and Sanaú (2015)	Sample of 15 OECD countries from 1980-2005	Country GDP and innovation (patents granted)	Human Capital: constructed from country education levels, differences in educational quality, and differences in productivity and wages	
D'este, Rentocchini, and Vega-Jurado (2014)	Panel survey data from 2006-2009 of Spanish firms submitting responses to the Spanish Innovation Survey	Firm observes a barrier to innovation: cost barrier, knowledge barrier, or market barrier	Human Capital: proportion of firm's total employees with a higher education degree	firm size, firm ownership is foreign, firm is start-up, firm received public support for innovation, firm is international, average number of patents, trademarks, utility models, and copyrights, firm importance of external sources of information, and firm sector
Link and Scott (2009)	Survey data on small business grants provided by the U.S. Department of Defense to support commercialization of new technologies	Commercialization of a new technology	Human/Social capital: founders had business background, outside private investment	the age of the project, firm revenue, related project awards, all developmental project awards, and product type

Braunerhjelm, Audretsch, and Carlsson (2009)	Sample of 19 OECD countries from 1981-2002	Entrepreneurship (self-employed) rate	Human Capital: patents in relation to population, gap between actual and potential GDP	stock of knowledge in the economy (accumulated R&D flows), barriers to entrepreneurship (tax burden measures), 30-44 age population share, urban population share, and economic growth
Grilli and Murtinu (2015)	Sample of Italian new-technology based firms founded between 1980 and 2008	Indicator of receiving a selective (competitive) subsidy and ability to establish an R&D alliance conditional on receiving subsidy	Human Capital: founders' previous technical education, previous industry-specific work experience, economic/managerial education, management experience, and the number of founders	firm industry
Lehmann, Braun and Krispin (2012)	All German company IPOs from 1997-2006	Indicator of IPO-firm acquisition bid by larger incumbent firm	Human capital: firm patents and founder patents	percentage of initial owners' ownership after IPO, firm age at IPO, time from IPO to bid, earnings/equity ratio, balance sheet size, an indicator of IPO activity in the industry, a growth and resource indicator, growth rate in employees, firm debt-to-equity ratio, a liquidity ratio, and industry indicators

Farag, Mallin, and Ow-Yong (2014)	Sample of entrepreneurial firms admitted to the UK's Alternative Investment Market from 2000-2007	Simultaneous equation estimation: Corporate governance (index), venture capitalists' ownership percentage, and financial performance in entrepreneurial IPOs	Human/Social capital: percentage share of venture capitalists' ownership	Tobin's Q, market capitalization, debt-to-asset ratio, R&D-to-sales ratio, count of assumed risk firm risk factors, venture capitalists reputation proxy, age of the firm at IPO, foreign firm indicator, CEO & founder indicator, IPO lock-up period, number of venture capitalists invested in the firm, and CEO & directors that are on other firm boards
Ozmel, Robinson, and Stuart (2013)	Panel of privately-held biotechnology start-up companies from Thomson Financial's VentureXpert database that received both venture funding and participated in alliance activity and founded before 2004	Time since the last venture capital funding event experienced by the firm	Human/Social capital: rounds of venture capital funding, venture capitalists' centrality in syndication network, and patents	count and level of firm alliances over 5-year window, time since last venture capital round, time since last alliance, IPO intensity of biotech firms, market returns, stock of firm patents, and whether firm has compounds in FDA clinical trials
Kaplan, Sensoy, and Stromberg (2005)	Sample of venture capital-financed firms that executed an IPO with visibility on an early business plans at the time of venture capital financing	Indicator of retaining the founder as CEO at IPO and at first annual report	Human Capital: alienable assets, or lack thereof	physical assets of the firm at business plan, age of the firm at business plan, tangible assets of the firm at business plan, patents and non-patent intangible assets at business plan, and founder's ownership at business plan

Social Capital & Innovation				
Hsu (2007)	Survey data of a group of start-up firms which had applied to participate in a semester-long educational program at MIT known as "Entrepreneurship Laboratory"	(1) Indicator of venture capitalist is direct, personal contact of founder(s) and (2) the pre-investment value of the start-up firm	Social Capital: executives recruited through founder(s) networks; Human Capital: number of start-ups started by founder(s), start-up team held MBA, PhD and/or MD degree, and indicator that founder(s) realized high returns on prior start-ups	number of founders, age of the start-up, number of employees, prior angel investor, number of patents, firm received multiple financing offers, equity take out through outside investment, indicators of firm strategy related to technology, products and/or organization, firm industry, and indicators for year of outside investment
Uzzi (1999)	Random sample from the National Survey of Small Business Finances of firms operating in 1989 in the U.S. non-agricultural sector	Selection model of firm acquiring a loan and the interest rate on loan	Social Capital: duration of relationship between firm and lender, the multiplexity of the relationship as measured by the number of business services used by the firm, and a dispersion measure of the firm's bank relationships	number of employees, firm age, sales growth, whether the firm is a corporation, the level of cash on hand, current assets ratio, debt/assets ratio, whether the firm was women-owned or minority-owned, the size of the firm's bank network, prime rate, bond spreads, whether the loan is collateralized or fixed-rate, and a measure of bank concentration in the firm's location

Cooke and Willis (1999)	Survey data of small and medium-sized firms involved in framework network programs in European from 1989-1998	Cross-tabulations and categorizations of knowledge exploitation, innovation, and business performance resulting from participation in network programs (no model specified)	Social Capital: integration into existing comparable small firm networks, integrity as measured through affiliation with professional networks, synergy through close links to program executives/mentors, and linkage from engagements with external networks	country of firm domicile
Landry, Amara, and Lamari (2002)	Survey data of manufacturing firms in Montreal from April to June 2000	(1) Indicator for innovation and (2) number of months elapsed between first investments in project and first sales (posited as 'radicalness' of innovation)	Social Capital: categorical rating of importance of developing new products: business networks, such as clients, suppliers, and competitors; information networks, such as engagement in trade-related meetings and conferences and intellectual property networks; research networks, such as government research labs, technology transfer organizations, and universities; participation assets, such as participating in meetings, associations, and networks of manufacturing firms; relational assets, such as knowing influential professionals in government agencies that promote economic development related to the firm's products; and reciprocal trust as	percentage of sales dedicated to R&D, number of advanced technologies used by firms, index of competitive pressure, sales, percentage of sales exported, and number of employees

			measured through importance in business relationships with clients, suppliers, and government agencies	
Perez-Luno et al. (2011)	Survey data of sample of Spanish firms in the manufacturing and service sectors with at least 20 workers in 2008	Scale (1-5) of radical innovation measured as the improvement in innovation over the previous 5 years	Social Capital: scale responses to four questions related to extent of cooperation and trust with other companies in collaboration agreements	scale responses to ease of understanding knowledge used in the firm, scale responses to questions related to the complexity of data in the firm, number of employees, firm age, and industry
Landry, Amara, and Rherrad (2006)	Random sample representative of all Canadian universities where researchers in natural sciences and engineering have obtained research grants from the Natural Sciences and Engineering Research Council of Canada from 1997-2002	Indicator of university spin-off	Social Capital: index assessing the intensity of linkages that a researcher had with private firms, government departments, and university communication department	number of researcher's publications, indicators of research department, indicator as to whether researcher asserts projects are focused on users' needs, indicator as to whether researcher often consults, an index measure of research novelty, indicator for large university, number of researchers in lab, percentage of time researcher spent teaching, experience of researcher, indicator for department seniority, and researcher gender

Gulati and Higgins (2003)	U.S. biotechnology companies founded between 1961 and 1994	Selection model of IPO success, calculated using the average standardized scores associated with 4 outcomes: IPO net proceeds, pre-money market value, 90-day and 180-day post-IPO market value	Social Capital: indicator of whether venture capitalists were prominent just prior to IPO, score of underwriter prestige, and number of prominent strategic alliances	equity market receptivity index measure, number of employees, firm age, number of rounds of private capital prior to IPO, indicator of location in key cities, indicator for product stage, number of senior managers and board members, and type of biotech industry

Human Capital and External Funding

Obtaining external funding to support an innovation is difficult, especially for small firms without proven products, a track record of success, or an earnings history. Lenders often evaluate a variety of measures to assess this risk before a decision to invest. Since information asymmetries usually exist between lenders/investors and firms, those considering providing funding to firms may need to rely on human capital measures of skill, aptitude, and ability with respect to the management of the firm in the absence of proven success.

Given these constraints, one compatible external funding arrangement associated with innovative firms is private equity, including venture capital and angel investments. In addition to evaluating key human capital elements of potential investments, private equity investors have their own human capital assets, such as business experience and social connections. Therefore, venture capital funding may produce a symbiotic human capital relationship with the firms in which they consider investing. To the extent that an investment relationship exists, those private equity human assets may be able to be exploited by the innovative firm seeking funding. Consequently, the role of human capital in the external funding process is of interest in the innovation process.

In evaluating investments, private equity firms assess a firm's characteristics when considering their decision to invest. Hsu, Haynie, Simmons, and McKelvie (2014) considered the factors driving investment decisions of both angel investors and venture capitalists. The authors developed a model to determine whether economic, human capital, firm maturity, and entrepreneurial passion matter differently for angel investors and venture capitalists. The purpose of their paper was to determine whether there are successful alignments of entrepreneurs with investors given the agency theory problem of conflicting goals where information asymmetries exist. The authors theorized that angel investors and venture capitalists have different investment

objectives and will attempt to deal with the agency issues in different ways. Venture capitalists may reduce agency risk (particularly risk from goal conflicts) by contracting with entrepreneurs through stage funding and by portfolio diversification. Angel investors may attempt to reduce their risk (primarily risk from information asymmetry) by engaging with entrepreneurs on a more frequent and hands-on basis. As such, the mechanisms each type of investor puts into place may be different. In the case of venture capitalists, mechanisms are intended to control for targeted economic outcomes, and for angel investors, the focus is on behavior-oriented outcomes. The authors found angel investors favored human factors, such as the existence of strong relationships with key stakeholders and the entrepreneur's passion about the venture, when considering an investment, and venture capitalists put more weight on the economic outcome associated with their investments. However, both types of investors valued human capital highly.

Gimmon and Levie (2010) evaluated the human capital characteristics of a start-up firm with the potential of the firm to obtain outside financing to ensure its longer-term survival. Drawing on human capital and signaling theory, the authors identified several human capital characteristics associated with a sample of start-up firms in an incubator program. They tested several hypotheses regarding the type of experience of the founders and the potential correlation with firm' access to external funding and to their survival. Their analysis found that prior business experience and an advanced degree (or title) held by the founder increased the probability of the firm receiving external funding. Additionally, the prior business experience of the founder and the characterization of the founder as a technologist (i.e., understanding the technical nature of the product(s) being produced) suggested the firm is more likely to survive. Their results imply that titles and experience signal strength to venture capitalists, but the true technical knowledge of the founder is the driving factor of long-term success. It should be noted that the authors did not evaluate or quantify the impact of a founder's social capital or the

founder's "entrepreneurial mindset" or "learning ability" in assessing the relationship between human capital characteristics and funding and survival outcomes.

Human Capital and Innovation

Just as human capital can encapsulate a multitude of experiences, talents and accomplishments, measures of innovation and commercialization can vary depending on the motivation, context, and availability of information. To articulate the type of innovation output associated with human capital, a brief overview of the definitions of innovation and commercialization is provided below.

Link and Siegel (2007) characterize innovation as an event stemming from invention. They asserted, "Invention is the creation of something new. An invention becomes an innovation when it is put in use" (p. 3). Therefore, innovation necessarily implies commercialization within their framework. However, a standard definition of measuring the occurrence or the degree of commercialization does not exist. Link and Scott (2010) suggest certain measures of commercialization can include sales of products, processes, services, rights to the technology, or the establishment of spin-off companies.

Additionally, there are indirect methods of approximating innovation or commercialization success, such as firm-specific output, developing strategies to advance innovation, and the creation of new ventures and relationships. While interrelated, three categories in the literature related to the interaction of human capital with innovation output are identified and explored:

(i) Human capital and firm output measures

(ii) Human capital as a cause of innovation

(iii) Human capital and the creation of alliances, spin-offs and social networks

Human Capital and Firm Output Measures

Audretsch and Lehmann (2005) analyzed the factors driving innovative high-technology ("new economy") companies' survival by evaluating the influence of both traditional human capital measures, such as firm age, size, growth rates, and ownership structure, as well as less traditional measures of human capital, such as owner and board of director education levels. The argument for their analysis was based on the theory that traditional measures of firm performance for "new economy" firms may not apply as those traditional measures do not reflect the value provided by intellectual assets. Typically, traditional measures place more weight on positive cash-flow and earnings, which may be non-existent in technology-based start-ups. The authors drew on the theory that entrepreneurs make decisions, and those decisions are based on creative thought, experience, and advisement that has been accumulated over the course of time. While difficult to measure directly, Audretsch and Lehmann (2005) theorized the level of academic degree achieved by executives, members of the board of directors, and owners may indicate the amount of human capital present in the firm, and those measures should positively impact firm survival. The results from their modeling process indicated that some of the traditional measures (e.g., executive ownership) of new technology firm survival diminish as more knowledge-based measures (academic pedigree of board members and firm patents) are introduced, supporting the notion that higher levels of human capital are correlated with firm survival.

Bonardo, Paleari, and Vismara (2011) looked at human capital and creation of firm value at the point of an IPO for firms affiliated with universities. The authors drew upon a body of literature related to evaluation of the "success" of university-based firms and they empirically tested whether there are benefits of university affiliation with innovative firms that ultimately issue public equity. The authors hypothesized that affiliation with a university is a signal to potential investors of human capital strength, which set investor's profit expectations and

ultimately firm valuation. Their results indicated firms that are affiliated with universities have higher valuation at the point of an IPO. The authors speculate that this result is potentially due to the signal of product/firm strength provided by the presence of university-based innovation. However, any benefits of affiliation do not appear to extend to the longer-term performance of the stock or to other company performance measures. In fact, their results imply that university-based firms perform worse than firms without university affiliation when evaluating performance measures of established firms. These results suggest university-affiliated firms may not have the right management skill set to achieve the valuation and performance levels as do similar but not university-affiliated firms.

The impact of investment in human capital and successful innovation can also be gauged by measures such as firm sales and returns. Sevilir's (2010) theoretical model evaluated the benefit of human capital investment in a firm, and specifically, investment in "general" human capital as defined by Becker (1964). Using returns as a measure of success, the author assumed that human capital investment can encourage employee innovation; however, there is uncertainty as to whether firm-specific or general human capital investment is the best type of human capital within which to invest. Investment in general human capital can increase the potential flight-risk of the employee to create their own firm to exploit the innovation(s) they have created with the human capital financed by the incumbent firm. Nonetheless, the author argued the employer is still better off (i.e., realized a positive return) by investing in general human capital because of the potential benefits (surplus) realized by employee-generated innovations while under the employment of the incumbent firm. Further, the development of the venture capital market to fund the potential employee spin-off firms is yet another incentive for firms to invest in general human capital as employees exert effort to achieve independence through their innovations, which again results in the incumbent firm benefiting from innovations before the employee

departs. Therefore, firm investment in general human capital can increase innovation leading to positive returns to the firm.

Gallié and Legros (2012) explored the impact of human capital on the number of firm patents. The authors argued that human capital and R&D expenditures should be key explanatory variables as in-service training of employees and R&D intensity provide innovative firms skills and knowledge to generate additional intellectual property. The results from their empirical analysis indicated a positive and significant relationship between various types of training and the number of patents filed at each firm. Additionally, R&D expenditures positively and significantly increase the number of patents, but the magnitude of the impact is relatively small. This could be the result of an intertemporal constraint: the internal capacity to generate patents is not persistent as firms generally do not have the ability to file patents year after year. The authors also found that the stock of knowledge within each firm is important in innovation. Finally, the authors found that firms with higher concentrations of executive and engineer employees result in increased innovation as those types of positions generally focus more on patenting activity. Taken together, investment in human capital through training has positive implications for innovation production by increasing the average number of patents that a firm can expect to generate.

Human Capital as a Determinant of Innovation

Human capital may be instrumental in allowing innovation to occur. Recognizing the inconsistency in the definition of human capital in the literature, Giménez, López-Pueyo, and Sanaú (2015) tackled the issue of causality between human capital and innovation by first developing a new measure of human capital in an attempt to encapsulate both of its quantitative and qualitative elements. The authors empirically tested this definition with multi-national data

by evaluating the causality between human capital and innovation. The authors theorized that a deeper, more nuanced measure of human capital should reduce the measurement error in empirical analyses using human capital as a key input. Additionally, a more comprehensive human capital measure should have greater explanatory power in growth models as a more precise measure of an individual's innovative ability and skill should result in better insights into productivity. The results from their analysis indicate bi-directional Granger causality when innovation and human capital are regressed against each other. The authors assert that this empirical relationship indicates firm innovation is a natural outcome of human capital endowments of owners particularly when human capital is measured in a more nuanced and comprehensive manner.

D'este, Rentocchini and Vega-Jurado (2014) explored whether human capital factors affect the probability of firms experiencing barriers to innovation. The authors bifurcated the barriers into two categories: a) deterring barriers, which prevent a firm from developing an innovation and b) revealed barriers, which occur once an innovation transpires. First, the authors defined a "potentially innovative" firm as one that actively invests in innovative activities or that does not actively invest but has experienced barriers to innovation. Non-potentially innovative firms do not invest and have not experienced a barrier to innovation (as such, they are unlikely to ever innovate). They speculated that higher levels of human capital can provide a significant advantage as a more skilled, diversified employee base allows for greater strategic focus and execution given their advanced training and education. Based on this assertion and the extensive literature on human capital benefits, it should follow that a highly skilled and educated workforce will be more resourceful in removing and/or adapting to innovation barriers, particularly those which prevent engaging in innovation. The authors found that those firms with higher levels of human capital were able to reduce deterring barriers to innovation when those barriers are

knowledge-based and market related (but not cost-based). These results support the assertion that firms with higher levels of human capital (i.e., skilled and educated workforces) can craft strategies to overcome certain innovation barriers. The analysis underscores the value that education, skill, and breadth of knowledge bring to assessing and minimizing constraints along a firm's innovation journey.

Link and Scott (2009) evaluated the potential influence of external funding on commercialization success for those firms receiving financial support in the SBIR program. The authors posited that a firm with external funding may be more likely to commercialize a technology since potential investors sort through and select firms within which to invest based on an assessment of success. They further suggested that outside investors may "provide useful business and management guidance that will help to bring about the commercialization of the project" (p. 266). Their results imply the impartation of knowledge from outside investors builds entrepreneurial human capital through experiential guidance and assistance in the commercialization process.

Human Capital and the Creation of Spin-offs, Alliances and Social Networks

Several studies have looked at the relationship between human capital and the types of relationships and other innovation output that can occur when firms invest in their workforce, signal expertise and leadership through management characteristics, and develop their social networks.

Acs, Braunerhjelm, Audretsch, and Carlsson (2009) looked at the potential impact of knowledge spillovers associated with incumbent firms' investment in human capital. The authors theorized that incumbent firms invest in human capital through R&D, and to the extent the knowledge stock gained through R&D is not fully utilized or appropriated, there will be

opportunities (i.e., spillover) for entrepreneurs to exploit that knowledge and create their own ventures. The key supposition is that entrepreneurial growth follows an endogenous growth model and thus is not an exogenous event. Using a theoretical framework of endogenous growth, the authors tested the factors driving entrepreneurial growth, including the stock of knowledge in the economy, the barriers to entrepreneurship (e.g., tax-based measures) and the extent of the incumbent's utilization of their human capital knowledge (e.g., patents and employment measures). The authors found that endogenous knowledge spillovers are positively correlated with entrepreneurial growth. Additionally, to the extent an incumbent does not utilize or adequately appropriate its own human capital, knowledge spillovers will result in entrepreneurial growth. These results support the notion that entrepreneurship occurs endogenously through knowledge spillovers generated by under-utilized incumbent firm research expenditures. Further, incumbent firms are better served to exploit their investments in human capital; otherwise, innovation that is funded by the firm could yield innovative outcomes without any direct benefit.

Grilli and Murtinu (2015) researched the signaling effect associated with the award of public subsidies and the ability of firms to leverage those signals to secure R&D alliances with third-party firms. The foundational theories of signaling and human capital provide the groundwork for their research in attempting to explain certain information asymmetries and productivity in high-tech firms. The essential issue with small innovative firms is their lack of a performance track record, which has implications for commitments of third-party funding and their ability to engage in productivity-enhancing outside partnerships. However, by being awarded selective (i.e., competitive) subsidies, the firm emerges from a vetting process with an effective stamp of approval of the firm's prospects or potential, which can be leveraged to reduce information asymmetries in future engagements and alliances. The authors suggested that human capital characteristics of the firm, such as founders' education and experience, should positively

affect the probabilities of being awarded a subsidy and developing R&D alliances due to their skill sets (i.e., a firm's ability to leverage and exploit their endowed human resources).

Their results indicate a positive and significant relationship between the receipt of a public subsidy and engagement in an R&D alliance, supporting the theory that a subsidy award signals the quality of the firm as an alliance partner. Additionally, there is a positive and significant relationship between the founders' technical education and the receipt of a subsidy, bolstering the notion that human capital plays a key role in funding. However, founders' technical education does not lead to the establishment of R&D alliances. The only human capital characteristic that appears to increase the probability of creating R&D alliances is the founders' industry work experience. The implication is that certain human capital characteristics are key to obtaining competitive public subsidies in high-tech firms, which is important to small innovative firms with no meaningful track record of performance and where information asymmetries exist.

Lastly, a more recent development in the literature relates the importance of developing meaningful social connections to achieve desired innovative outcomes. Leyden and Link (2014) developed a theoretical model to formulate the interactions of an entrepreneur between their social network and the innovation discovery process. The primary supposition of their model is the existence of a two-step entrepreneurial search process: creation and refinement of social networks and the discovery of an innovation that suits the network in an uncertain environment. Assuming an individual is interested in becoming an entrepreneur, he/she will create a social network based on "strong" and "weak" ties. As those ties are further developed and feedback is obtained regarding the value and effectiveness of those ties, the optimal level of both strong and weak ties is settled upon to find the innovation best supported by the network. Underlying the two-step process is the existence of uncertainty, which, according to the authors, is a key characteristic of an entrepreneur. Given the uncertainty, the entrepreneur needs to be nimble and

proactive using inputs into the search process, such as knowledge, actions and resources, which are reasonably expected to result in innovations. Therefore, the entrepreneur search process may involve any combination of inputs which generate regions within which social networks can be developed and enhanced towards innovations. The optimal search region is one that finds the right combination of cost and benefit: the intersection of average cost and average benefit lines in a cost/benefit (y-axis) and search area (x-axis) space. The importance of searching and developing a social network to enhance the chances of finding an innovation with the expected return desired by the entrepreneur is a critical conclusion.

Human Capital and Initial Public Offerings

Venture capitalists typically have a targeted horizon for returns from their investments. In many cases, venture capitalists will look to the stock markets to monetize their investments. Therefore, there is a strong connection between venture capital funding and IPOs. As such, the literature reviewed considers several different dimensions of the interactions between human capital, venture capital, and IPOs.

While an IPO may be one path to long-term growth potential, to the extent conditions are favorable, small innovative firms could become take-over targets by larger firms. In the evaluation of a potential acquisition, it is likely that any acquiring firm will evaluate the human capital of the target firm. Lehmann, Braun, and Krispin (2012) explored the driving forces behind entrepreneurial firm merger and acquisition (M&A) activity, and particularly, the potential influence of human capital characteristics on the probability of a firm being acquired. The key factors in their analysis include the amount of human capital owned by the inventor/founder of the entrepreneurial firm and certain performance, financial, and demographic metrics (e.g., growth, firm age, industry) that may impact the probability of the firm being acquired by a larger

incumbent firm. The authors asserted there is an inherent matching process in the capital markets between larger incumbent firms and smaller, high-tech entrepreneurial firms that assembles entities with complementary products/technologies and/or exploits opportunities as a result of being part of one organization. However, as with any corporate restructuring, there are uncertainties and asymmetric information that may result in the union being less than optimal if not properly constructed. In particular, there may be an inability to exploit technologies from a corporate combination due to those technologies being indivisible from the founder/owner/investor. As such, acquiring firms will likely assess the market and contemplate takeover bids based on their expectations of a good corporate match. The authors offer many hypotheses related to the relationship between human capital and M&A activity. The results from their analysis suggest there is evidence that incumbent firms evaluate the potential for a mismatch in a corporate combination based on their ability, or lack of it, to exploit intangible assets of the target firm. It is reasoned that to the extent intangible assets are indivisible from the founder/owner, potential acquirers will forego those particular transactions and instead choose targets with human capital assets that are cumulative to the incumbent.

Farag, Mallin, and Ow-Yong (2014) looked at the other side of the venture capital/entrepreneurial firm and human capital relationship. The authors sought to answer the question of whether venture capital participation in entrepreneurial firms results in improved governance and ultimately better performance given the venture capitalist's engagement in monitoring activities within the firms they invest. They first suggested a positive relationship between venture capital ownership in high-growth IPO companies and the characteristics of their governance. The motivation for this first hypothesis is based on the notion that venture capital brings a level of influence and determination to the governance structure of the firm in order to realize an expected return. A second hypothesis suggests a positive relationship between the

governance structure of entrepreneurial IPO firms and their financial performance, which stems from the literature supporting the value of strong governance mechanisms and management accountability. The third hypothesis connects the relationship between venture capital ownership of growth firms and their financial performance. The authors expected a positive relationship due to the potential impact of venture capitalists in fostering a culture of firm innovation and economic growth. The results from the models indicated a positive and significant relationship between firm governance and venture capital ownership. Directionally, the relationship moves from venture capital ownership to corporate governance. The authors also found a causal relationship between governance and firm financial performance. Lastly, the paper established an indirect relationship between venture capital ownership and firm performance by way of improved corporate governance. To the extent venture capital provides a meaningful level of human capital knowledge and discipline into the management structure, executives, boards of directors, and IPO investors, and their regulators should consider those potential advantages when making funding and investing decisions.

With respect to the role of human capital in IPO activity, Ozmel, Robinson, and Stuart (2013) looked at outcomes associated with venture capital funding and strategic alliance (SA) relationships. Their theory suggested that venture capital funding provides firms with increased relationship opportunities with respect to other venture capital portfolio companies as well as increased access to expertise through SAs. The authors questioned whether venture capital funding momentum or SA partnership momentum is present with firms with existing venture capital funding and if either of these lead to an increase (hazard) of future acquisition or IPO. The authors investigated the potential interplay between venture capital funding and SA relationships with biotech companies to apply this theory to small, private entrepreneurial firms. The results indicate higher past SA activity does not imply future venture capital funding, and

prior venture capital funding does not appear to crowd out SA partnerships. Results also show both venture capitalists and SA partners provide some type of signal or certification of firm quality, which is a benefit to the firm's future funding prospects.

Finally, in an analysis of the impact of human capital on IPO activity, Kaplan, Sensoy, and Stromberg (2005) reviewed the characteristics of venture capital-backed start-ups that issue an IPO. Drawing on the theory of the firm, the authors attempted to understand the pattern of founder and specific human capital in attainment of an IPO and beyond. Further, they looked at the extent that alienable assets (i.e., those that can be readily assigned) are instrumental in firm management and ownership. The authors analyzed venture capital-backed firms that were considered start-ups during the early to mid-1990s and issued an IPO later in the decade. Statistics and comparisons were derived by the authors regarding the human capital and non-human capital assets associated with the firms with particular attention to those that survived at least three years beyond the IPO. In general, the authors found that the "glue" supporting the success of these firms is centered around alienable (non-human) assets relative to the human capital and non-alienable assets of the firm. The authors interpreted the results as indicating human capital is more important at the point of business plan and less important as the firm matures and generates alienable assets. They believed this analysis supports the theory that firms form and grow around non-human, alienable assets. These findings do not necessarily dismiss the potential importance of human capital in innovative outcomes; instead it may suggest that hard assets are simply easier to value than soft (e.g., human capital) assets, and when seeking an IPO, the market may place more value on tangible assets.

Summary

The scope of the literature on the intersection of human capital and innovative behavior and innovative outcomes is broad and diverse, but several themes are evident. First, greater levels of human capital within a firm generally translate into firm survival, positive signals of potential success, favorable returns on investment, and an increase in the number of firm patents. Second, human capital can reduce barriers to innovations and there is empirical evidence of human capital causing innovations. Third, investments in human capital can yield new entrepreneurial opportunities, awards and subsidies, and social relationships that lead to innovations. Lastly, funding for small innovative firms can be influenced by several human capital characteristics. The more divisible the intangible assets of the firm with respect to its founder(s) as well as the ability to identify through signaling and assess the quality of human capital assets, the more external funding options, including IPOs, are likely available to small firms.

While these findings are a useful first step in understanding the impact of intangible capital on innovation output, a deeper review of the literature relating the other form intangible capital, social capital in particular, to innovation outputs is warranted. The next chapter explores this literature and identifies the gaps that exist with respect to the relationship between social capital and innovation outputs and how those gaps are addressed in this dissertation.

CHAPTER IV

LITERATURE REVIEW OF SOCIAL CAPITAL AND INNOVATION OUTPUTS

While the literature evaluating the impact of human capital in the innovation process is extensive, there are relatively fewer economic studies regarding the relationship between social capital and innovative outputs, such as obtaining additional funding, the commercialization of an innovation, or firm growth-related activities (e.g., an IPO). The following literature review describes several studies relating social capital to innovation outputs. However, a gap in the literature remains with respect to the potential relationships between both strong and weak social ties and the outputs from innovation using empirical data. The contribution of this dissertation is to explore that gap through the conceptualization and measurement of social capital as a productive form of capital and empirically testing this theory.

Social Capital and External Funding

Jonsson and Lindbergh (2013) reviewed the interaction of social capital and external funding arrangements for entrepreneurial firms in need of financing in the fashion industry. The authors contemplated that entrepreneurs develop social capital to obtain financing from external sources to grow their business. While their study is primarily theoretical, it provides a generalized viewpoint that active entrepreneurial engagement in social capital accumulation, and particularly weak social ties, is a necessary condition to achieve certain business goals.

Hsu (2007) applied these theoretical principles with an empirical study of the impact of social capital in venture capital financing. Using survey data from firms that have received venture capital funds, Hsu (2007) tested whether the strong social ties of the firm's founders, as

measured by the network used to recruit non-founder executives, lead to higher firm valuations and potential venture capital funding opportunities. The primary supposition of Hsu (2007) is that human capital and social capital are complementary, and entrepreneurs who have experience in founding new ventures cultivate social capital through human capital accumulation. The results from their model indicated that social capital, as specified, has a positive and significant correlation with firm valuations, which has strong implications for obtaining external funding from venture capitalists. Hsu (2007) noted that this outcome provides "evidence of the possible contingent effects of human capital in the sourcing and valuation of venture capital, suggesting that a more complex treatment of the asset is in order" (p. 738).

In another empirical analysis, Uzzi (1999) explored the extent to which weak social ties benefit firms when seeking financing from banks. The social embeddedness, which the author described as "the degree to which commercial transactions take place through social relations and networks of relations that…govern business dealings" (p. 482), creates an important social dimension to the relationship between the firm and the financier. Uzzi (1999) asserts the richness of the relationship that is developed over time by the entrepreneur with their lender provides a foundation of trust and reciprocity between both parties, ultimately resulting in more favorable lending terms to the entrepreneur. Using data obtained through firm surveys, Uzzi (1999) demonstrated that firms that are more social embedded with their lenders (i.e., longer tenure and a deeper financial relationship), increase their access to financial capital with lower borrowing costs.

Social Capital and Innovation

Similar to the discussion of the relationship between human capital and innovation, the empirical literature related to social capital and innovation spans a wide range of outcomes.

Focusing on the direct impact of social capital on innovation, there are several studies that attempt to identify the social dimensions within entrepreneurial firms that may lead to new innovations.

For example, Cooke and Wills (1999) evaluated the potential benefits to an innovative firm from collaboration and social capital creation. The authors provided an exploratory construct of the way in which weak social ties may promote innovative activity. To assess the relevance of social capital, Cooke and Wills (1999) developed a dataset consisting of responses from surveys from small and medium sized enterprises (SME) in selected European countries. The authors concluded that "significant portions of the surveyed SME population ascribed improvements to business performance, innovation, and knowledge exploitation to the newly-formed social capital" (p. 233). Although the results are generalized and the method through which the social capital measures are developed is subjective, Cooke and Wills (1999) provide incremental insights into the perceived benefits of social engagement in small firms.

In a paper motivated by a theoretical assertion that both tangible and intangible inputs drive innovation, Landry, Amara, and Lamari (2002) attempted to answer the question of whether social capital determines innovation. Since innovation is assumed to be a process and not just a discrete event, their analysis suggested that layers of social capital measurement must be included in the evaluation. The authors addressed the measurement of weak and strong social ties by developing several indicators to quantify the collective impact of social networks on innovation. Using survey data from Canadian manufacturing firms, the social capital explanatory variables include structural and content dimensions of social interactions, such as the extent of business networks and the importance of trust in the innovation process. As with most empirical analyses using social capital as independent variables, there is a degree of subjectivity and inference in the evaluation of response of survey questions, and the authors have taken some liberty in the

assessment of measurement of social capital. Nonetheless, Landry, Amara, and Lamari (2002) showed that in a two-stage analysis of first, deciding to develop and innovate and second, the extent of innovative effort, the weak social tie measure representing relational social assets (i.e., knowing key individuals outside the firm that are potentially key in successful innovation) is an important social dimension in the innovation process.

Expanding on the relational, or content, dimension of social capital and its potential effects on innovation, Pérez-Luño, et al. (2011) delved into the specific types of social interactions that could affect innovation. Their analysis looked at weak social ties that are cultivated with external parties to determine whether those relationships result in innovation. While the conclusions are somewhat mixed, their study supports the notion that social relationships in a business setting can provide key advantages in transferring knowledge, especially when the information is tacit.

Social Capital and Initial Public Offerings

For innovative firms to reach long-term success with their products and services, they must eventually move beyond venture capital and other late-stage developmental funding to a more permanent source of financial capital. It is a natural progression for innovative firms to execute a strategic direction that allows for long-term operational and financial support of the commercialized technology, either through a spin-off from an existing institution (e.g., a university or parent company) or issue stock in an IPO that will financially support their future innovations.

There is no shortage of economic papers that review the success or failure of innovative firms executing a spin-off or IPO and the factors that potentially drive those outcomes. Many of those studies debated the merits of human capital, market timing and uncertainty, venture capital

participation, underwriter support, governance structures, and other influences, but the literature relating social capital to long-term capital structures of innovative firms is less explored. A likely reason for the dearth of research on this topic is the intangible nature of social capital and the difficulty in directly linking social ties to an event as important as becoming an independently managed and funded company. Nonetheless, several such studies have attempted to relate social capital with spin-off and IPO outcomes of innovative firms.

Landry, Amara, and Rherrad (2006) looked at university spin-offs to determine the potential reasons why some university researchers are more likely to create spin-offs than others. To answer this question, the authors posited that "researchers are entrepreneurs who use a great number of idiosyncratic resources and capabilities, which are deployed and coordinated in the process of spin-off creation" (p. 1601). One of those resources is social capital, which the authors described as the measure of the degree to which university researchers are linked with individuals outside of research and development activities. Their weak social tie measure is a simple index of the level (but not quality) of interaction with third parties. The empirical results point to a positive correlation between their social capital measure and the incidence of a university spin-off.

With respect to social capital and IPOs, Gulati and Higgins (2003) evaluated the type of social ties that are related to IPO success. The authors hypothesized the social capital necessary to successful complete an IPO is situational and not uniform across firms. For example, firms interested in issuing an IPO may have to rely on different social connections based on market conditions. Gulati and Higgins (2003) test the level of embeddedness (i.e., the extent of non-economic relationships) of IPO-seeking firms with their venture capitalists, underwriters/investment banks, and strategic alliances. Their results indicate that weak social ties with venture capitalists may be more important in down markets and those with investment banks

are more beneficial when there is a degree of IPO activity. While their findings provide some level connection between social capital and IPOs, a significant limitation in the analysis is that the dependent variable in their model is related to an existing IPO, so the actual cultivation of social capital leading up to the IPO is not captured.

Summary

There are a limited number of analyses that evaluate both the strong and weak social ties of a firm relative to their innovation output. However, the importance of social capital in innovation has been explored in a number of ways that further the dialogue on the topic. With respect to external funding, it has been shown that relationships with venture capitalists and bankers are key in obtaining outside financing and with favorable terms. Social capital also plays an important role in innovation and commercialization. Several studies have concluded that entrepreneurs consider their social engagements key to innovative success. Lastly, while the empirical research relating social capital to firm growth-related activities, such as IPOs, is sparse, there is some preliminary evidence that social networks can possibly improve the likelihood of growth as a separate firm through the public equity markets.

As insightful as these studies are in understanding the potential relationship between social capital and innovation output, there remains a gap in the literature demonstrating the impact of strong and weak social ties on innovation outputs, including the social capital factors affecting developmental funding, product commercialization, and firm growth-related activities.

The next chapter establishes a theoretical framework with social capital as a key input into the innovation process. Innovation production is assumed to include three important outputs: 1) obtaining late-stage research funding, 2) commercialization, and 3) experiencing growth-related activity for the from the development of an innovation by issuing an IPO, creating a spin-

off firm, or by executing a firm sale, firm merger, or licensing agreement. Therefore, it is hypothesized that social capital is an important input into the process of generating outputs from innovation. This theory leverages a model developed by Leyden and Link (2014) which provides a foundational approach to evaluating the influence of both strong and weak social ties in innovative activities and external funding. Social ties may improve ideation and new product development, and policies that encourage these interactions, such as collaborations may lead to the aforementioned innovation outputs

CHAPTER V

THEORETICAL FRAMEWORK OF SOCIAL CAPITAL IN INNOVATION

Types of Productive Capital Within an Innovative Firm

The term *capital* is often used to describe a variety of assets. In economic theory, capital is a factor of production from which revenue is derived (Smith 1776/1976). However, it is important to delineate among the various forms of capital—both the tangible and intangible types of capital—in the discussion of the drivers of a successful innovation. In the context of this dissertation, tangible capital for innovative firms is narrowly defined to include physical capital while intangible labor capital includes human capital and social capital. Financial capital is also considered in innovation production as it can be used to acquire physical capital and human capital as well as mediate the accumulation of social capital when trustworthy relationships are developed with financial investors. That is, each type of input capital can be considered a function of financial capital. A description of physical capital, human capital, and social capital and their respective impact on the production of innovative outputs is provided below.

Physical capital includes fixed assets that are used in the production of goods and services, such as machines, equipment, and laboratories. Physical capital is often a critical input through which an innovation is developed and produced, so the ability to procure physical capital is imperative to the success of an innovative firm. In cases where equipment or machinery is not readily available, firms use financial capital to acquire the necessary physical capital to develop an innovation.

Human capital and social capital represent the intangible dimensions of labor capital. Human capital, as discussed in prior chapters, includes the education, experience, and training of

a firm's employees, which have been shown to be a driver of a variety of production outputs, including innovation outputs. Firms invest in human capital to develop a broad range of skills, abilities, and knowledge to increase the probability of being successful. Human capital also provides the means by which physical capital is deployed in the manufacturing of products and services. Whether a firm acquires top talent or purchases training materials for their employees, there is often a financial commitment to accumulating human capital.

Firms cultivate social capital by encouraging and supporting the development of strong institutional knowledge and by fostering an environment of deep interpersonal connections among its employees and external partners. These interactions promote collaboration and trustworthy relationships that are expected to positively influence production in general and innovation in particular. Social capital encapsulates the cultural cohesion, shared identity, and the creativity of the firm through the establishment of social norms of trust and reciprocity among coworkers and other associates within the firm. Social capital propels the firm to achieve shared goals and signals the propensity to continue to be able to innovate. Additionally, the social capital of a firm is enhanced with the interaction and engagement with external parties that complement skills sets and provide feedback, guidance, and verification in the firm's efforts to reach innovation goals. In instances where a firm obtains financial investment, social capital is accumulated when those interactions with investors result in the exchanging of ideas, the sharing of best practices, and leveraging of the investor's expertise.

Financial capital, which can originate from many sources, such as from firm founder resources, financiers, or venture capitalists,[3] provides the financial means to acquire, develop, and generate physical capital, human capital, and social capital, respectively. For example, an

[3] A more comprehensive discussion of the benefits of venture capital is presented in Chapter VII.

innovative firm may use financial capital from personal savings of the founders to purchase equipment or hire employees that have the desired experience, education, and training to conduct R&D by the firm. Likewise, an innovative firm that receives financial backing from a third party, such as a venture capitalist who has expertise in similar innovations, may become enriched with social capital as ideas are exchanged, mutual trust is built, and common goals are pursued. Therefore, physical capital, human capital, and social capital may be accumulated through the implementation of financial capital that supports the execution of the firm's innovative activities. The implication is that there are scenarios where financial capital is an indirect input into innovation production.

Successful innovation outcomes, therefore, are achieved through the direct capital inputs of physical capital, human capital, and social capital and the indirect capital input of financial capital. Table 2 depicts each form of capital input and their respective impact on innovation output, including financial capital. The remainder of this section discusses the relationship between social capital and production of an innovation.

Table 2. Description of Capital Inputs into Innovation Outputs

Forms of Capital Inputs	Definition	Impact on Innovative Outputs
Physical	Fixed assets, including machinery, equipment, and laboratories	Physical inputs used in the development and production of a commercializable good or service
Human	Education, experience, and employee training	The skills, abilities, and knowledge of the firm's employees that generate innovative content and utilize the firm's physical capital to produce innovation output.
Social	Social networks and the social norms of trust and reciprocity cultivated internally and externally to the firm	Collaborative and trustworthy relationships that generate ideas, encourage creativity, and build a cultural cohesion and shared vision of the firm, which promotes innovation output
Financial	Financial resources	Financial capital allows firms to acquire, develop, and accumulate physical capital, human capital, and social capital, which are inputs into innovation production

Social Capital and Productivity

A fundamental argument around the relevance of social capital in the social science literature is that relationships are important in the pursuit of goals. It follows then that the relative strength of certain relationships can affect the likelihood of achieving goals or outcomes, such as innovation outputs, that may not occur if not for the existence of social capital. The productive nature of social capital has been explored by those scholars who are closely associated with the theory of social capital. Coleman (1988), for example, noted:

> Like other forms of capital, social capital is productive, making possible the achievement of certain ends that in its absence would not be possible. (p. s98) Just as physical capital and human capital facilitate productive activity, social capital does as well. (p. s101)

Putnam (2000) also described the productive nature of social capital:

> By analogy with notions of physical capital and human capital — tools and training that enhance individual productivity — the core idea of social capital theory is that social networks have value. Just as a screwdriver (physical capital) or a college education

> (human capital) can increase productivity (both individually and collective), so too social contacts affect the productivity of individuals and groups. (pp. 18-19)

Fukuyama (1995), in a discussion of the role of social capital in the context of global industrial structures, noted the benefits and effectiveness of social cooperation within organizations:

> Virtually all economic activity, from running a laundry to building the latest-generation microprocessor, is carried out not by individuals but by organizations that require a high degree of social cooperation. As economists argue, the ability to form organizations…depends on a prior sense of moral community, that is, an unwritten set of ethical rules or norms that serve as the basis of social trust. Trust can dramatically reduce what economists call transaction costs—costs of negotiation, enforcement, and the like—and makes possible certain efficient forms of economic organization that otherwise would be encumbered by extensive rules, contracts, litigation, and bureaucracy. (p.90)

For developing a theoretical framework to explain the relationship between social capital and innovation outputs for a firm, social capital is narrowly defined to be the intangible relationships and connections cultivated 1) among the employees of the firm (strong social ties) and 2) with individuals and organizations outside of the firm (weak social ties). With respect to the strong social ties within firms, Halpern (2005) asserted:

> It can be argued – rather convincingly – that one of the most common and important forms of social capital is the firm or company…there are major economic advantages to bringing together a group of individuals with complementary skills into a closely coordinated network, with shared understandings and mutual commitments that facilitate cooperative action for maximum productivity…the firm can be viewed as a form of social capital – and perhaps primarily as 'bonding' social capital. (p. 53)

Coleman (1988) described the importance of weak social ties within a firm:

> Because purposive organizations can be actors ("corporate actors") just as persons can, relations among corporate actors can constitute social capital for them as well (with perhaps the best-known example being the sharing of information that allows price-fixing in an industry). (p. s98)

Granovetter (1973) contended that weak social ties are important as they promote diffusion of information and noted, "it is through [interpersonal] networks that small-scale interaction becomes translated into large-scale patterns, and that these, in turn, feed back into small groups" (p. 1360). By delimiting the concept of social capital within a firm to include those connections among the firms' employees and relationships with external parties, a more targeted review of the impact social capital can be explored.

Strong social ties are characterized by, among other things, interpersonal connections among individuals with common knowledge or with institutional knowledge. For example, firms can generate social capital by encouraging a work environment that rewards innovative thought and action through collaborative activities. Further, a deep knowledge about a product or process by a group of individuals within an organization is characteristic of a strong social tie as there a cohesion and common purpose for those individuals. The deeper the knowledge, trust, and alignment of common goals among the employees of the firm, the more efficient the firm will be in the execution of innovation production initiatives.

Weak social ties are characterized by heterogeneous knowledge among social connections that create an environment of idea generation, sharing of best practices, and objective dialogue. A social network associated with weak social ties can furnish a firm with a set of personal connections that augment an existing base of institutional knowledge and lend credibility to a firm's objectives through guidance and feedback. Toward that end, firms may develop relationships with a variety of external parties to draw on expertise and leverage connections that may assist in the realization of an innovation. When firms create weak social ties, it would be in their interest to signal the strength of the weak ties to prospective business partners to convey the existence of those interpersonal relationships that have assisted in producing an innovation, potentially lending credence to product quality and firm sustainability. For example, a firm that

has relationships with influential external advisors or has developed strategic agreements that leverage outside expertise may stand out relative to its competitors since those relationships signal an ability to successfully build connections and socialize the firm's business prospects with external partners.

Social Capital and Innovation

While the economic literature on the relationship between social capital and innovation outputs is thin, there are studies on the importance of strong and weak social ties in the pursuit of innovations.

For example, Fountain (1998) summarized the importance of social capital as a catalyst of innovations, and particularly innovation in science and technology. Fountain (1998) described social capital as those elements of social organization that "facilitate coordination and cooperation for mutual benefit," and it "accumulates when used productively" (p. 105). Fountain (1998) also stressed the importance of weak social ties to achieve innovative outcomes by noting:

> Internal expertise remains necessary to evaluate external research and development, but external relations facilitate access to new information and expertise that is not easily built within the firm…Many industries have developed social capital through external relations with other organizations to increase their ability to innovate and to absorb innovations. (p. 109)

Chou (2006) developed a theoretical innovation growth model with social capital as an input. In the model, social capital includes both strong social ties generated from "learning-by-doing" (p. 904) associated with prior innovation activities as well as weak social ties cultivated through associations with external parties. With respect to the weak social tie component, Chou (2006) noted the intentional effort necessary to build social capital when innovating,

> …in order to leverage the social capital that is embodied in the [weak social tie] networks described previously, firms have to invest at least some labor resources towards seeking suitable network partners and identifying productive collaborative activities. (p. 904)

Chou's (2006) model showed that weak social ties are important in economic growth as the benefits of "learning-by-doing" through prior innovations and investments in time and prior effort to cultivate relationships with third parties provide incremental opportunities to increase output. The practical implications of the model's results include suggested changes in policy related to increasing the levels of social capital. The author summarized this conclusion by stating:

> In recognition of the importance of social capital within innovation networks, government policies should focus on inducing firms to collaborate more intensively with other firms, research labs, universities and government agencies in order to increase the number, size and efficacy of networks. Governments should lay the physical infrastructure that encourage networking such as building research and development hubs, industrial parks and clusters for high-technology firms. (p. 910)

Expanding this conceptual theory to innovation output, social capital is a key input for firms developing innovations in two ways. First, firms that develop a corporate culture which rewards trust and reciprocity among employees builds strong social ties that are necessary to produce innovations. Second, the development of external relationships builds weak social ties that advance the innovative goals of the firm. These relationships generate benefits by providing a platform to collaborate as well as to showcase innovative efforts to third parties whose participation is necessary to produce innovative output that may not transpire without such social engagement.

There are examples of firms that appear to possess social capital and have been successful.[4] However, there are also examples of firms that possess all the traditional capital factors of production (physical, human, and financial capital), but yet have failed to meet their innovation goals. A recent start-up failure that has received extraordinary media coverage regarding its deficiencies, including its level of social capital, is the health-tech company Theranos.[5] An often reported critical error by the firm and its founder was the lack of development of relationships with external researchers to assist in the verification of the technology. Further, Bilton (2016) wrote about the potential lack of Theranos' healthcare relationships among its board of directors by stating it was "…a board that was better suited to decide if America should invade Iraq than vet a blood-testing company."

The importance of social capital as not just an adjunct of human capital, but as an independent input into the production of innovation outputs, is a key argument in this dissertation. By leveraging the trust, commitment, and collaboration through investment in relationships, a firm accumulates a form of capital that can directly impact innovation.

Social Capital within a Production Framework

To evaluate the productive nature of social capital within a firm, it is asserted that innovation outputs result from the implementation of several forms of productive capital, including social capital. To begin, a standard economic production function is introduced to establish the theoretical relationship between innovation output and capital inputs. Equation [1] shows that innovative output (I) depends on several direct inputs: physical capital (K), the labor

[4] See case study in Appendix A: Social Capital and Innovation Success: Fitbit
[5] This case study is presented in the Appendix B: Social Capital and Innovation Failure: Theranos

capital inputs of human capital (*H*) and social capital (*S*), and an unmeasurable innovation shift factor (*A*), which includes other unobservable factors not measured by these capital inputs.[6]

[1] $I = A * f(K, H, S)$

Additionally, as discussed earlier in the chapter, there are scenarios where financial capital is used to acquire, develop, or accumulate physical capital, human capital, and social capital. Under these scenarios, financial capital is an indirect input into production. For example, if a firm must purchase equipment with certain characteristics or hire employees with specific skills to perform research, financial capital is used to acquire and develop physical capital and human capital. Further, by obtaining financial capital from outside investors, a firm gains valuable social capital through the sharing of ideas and leveraging of external expertise due to the investor's experience and network connections. Equation [2] is thus an extension of Equation [1] that captures the indirect impact of financial capital in innovation production.

[2] $I = A * f(K(F), H(F), S(F))$

Equations [1] and [2] characterize a relationship between capital inputs (and with respect to equation [2], the indirect capital input of financial capital) and innovation outputs for a single firm at a single point in time (for representational simplicity, subscripts representing each firm *i* at time *t* are suppressed). The relationships in equations [1] and [2] are posited without constraints on the timing of physical capital, human capital, or social capital accumulation during the innovation process. However, there is an implicit sequencing in equation [2] given that the

[6] Traditionally, *L* is used to represent labor input. In this dissertation, labor input takes two forms: human capital, represented by *H*, and social capital, represented by *S*.

accumulation of financial capital, as an indirect input into production, often precedes the accumulation of physical capital, human capital, and social capital. This general assumption of a contemporaneous relationship between innovation outputs and physical capital, human capital, and social capital is based on the absence of an *a priori* argument for the imposition of specific timing of these capital inputs relative to the production of innovation outputs. While lagged values of direct capital inputs could be relevant in the realization of innovation output at time *t*, the timing is not obvious, and is therefore is not specified. However, relaxing the timing constraint can be a future extension of the framework and of the empirical analysis.

By assuming a contemporaneous framework, a counterargument arises for the potential of reverse causality between one or more capital inputs and innovation outputs. The supposition in this dissertation is that capital inputs impact innovation output. A counterargument could be made that additional amounts of innovation output can attract better talent (human capital), lead to more networking opportunities and the accumulation of social capital, or increase the potential for obtaining additional financial capital. This counterargument is not without merit, especially considering the fluidity of capital inputs (and particularly human capital and social capital). Nonetheless, the empirical work in this dissertation follows the theory of using capital inputs to create outputs under the simple assumption that capital is actively procured and accumulated, and it is not a direct outcome from the generation of production outputs. As such, this dissertation it is limited with respect to the counterargument of reverse causality.

Social capital as an input into production is of interest in the framework of innovation output because it embodies the cultural and interpersonal richness of the firm generated through the cultivation of strong and weak social ties. Leyden and Link (2014) develop a theoretical model whereby entrepreneurs build their social network through both strong and weak social ties to accommodate an innovation. Further, Leyden and Link (2014) assume the firm's entrepreneur

receives feedback that refines the search process for the optimal level of social capital to support an innovation. Following this reasoning, an innovative firm's stock of social capital is a function of strong and weak social ties at any point within the social capital investment process. The next section applies these concepts to specific innovation outputs that are the derived from a combination of the aforementioned capital inputs, of which the focus is social capital.

Social Capital and Innovation Success

The path to a successful innovation is idiosyncratic. While the life-cycle of an innovation may follow a theoretical pattern of research-to-development-to-commercialization-to-profit, it is not a necessary condition that a successful innovation follows a predetermined sequence of outcomes. The reason is that innovative firms are not all starting at the same place nor have the same goals associated with an innovation process.

Åstebro (2003) outlined a set of specific hurdles an inventor must clear for an invention to be a commercial success. In the first hurdle, the evaluation phase of the potential success of inventions, Åstebro (2003) considered whether an inventor received a positive reaction or score to the invention idea or prototype from an objective source. To the extent the innovation scored a high likelihood of commercialization, the inventor continued down the path to the second hurdle of commercialization. Åstebro's findings suggest that those inventors who received positive feedback on the invention have a higher probability of it being commercially successful. More importantly, those inventors that received positive feedback by an objective source about the invention in the evaluation phase were better situated to win outside funding since the signal provided by the positive evaluation indicated a higher likelihood of reaching the commercialization phase.

Åstebro's (2003) study offered a framework for attaining specific milestones in the innovation process, but this dissertation takes a more generalized approach by evaluating whether certain types of capital inputs, including social capital, impact three outputs theorized to be important in the success of an innovation: 1) obtaining developmental funding for the innovation, 2) commercialization, and 3) executing a growth-related activity. While these three outputs could occur in sequence, there is not an assumption that any one output is conditional on the generation of another output. Additionally, it is possible for a firm to not realize one or two of the three outputs, but yet the innovation may be deemed successful. For example, a firm may commercialize a product without the benefit of external developmental funding. Therefore, there are no explicit conditions on the timing of each of three innovation outputs in the empirical models presented herein.

However, it is certainly reasonable to assert that innovation generally follows a sequential process and that innovation outputs depend on other innovation outputs. The key theoretical consideration in terms of making of determination of cross-dependency of the innovation outputs is whether a dependency should exist. Innovation is fluid and firms operate at different levels of innovation, so their respective outputs can vary widely from a timing perspective. This could be due to the type of firm, the innovation, the industry, or stage of development. The main thrust of this dissertation is that social capital (and all that it entails: social trust, expectations of reciprocity, cultural cohesion, relationship development, mentoring, etc.) leads to innovation output and not that other innovation outputs drive innovation, so there is not a strong theoretical motivation for assuming that all the innovation outputs explored are dependent on each other. Innovation for a firm is something that occurs through the intentional cultivation of social interactions that promote diverse thinking to drive innovation behaviors and is not presented as a function of prior innovation output in this dissertation.

With respect to the innovation output of obtaining additional developmental funding, as a firm transitions from product research to product development, financial resources may be necessary to cross the so-called "Valley of Death" to be able to bring their product to the market.[7] To obtain additional developmental funding, a firm must demonstrate the commercial potential of its innovation. Potential funders will observe the type of physical tools available to produce the innovation, the level of human capital available to carry out commercialization and develop a revenue stream, and the corporate culture and strength of the working relationships within the firm. Additionally, investors will evaluate how their expertise can add value to the success of the innovation resulting from their financial participation in the firm. Therefore, additional developmental funding is a function of physical, human, and social capital. This relationship is represented in equation [3] where I_A represents the innovation output of obtaining additional developmental funding.

[3] I_A = *Firm Received Additional Developmental Funding for the Funded Project*
$= A_A * f_A\,(K(F), H(F), S_A(F))$

The social capital input in equation [3] includes the strong social ties from relationships among employees and others involved in the product development process that build institutional knowledge and a culture of innovation success. To potential funders, this culture may signal a firm's ability to deliver on its innovation and be a determinant of investment. Social capital measures that include results of collaborative work, such as the development of publishable and patentable research, as well as the tangible results from working together towards a common goal of winning funding are considered for this output. Additionally, the infusion of an innovative

[7] Further discussion of the "Valley of Death" is in Chapter VII, Small Business Innovation Research Program, in this dissertation

culture brought to the firm by the founders who have experience in generating new ideas is also a measure to evaluate against receiving additional developmental funding.

For the innovation output of a commercially viable product or service, it is expected that a key source of social capital for this output is the relationships and guidance received from outside investors providing funding. Additionally, innovative firms need to engage with other third parties to establish collaborations that enhance the prospects of selling the innovation to the market. Relationships with external parties encourage diverse perspectives, sharing of ideas and research, and constructive reviews and feedback. Measures for this type of social capital include the level of engagement with strategic financial and operational partners to bring the innovation to market. This type of social capital is necessary for commercialization and may also be a signal to potential customers of product quality to the extent these relationships provide validation or support for the innovation.

Equation [4] indicates that physical, human, and social capital are direct inputs into the innovation output of commercialization sales (I_B). In this model, the indirect financial capital associated with social capital is expected to be related to the existence of potential private investors. By allowing external financial capital to work through social capital, the intangible benefits generated through the cultivation of financial relationships can be included as an indirect input into innovation output.

[4] I_B = *Firm Reported Commercialization of Product, Process, or Service Sales*
$= A_B * f_B\,(K(F), H(F), S_B(F))$

Lastly, firms that successfully innovate should be expected to continue to grow and potentially raise equity. Growth occurs when the firm possesses the appropriate mix of capital inputs that result in operational and financial independence resulting from the successful innovation. The relationship between capital inputs and firm growth-related activities, such as a

and IPO, a spin-off firm, a firm sale or merger, a joint venture, or a product licensing agreement, is identified in Equation [5] where I_C represents this output in the innovation process.

[5] I_C = *Firm Experienced Growth-Related Activity, such as an IPO, a Spin-off Firm, Sale, Merger, Joint Venture, or Licensing Agreement*

$$= A_C * f_C\,(K(F), H(F), S_C(F))$$

The social capital input includes the cultivation of social ties that further deepen the firm's ability to continue to innovate and leverage spillovers to new innovative outputs. For example, measures that quantify the establishment of internal and external relationships to solidify the firm's propensity to innovate are the types of social ties supporting the third output. Similar to Equation [4], the financial capital associated with private investors is an indirect input into production as those financial relationships increase a firm's social capital. Potential investors will evaluate the ability of the firm to sustain its innovation and commercialization momentum, and when considering participation in an IPO, a firm sale or merger, or another long-term innovation partnership, relationships that signal long-term viability of the firm may lead to successful execution of this innovation output.

In the models as shown in equations [3], [4], and [5], each innovation output variable represents a measure of innovation output realization. The independent variables of physical capital, human capital, and social capital, along with the indirect capital input of financial capital, measure the level or existence of each type of capital. Of particular focus is the impact of the social capital on innovation outputs, so the measurement of social capital is important in the ability to estimate the extent of the relationships in these equations. However, the practical hurdle in empirically testing this theory stems from the difficulty in measuring the strong and weak social ties of a firm. This issue is investigated more thoroughly in Chapter VIII, which outlines a framework through which social capital can be measured for innovative firms by

describing a path to operationalize the two core dimensions of social capital—structure and content.

CHAPTER VI

SOCIAL CAPITAL AND FINANCIAL CAPITAL FOR INNOVATIVE FIRMS

As suggested in the previous chapters, physical capital, human capital, and social capital are each a function of financial capital, and financial capital has an indirect impact on production. Therefore, for an innovative firm to be productive, it must be able to procure financial capital to build a stock of productive resources—physical capital, human capital, and social capital. The ways in which financial capital can be used to acquire and develop physical capital and human capital, respectively, is straightforward. Physical capital can be purchased with financial resources and firms pay wages and potentially fund training to craft a workforce that is consistent with human capital accumulation goals. The relationship between social capital and financial capital is more nuanced, and this chapter focuses on the potential impact of different types of financial capital on the accumulation of social capital.

Sourcing financial capital is not a simple task. In fact, innovative firms that are in the early stages of researching or developing a new product may find funding to be a significant problem and impediment to innovation success. The cost of conducting R&D may become insurmountable and thus the firm may simply not have sufficient resources to bring the product to the point of commercialization. Even if the product is thought to have commercialization potential, the lack of access to continued funding can preclude fiscal success. Additionally, innovative firms focused on products requiring regulatory oversight or other third-party certification have additional challenges to commercialization given the unique obstacles of bringing those products to market, potentially creating another level of delay and even drained coffers (Hofmann, 2007).

If innovative firms with potentially successful products cannot acquire the financial resources to commit to early-stage R&D due to restricted access to sources of financial capital, they may fall into the so-called "Valley of Death." For survival, it is thus necessary for such firms to seek out the appropriate type of funding to support their R&D. If and when such financial support is obtained, those funds not only leverage the firm's ability to bring its product to market but also to set the stage for possible future funding in later stages through an IPO.

Those firms seeking funding face choices when determining the feasible set of financing options. Additionally, funding sources are evolving due to changing market conditions, changes in funding infrastructure, and government support, so firms must consider the costs and benefits associated with each funding option. There are time considerations as well, and firms will seek to obtain the most effective form of funding that minimize their effort. Although not exhaustive, there are three broad categories of funding options to support innovative firms with their R&D efforts: traditional bank and alternative lending; peer-to-peer funding; and private equity, including venture capital.[8] A brief description of each type and the potential social capital implications for the firm associated with these funding sources follows.

Traditional Bank and Alternative Lending Institutions

While securing a loan from a bank to fund new product development is difficult, the traditional bank lending route may accommodate firms who have a track record in their business and are seeking to finance their next product. Small Business Administration (SBA) loans or

[8] Other potential sources include cash on hand, grants or awards from foundations or other non-profits, and tax incentives, but since firms are generally seeking to obtain longer-term, sustainable sources of funding for R&D and may not have profits from which tax incentives are useful, the discussion is limited to the aforementioned list of funding options.

asset-based loans are potential options under certain circumstances. For most firms seeking early-stage funding, obtaining a loan with acceptable financing terms from a bank is a challenging proposition given stringent underwriting requirements.

Seeking to capitalize on the gaps in the lending business, alternative lending institutions, such as OnDeck, which provides small business lending, and Opportunity Fund, a non-profit microlender, have been born out of the notion that small business lending is underserved. Unfortunately, loans from these types of alternative lenders may not be available on a large enough scale and at reasonable enough interest rates to justify the hassle and expense of assembling multiple lending sources to fund early-stage R&D.

Given the requirements and inflexibility of traditional bank and alternative lending institutions, the opportunity for an innovative firm to benefit from the existence of these sources to meet early-stage R&D needs is curtailed, and therefore generating social capital through this type of funding arrangement is less likely.

Peer-to-Peer Funding

Crowdlending and crowdfunding are relatively new channels of financing for small businesses. Collectively, these peer-to-peer financial transactions are typically between entities (usually individuals) willing and able to invest or lend and those firms seeking funds.

Crowdlending companies such as Funding Circle and Prosper provide platforms to link borrowers with lenders. While terms and availability are nuanced, the ability to borrow money in a pooled manner provides debt raising capabilities for small firms outside of traditional bank lenders. However, the long-term viability of the crowdlending business model is unknown, so access to reliable credit through this channel is limited for a firm with significant R&D funding needs.

Crowdfunding has roots in raising money to support creative endeavors and has quickly evolved to become a legitimate source of capital for innovative business prospects. The success of the firm Oculus Rift, which was initially funded through Kickstarter and later acquired by Facebook, is widely cited as an example of the power of crowdfunding (Profatilov, 2014). Recognizing the limitations of traditional funding sources, the burgeoning infrastructure of peer-to-peer financing options, and the need for early-stage funding for small businesses, the Jumpstart Our Business Startups (JOBS) Act of 2012 (the "JOBS Act") (Public Law 112-106) was enacted to allow firms to issue securities through a "funding portal" (i.e., crowdfunding), such as AngelList and Crowdfunder.[9] The JOBS Act relaxes securities registration requirements for businesses seeking funding (up to $1 million) and opens up opportunities for those firms to develop products and services that would have otherwise been unobtainable. The timing of the JOBS Act was in response to the U.S. economic downturn beginning in 2008. As the financial crisis unfolded during that time period and a recession took hold of the economy, pressure intensified for the Obama administration to put forth meaningful policies to address slower economic growth and the uncertain duration of increased unemployment (Weisman, 2012).

Given the limited track record of the JOBS Act, it is not yet known if firms with early-stage R&D financing needs are benefiting from this crowdfunding channel. Peer-to-peer

[9] On October 30, 2015, the Securities and Exchange Commission (SEC) finalized rules regarding the intermediation, purchase, sale and reporting requirements related to Accredited Investor and non-Accredited Investor participation in small businesses through SEC-registered "funding portal" channels as required in the JOBS Act (SEC.gov 2015). Subject to certain disclosures, the rules allow individuals to invest over a 12-month period at least $2,000 (and up to 5% of their income or net worth, whichever is smaller, if their income/net worth is less than $100,000; or up to 10% of the lesser if both income and net worth are in excess of $100,000) in companies in aggregate that issue securities through an approved funding portal (but in no case can aggregate crowdfunding securities purchased within a year by an individual exceed $100,000). Firms can raise up to $1 million through this method of solicitation during a 12-month period as long as they have less than $25 million in total assets. All these levels will be adjusted for inflation by the SEC every 5 years.

platforms are clearly growing and may become a truly important source of R&D funding.[10] As it stands today, however, crowdlending and crowdfunding are not natural options for firms seeking longer-term financing. Nonetheless, these channels are an important area to explore in future research to evaluate how social platforms can impact innovation and commercialization.

Private Equity

Private equity is a broad category of investing that includes, but is not limited to, full company purchases (through debt, equity or a combination), angel investing and venture capital. Generally, both angel investing and venture capital focus on the purchase of equity in the business seeking to fund activities related to a new innovation or product. Angel investors, who may be individuals or families, generally provide early-stage funding while venture capitalists tend to invest in later stages of product development (Hsu et al., 2014). The venture capital channel has been a significant source of capital to firms where traditional financing sources, such as public equity and debt-financing, are limited or not available. The amount of available venture capital and the types of firms to which capital is deployed varies considerably in amounts, and the availability varies by region of the United States. While recent venture capital investment amounts have been the strongest since the early 2000's, the availability of venture capital to

[10] Crowdnetic (2015), now FinMkt, reported the amount of capital raised (measured in recorded capital commitments (RCC)) for the first 2 years since the implementation of Title II of the JOBS Act was $870 million covering 6,063 offerings, which is an increase of over 125% and 28%, respectively, from the first year. Additionally, Crowdnetic tracked the success of crowdfunding offerings, which is defined as receiving any amount of the RCC. The success rate increased from approximately 20% through year 1 to over 26% through year 2. While this may indicate there is still a fairly high percentage of issuances that do not come to market, there was a 30% increase in success rates from year 1 to year 2. FinMkt no longer tracks this data, but according to crowdfunding.com (2018), equity crowdfunding now accounts for 15% of crowdfunding volume. (crowdfunder.com/blog/wp-content/uploaded-files/History-of-Equity-Crowndfunding.pdf)

early-stage start-ups is mixed.[11] Many studies have looked at the potential reasons, motives and timing of venture capital participation. For example, Gompers, Kovner, Lerner, and Scharfstein (2008) asserted that investments can be influenced by several factors, such as venture capital firm experience and recent IPO valuations, which implies a level of cyclicality with this type of funding source that favors late-stage firms. Hsu et al. (2014) showed that although venture capitalists and angel investors place different weights on firm characteristics, both investment resources value highly human capital characteristics (i.e., experience) of the founders of the firm or the active principals. As such, the vetting and due diligence process by venture capitalists when considering investments likely covers a variety of firm and non-firm specific issues. Therefore, the selection process by a venture capital firm can be quite rigorous so a venture capital firm may not be accessible to firms seeking key early-stage R&D funding.

However, to the extent innovative firms can secure early-stage funding from other sources, the ability to acquire such financial capital and to use those resources to further their R&D activity may signal a level of innovative social capital that improves the firm's chances for venture capital participation. Further, the selection process by venture capital firms can provide firms with a key informational advantage. Generally, venture capitalist firms invest as well as participate in the management of the firms in which they take an equity position (often in the form of a board position(s) and/or special consultant). Thus, firms that are successful in obtaining venture capital financing often find access to skilled individuals who may provide critical information transfers to firms, thereby building the firms' social capital and potentially increasing the probability of commercialization success and growth.

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[11] According to The MoneyTree™ Report by PricewaterhouseCoopers and the National Venture Capital Association based on data from Thomson Reuters, the amount of venture capital invested in 2014 was over $48 billion in 4,356 deals.

Summary

This chapter highlights three potential financial providers an innovative firm may be involved with to acquire early- and late-stage financial capital—traditional bank and alternative lending institutions, peer-to-peer funding, and private equity. The relationships with these providers may also result in additional social capital benefits for the firm as deeper ties are cultivated with these lenders throughout the funding process. While it is generally more difficult for innovative firms to obtain funding for R&D through traditional bank and alternative lenders, financing markets are developing to support peer-to-peer funding; however, each source has its limitations. Private equity has historically been a source of early- and late-stage funding for innovative firms, and it also has the potential to build important relationships that the firm can leverage.

The next chapter discusses an important public/private partnership that has helped thousands of innovative firms obtain early-stage financing—the SBIR program. This program also has the potential benefit of accumulating social capital for the firm as it is intended to drive new and innovative technologies through to commercialization and to acquire additional development funding from non-SBIR resources, such as private equity.

CHAPTER VII

SMALL BUSINESS INNOVATION RESEARCH PROGRAM

The Federal government supports mechanisms to spur private sector innovation and to accelerate technology commercialization, and these are often referred to as public/private research partnerships. To expand R&D research, the government can support universities and research centers, use the tax code to stimulate private sector R&D spending, and provide direct government funding in a private/public partnership arrangement.

One of the initial moves by the U.S. government to accelerate commercialization of new technologies following the productivity slowdown, in the early-1970s and then again in the late-1970s and early-1980s, was passing legislation (Bayh-Dole Act of 1980 and the Stevenson-Wydler Act of 1980) to promote the movement of existing research and innovation into the private sector. These legislations were aimed at universities and government agencies, respectively, to transfer their technologies to the private sector and not in direct support of private sector R&D in the manner that the previous chapter discusses.

The SBIR program, promulgated through the passage of the Small Business Innovation Research Development Act of 1982 (the "1982 Act"), was designed to provide funding directly to firms unable to financially sustain themselves while transitioning from idea development to product commercialization.[12] Recognizing that research-intensive projects require longer-term funding to carry research across the "Valley of Death" and into the commercialization stage, the

[12]About the SBIR. Retrieved May 25, 2016, from https://www.sbir.gov/about.

government requires Federal agencies with extramural budgets in excess of $100 million to set aside a percentage of their R&D budgets to SBIR awards.[13] Applicants apply to the Federal agencies directly in response to an agency's request for technology-specific research.

The remainder of this chapter outlines the history of the SBIR program and the current implementation of the SBIR program at the NIH. In 2005, at the request of the U.S. Congress, survey data on a random sample of Phase II SBIR award recipients were collected by the NRC to assess, among other things, the effectiveness of the award program by quantifying the firm's commercialization activities, including sales and the development of intellectual property. The results of this survey are in the dataset used in the empirical analysis in this dissertation.

The NRC survey asked recipients a variety of questions regarding the nature of their firm and founders, including funding sources, the firm's history of receiving SBIR awards, and the relationships cultivated in the process of technological commercialization. These data allow for the evaluation of innovative outcomes through the intersection between funding, entrepreneurial activity, social capital accumulation, and the product commercialization process.

SBIR Program Research Phases

The SBIR program defines three distinct research phases:

1. Phase I: Develop the technical specifications and commercial viability of the project, which generally lasts for a period of 6 months.

[13]Per the SBA Policy Directive, the term "extramural budget" means the sum of the total obligations for research/R&D minus amounts obligated for research/R&D activities by employees of a Federal agency in or through Government-owned, Government-operated facilities.

2. Phase II: Further the development of the research and commercialization potential, which is intended to be available for a longer period of time than Phase I (2 years on average) as the firm finalizes R&D on their innovation.

3. Phase III: (unfunded) Firms are expected to acquire additional funding (including venture capital) to commercialize product(s) supported by SBIR.

SBIR is a competitive program available to U.S. small firms (<500 employees) where U.S. individuals own 51% or more of the firm.[14] Unlike many other public/private partnerships, the SBIR program is one of the few public programs that continues to provide funding directly to small businesses.

History of the SBIR Program

SBIR was conceptualized in the 1970's as a means to address the "importance of small, high-tech firms to the economy" as well as "the fierce opposition [high-tech firms] faced from other recipients when pursuing Federal R&D funding."[15] Recognizing the need for early-stage funding for small, innovative entrepreneurs, in 1977 the National Science Foundation (NSF) set aside a portion of their budget to fund firms with projects believed to be "instrumental in converting government R&D into public benefit through technological innovation and commercial applications, therefore stimulating aggregate economic growth."[16] At the time, the management team at NSF was convinced the impact of providing early-stage funding to

[14] The SBIR/STTR Reauthorization Act of 2011 expanded ownership rules to allow for multiple private equity firms, including venture capital operating companies and hedge funds, to own 50% or more of the firm, subject to limits by Federal agency, but not any single private equity firm can own more than 50%.

[15] Birth and History of the SBIR Program, Retrieved June 8, 2016 from https://www.sbir.gov/birth-and-history-of-the-sbir-program.

[16] ibid.

underserved innovative entrepreneurs was substantial, and in the first year alone, 42 Phase I and 21 Phase II awards were provided.

The success of the NSF program and the demand for other government agencies to provide a similar funding program sparked further political discussion, eventually leading to the 1982 Act. In justifying the development of SBIR, several key points were instrumental in motivating the enabling legislation (National Research Council, 2008), including

- Evidence that a declining share of Federal R&D was going to small businesses;
- Broader difficulties among innovative small businesses in raising capital in a period of historically high interest rates; and
- Research suggesting that small businesses were fertile sources of job creation

The U.S. Congress stated in the 1982 Act three critical factors for the creation of SBIR;[17]

1. technological innovation creates jobs, increases productivity, competition, and economic growth, and is a valuable counterforce to inflation and the United States balance-of-payments deficit;

2. while small business is the principal source of significant innovations in the Nation, the vast majority of Federally funded research and development is conducted by large businesses, universities, and Government laboratories; and

3. small businesses are among the most cost-effective performers of research and development and are particularly capable of developing research and development results into new products.

Consensus around the creation of SBIR gelled in the early 1980's and the objectives of the program were codified. Initially recited in the 1982 Act and further refined by the SBA, which oversees SBIR, within the SBIR Policy Directive (SBA, 2014), the current four purposes of the SBIR program are to:

[17] Public Law 97-219, Retrieved from https://web.archive.org/web/20130330045320/http://history.nih.gov/research/downloads/PL97-219.pdf.

1. Stimulate technological innovation;

2. Use small business to meet Federal R&D needs;

3. Foster and encourage participation by socially and economically disadvantaged small businesses, and by women-owned small businesses, in technical innovation; and

4. Increase private sector commercialization of innovation derived from Federal research/R&D, thereby increasing competition, productivity and economic growth.

The fundamental element of SBIR is the compulsory or set-aside allocation of a portion of the participating government agency's extramural budget to small business innovative ventures. In other words, the SBIR program is a set aside program. When initially established the allocation (by definition, the "Required Expenditure Amounts") was delineated between those agencies with an extramural budget greater than $10 million and the agencies with extramural budgets in excess of $10 billion. Table 3 shows the progression of the set-aside percentages since the implementation of the 1982 Act.

Table 3. SBIR Program Terms and Changes

Public Law	Year	Award	Extramural Budget Allocation			Key Changes
			Year	> $10mm	> $10b	
PL 97-219	1982	Phase I: $50,000 Phase II: $500,000	1983 1984 1985 1986 1987-1992	0.20% 0.60% 1.00% 1.25% 1.25%	0.10% 0.30% 0.50% 1.00% 1.25%	• Creation of SBIR • SBA to create SBIR Policy Directive • Annual reporting
				> $100mm		
PL 102-564	1992	Phase I: $100,000 Phase II: $750,000	1993-1994 1995-1996 1997-2000	1.50% 2.00% 2.50%		• Increase in the extramural minimum • Increase in the extramural allocation • Increase in the award amounts • Emphasis on commercialization • Establishment of STTR
PL 106-554	2000	Phase I: $100,000 Phase II: $750,000	2001-2008	2.50%		• Assessment of the program • Establishment of database • Establishment of FAST[18] program • Establishment of mentoring networks
PL 97-219	2011	Phase I: $150,000 Phase II: $1mm	2009 2010 2011 2012 2013 2014 2015 2016 2017	2.50% 2.50% 2.50% 2.60% 2.70% 2.80% 2.90% 3.00% 3.20%		• Increase in the extramural allocation • Increase in the award amounts • Expanded access to venture capital

Source: Public Law

There have been three significant reauthorizations of the SBIR program to date. The key changes that have occurred subsequent to the 1982 Act include a continued increase in the percentage of each agency's extramural budget allocated to SBIR; increases in the targeted Phase I and Phase II award values (although there is some discretion in awarding larger amounts) and; most importantly from the perspective of empirical analysis, the requirement in the 1992 reauthorization that participating Federal agencies with SBIR budgets in excess of $50 million conduct an assessment of the program in an effort to determine "how the SBIR program has

[18] The Federal and State Technology (FAST) Partnership Program provides one-year funding to organizations to execute state/regional programs that increase the number of SBIR/STTR projects.

stimulated technological innovation and used small businesses to meet Federal research and development needs."[19]

Current information on the SBIR program is the included in the SBIR Program Policy Directive dated February 24, 2014 (SBA, 2014), which is a document prepared by the SBA and outlines guidance for Federal agencies participating in the SBIR Program. Among many other items, the SBIR Program Policy Directive provides the minimum levels of funding required by participating agencies as well as inflation-adjusted award amounts.

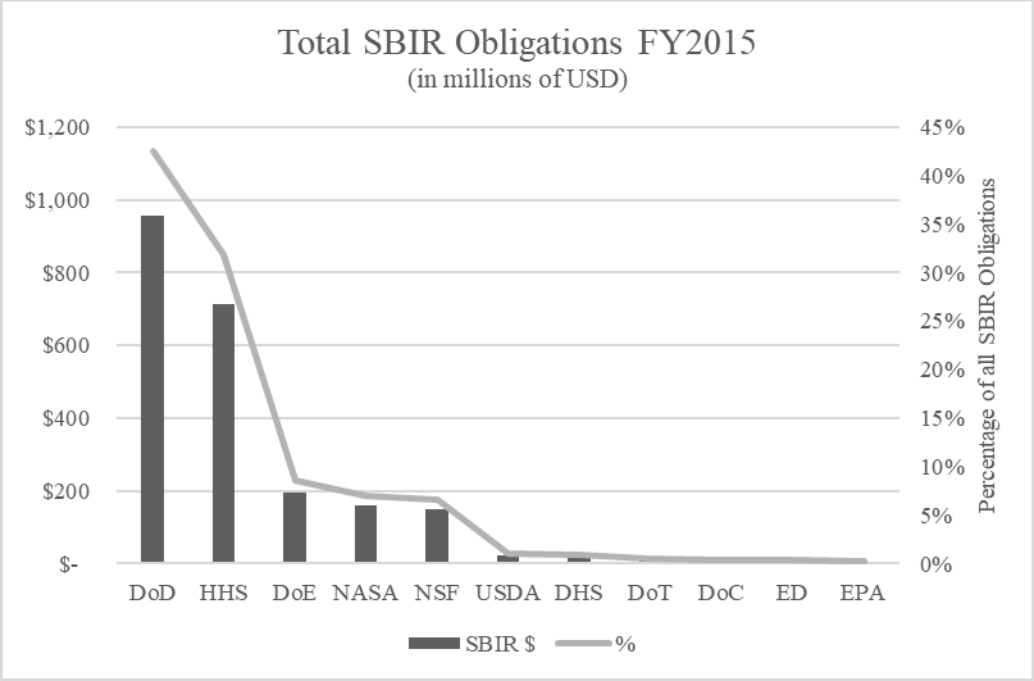
Although eleven Federal agencies participate in SBIR, five of those agencies constitute nearly all of the awards distributed. As outlined in Figure 1, the largest participating Federal agency is the Department of Defense (DoD). Other major participating agencies are the Department of Health and Human Services (HHS) which includes the NIH; Department of Energy (DOE); National Aeronautics and Space Administration (NASA); and National Science Foundation (NSF). These five agencies comprise 97% of SBIR distributions in fiscal year 2015, the most recent published annual report of SBIR/STTR.[20,21]

[19] Public Law 106-554, Retrieved from https://web.archive.org/web/20130330045320/http://history.nih.gov/research/downloads/PL106-554.pdf

[20] SBIR/STTR Annual Reports: https://www.sbir.gov/annual-reports-files

[21] The other participating Federal agencies include: Department of Homeland Security (DHS), Department of Agriculture (USDA), Department of Education (ED), Department of Commerce (DoC), Department of Transportation (DoT), Environmental Protection Agency (EPA).

Figure 1. Total SBIR Obligations



Source: SBIR/STTR Annual Reports

SBIR at the Department of Health and Human Services

Given the significant level of SBIR award distributions from the NIH, a deeper review of the approach and implementation of the SBIR program at the HHS is provided. The SBIR program at the HHS operates at each of the 24 participating NIH Institutes and Centers (ICs), Centers for Disease Control and Prevention (CDC), Food and Drug Administration (FDA), and the Administration for Children and Families (ACF).[22] The SBIR program was designed to allow each Federal agency to have a high degree of discretion with respect to the implementation of the requirements of the program. However, given the large number of independently managed ICs

[22] HHS Innovative and Research Programs, http://www.hhs.gov/grants/small-business-programs/innovative-research-programs/index.html

and their respective operating procedures, the practical implication is that management of SBIR across NIH is quite decentralized. The decentralized nature of SBIR within NIH not only allows for flexibility, but also it can create a complex application process for a firm seeking funding.

Compounding the complexity, the NIH awards both awards and contracts, and each of the funding channels has its own guidelines, timelines, and accountability features. Additionally, since the ICs each have a unique mission, the breadth of research supported by the SBIR program as well as the control and duration of the commercialization journey is different across NIH entities. For example, certain innovations within the healthcare field may have short development cycles, such as software, but medical devices and pharmaceutical products could have longer commercialization periods due to regulatory approval requirements. NIH also has the ability to provide a secondary Phase II funding for firms that have extended regulatory review periods. Contract awards may be advantageous within some ICs as they allow the IC the ability to determine terms and to have some level of control and oversight in the R&D process, which may be more ideal in a specific area of research, such as cancer drugs. For those ICs that deal primarily in contract awards, the portfolio of contracts may begin to give the appearance of a venture capital operation, so clear objectives of the ICs are critical to ensure compliance with the stated goals of the SBIR legislation. Overall, navigation and organization skills are paramount for a firm seeking to fund their innovation in the healthcare field with SBIR awards.

With the size of the NIH extramural budget and the diversity of research area options, the agency is expected to process the applicants effectively, which requires a clear, robust solicitation process. Toward that end, the NIH provides resources on their website, including announcements containing deadlines and information regarding the type of research of interest at each of the NIH

ICs.[23] There are broad omnibus announcements, which "allows an applicant to submit an investigator-initiated project for consideration by any of the NIH 24 ICs, the CDC, and the FDA," and there are targeted announcements that "are periodically issued by one or more ICs and focus on specific areas of science that are priorities to the issuing institutes or centers."[24] Each IC will further articulate their needs and requirements within the targeted announcement specific to their awards. While 95% of NIH SBIR awards are grants, certain ICs offer SBIR contract awards. Contract applications are reviewed by the ICs directly and generally only have one submission date with specific research objectives. For purposes of outlining SBIR at the NIH, the discussion of the structure of the program will be centered around the grant award process since it constitutes the vast majority of the NIH's SBIR funding.

From the perspective of a firm applying for a research award from the NIH, it is important to have focus with respect to articulating the type of research and innovation that is occurring at their firm juxtaposed to the requirements of the awards provided by IC as described in their announcements in order to be successful. NIH encourages SBIR applicants to contact an SBIR program manager in the early stages of the process so that all relevant requirements are clear. Recognizing the complexity, NIH provides guidelines around the application process and offers services and resources for potential awardees as to minimize application errors and to bring in the largest pool of desired applications.

Submission for NIH SBIR grant awards are on a scheduled cycle of three due dates per year. This allows the applicant to begin to receive funds quicker than a once per year submission and distribution to the extent an award is provided (National Academies, 2015). In general, a

[23] https://sbir.nih.gov/
[24] NIH SBIR Frequently Asked Questions, https://sbir.nih.gov/faqs#app-prep-sub14

firm seeking SBIR funding for the first time may, subject to restrictions as outlined in the announcement, apply for a Phase I award, a Phase II award, a Fast Track proposal, which includes a completed Phase I and completed Phase II application, or a Direct to Phase II award in the case of completed feasibility technologies. Phase I award recipients apply for a renewal of the award for Phase II funds. To the extent a firm did not receive funding with the first application, resubmissions are allowed but follow specific guidelines depending upon the type of funds requested and the characterization of the project. Applicants must undergo a five-step registration process in order for the award application to move forward. Registration begins with obtaining an identification number followed by recordation of key information on four other award-based registries, including the identification and registration of the project director or principal investigator for the applying firm that is facilitating the SBIR award in the NIH database.[25]

Once an SBIR application is submitted, the evaluation process begins with an initial review by the NIH Center for Scientific Review to determine whether the basic application requirements are met. The crux of the award evaluation, however, takes place in the peer review process. The NIH states that the peer review "includes both academic and industry professionals who have a robust knowledge about the SBIR and STTR programs."[26] The peer review evaluates a variety of selection criteria, including the significance of the project, the experience of the principal investigator, the environment within which the innovation is being developed, and the nature of the innovation. After peer review, an impact score is assigned to each application and submitted for review to an advisory board of other industry, academic and government research

[25] NIH SBIR Frequently Asked Questions, https://sbir.nih.gov/faqs#app-prep-sub14
[26] ibid.

experts, which provides a recommendation to the IC director, who makes the final award decision. In order to meet stated SBIR objectives, the NIH notes "for Phase II SBIR/STTR applications, a technology's commercialization potential is also evaluated during the review process." If an application is denied, NIH will provide resources and feedback indicating the areas of potential revision to increase the changes of award selection.[27]

The NIH offers SBIR awardees two programs, which provide technical assistance to firms seeking assistance with managing their project to success. The first, the Niche Assessment Program, is available to Phase I awardees as a resource, and,

> …provides market insight and data that can be used to help small businesses strategically position their technology in the marketplace. The results of this program can help small businesses develop their commercialization plans for their Phase II application, and be exposed to potential partners.[28]

The Commercial Accelerator Program (CAP) is the second program, which is designed to assist Phase II awardees reach their commercialization success, and.

> …provides selected participants with individualized assistance toward accomplishing key commercialization goals. This is achieved through individual mentoring and consulting sessions, training workshops, access to domain experts and focus on outcomes that will enhance the commercialization profile and readiness of participating grantees.[29]

Together, the Niche and the CAP program offer innovative firms the opportunity to draw on experience and talent through the SBIR funding process to increase the probability of commercialization success, which can enhance the social capital profile of the firm.

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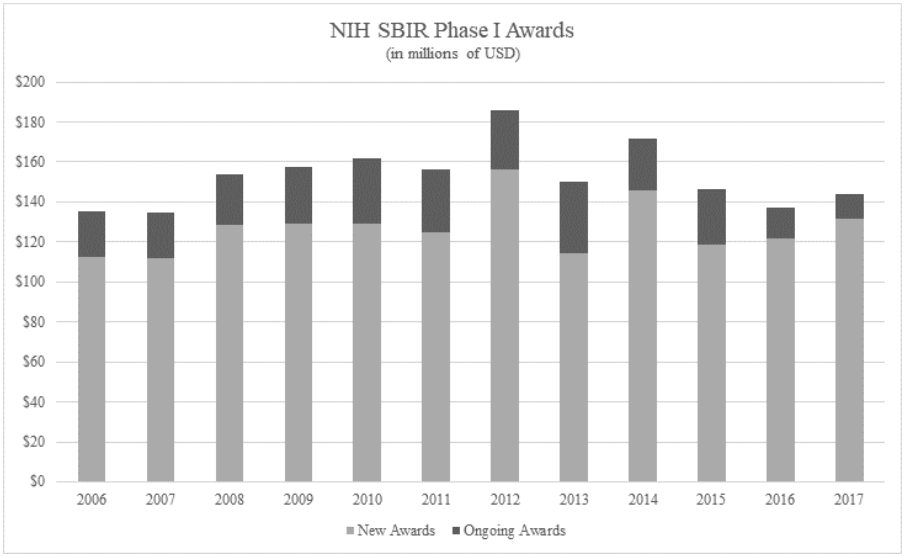
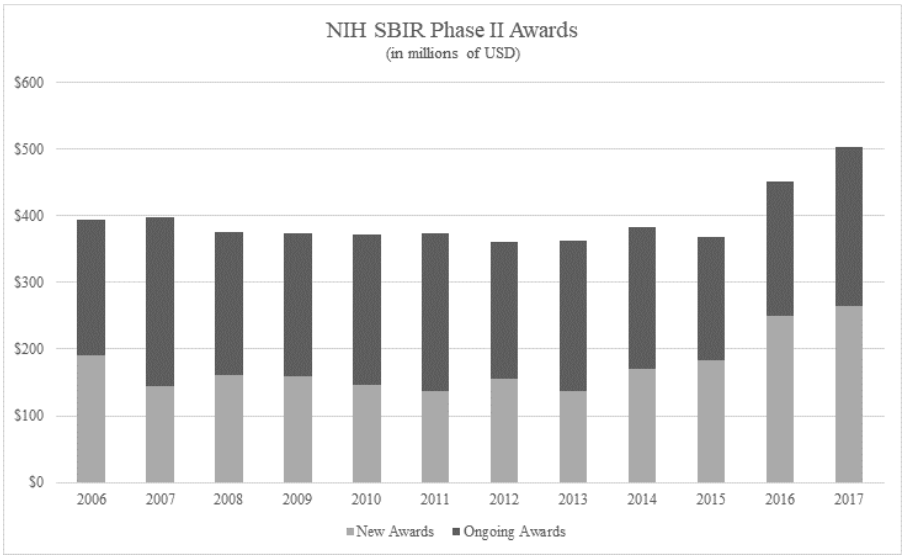
[27] NIH SBIR Selection Process and Criteria, https://sbir.nih.gov/review/selection-process
[28] NIH SBIR Niche Assessment Program, https://sbir.nih.gov/nap
[29] NIH SBIR Commercial Accelerator Program, https://sbir.nih.gov/cap

The NIH is the second largest Federal agency in awarding SBIR awards, representing approximately 32% of all SBIR obligations among the eleven participating agencies. While there are annual reporting requirements associated with SBIR, NIH maintains its own database to track a variety of metrics associated with the program. The NIH RePORT portal allows the public to query information on the SBIR program (as well as STTR). At the aggregate level, SBIR awards are generally reported as current SBIR obligations, which include both new and ongoing awards. As Figure 2 indicates, the value of new Phase I and Phase II awards is not constant from year to year, but new awards represent a significant amount of money distributed to early-stage projects of innovative firms. As expected, Phase II ongoing awards consist of a greater share overall SBIR Phase II awards at the NIH given the potential multi-year distribution of those funds.[30]

[30] Source: SBIR/STTR Competing & Non-Competing Grants and R&D Contracts (FYs 2008-2017), retrieved on October 29, 2018 from https://sbir.nih.gov/statistics/award-data

Figure 2. NIH SBIR Phase I and Phase II Awards





Source: SBIR/STTR Competing and Non-Competing Grants and R&D Contracts[31]

[31] https://sbir.nih.gov/statistics/award-data. Amounts are in nominal USD.

Summary

The SBIR program is a long-standing program that provides important funding for small innovative firms. Started through legislation in 1982, SBIR has grown to be a multi-billion dollar award program that is supported primarily by five large Federal agencies. SBIR funds early stage product viability evaluation through Phase I awards, and based on pre-determined criteria and review, Phase II awards may be available to firms who have moved from the proof of concept stage to R&D. Each agency supporting SBIR, including the NIH, has some latitude to select and fund projects, but as a guideline, Phase I awards are generally up to $150,000 for up to 6 months, and Phase II provides up to $1 million for potentially two years. The NRC survey information on NIH projects generated from the survey provides the data to support the analysis of social capital and innovation.

CHAPTER VIII

MEASURING SOCIAL CAPITAL FOR INNOVATING FIRMS

To perform an empirical analysis that quantifies the impact of social capital on innovation outputs, measures of social capital within an innovative firm must be developed. Since social capital is an asset of the firm with intangible characteristics, any quantification of social capital will include some level of subjectivity. Narayan and Cassidy (2001) noted this element of subjectivity and asserted, "theories such as social capital comprise constructs that are inherently abstract and require subjective interpretation in their translation into operational measures" (p. 61). While subjectivity is inherent, Stone (2001) cautioned scholars to avoid "the common practice of mistaking a range of factors/outcomes which may be related to social capital for measures of social capital itself" (p.34).

Notwithstanding the difficulty in measuring a variable, developing theories of the ways in which social capital characteristics can be observed is a first step toward incorporating that firm asset into empirical analysis. Moreover, a theory regarding the measurement of social capital of an innovative firm should suggest the use of specific social capital measures in evaluating innovation output. Stone (2001) stated:

> A theoretically informed approach to the measurement of social capital is essential to overcoming empirical confusion and enabling proper investigation of social capital as it relates to a range of outcomes. By linking social capital measurement directly to theoretical understandings of the concept, we are able to: first, recognize that social capital is a multidimensional concept comprising social networks, norms of trust, and norms of reciprocity; second, understand social capital properly as a resource to action; and third, empirically distinguish between social capital and its outcomes. (p. 6)

Traditional measures of social capital include those that quantify the social norms of trust and reciprocity in a variety of social and group interactions. A common approach to social capital measurement is compartmentalizing the impact of norms of trust and reciprocity to societal issues at the micro-, meso-, or macro-level, such as health-related outcomes, community effects, or productivity, respectively. The difficultly in applying traditional measures of social capital to innovative firms is the motivation and context of social relationships. In contrast to individuals who, or communities of individuals that, may be utility maximizers and where outcomes associated with social capital may occur at various levels, an innovative firm is generally a profit maximizer that utilizes social capital among its employees and external parties as an input into some type of innovation output that ultimately generates profit.

A theoretical approach to measuring social capital in innovative firms begins with a framework that identifies the dimensions of social capital that are relevant to innovative, profit-seeking firms. Stone (2001) posited that a theoretical framework should distinguish measures and outcomes of social capital, and she stated "separating the measure of social capital from its outcomes enables social capital to be positioned unambiguously within any research design, and be understood clearly in relation to its predictors and/or outcomes" (p. 6). While it is optimal to separate social capital input measures from social capital output measures in empirical research, often data are not available to decouple the two. Stone (2001) noted "…indicators are relied upon frequently in social capital research, particularly studies reliant upon secondary analyses, where existing data is limited" (p. 5), but these studies can result in "considerable confusion about what social capital is" (p. 5).

To address the measurement of social capital in the context of innovative firms, there are three considerations: 1) identifying the relevant dimensions of social capital 2) determining the appropriate measurement of each dimension of social capital identified and 3) operationalizing

the measures of social capital for empirical analyses. The measurement of social capital is distinct from the outcomes of social capital. Social capital outcomes include the outputs to innovation production where social capital is one type of input. As previously discussed and as described in prior chapters, the outputs of innovation production of interest in this dissertation include the firm obtaining additional developmental funding, the firm commercializing a product or a service, and the firm experiencing a growth-related activity, such as an IPO, a spin-off, a firm sale, a firm merger, a joint venture agreement, or a product licensing agreement.

Dimensions of Social Capital

With respect to the first consideration above of identifying the dimensions of social capital, Stone (2001) asserted there are two core dimensions of social capital—structure and content—inherent in most empirical work. Stone (2001) contended the structural element of social capital may be formal or informal, and the distinguishing factor between these elements is whether or not the relationship is formalized through active engagement. Informal networks include those relationships developed internal to an organization or firm where norms of trust and reciprocity can operate. Formal networks include social relationships with formally constituted groups, where active participation in a group is necessary to extract social benefits. The content aspect of social capital includes social norms, including norms of trust and reciprocity after the networks have been established. Stone (2001) highlighted that last point and stated, "[b]efore specific characteristics of social capital networks can be explored, or their quality investigated, the network type being studied in any given social capital research must be identified" (p. 8).

Approach to Measuring Each Dimension

With respect to the second consideration of determining the appropriate measurement of social capital, the identified structural and content dimensions of social relations need to be quantified. For the structural dimension, measurement of informal and formal networks is contextual. For example, Stone (2001) suggested an inclusive approach that considers the quality and culture of social relations and not simply the existence of an informal network. Data that capture information about the number and types of interactions and also the variation and degree of activities in which they have engaged are consistent with this approach. Likewise, measurement of social capital in formal networks should capture the motivation, reciprocity, and the extent of cooperation within the relationship. Despite differences in formal networks across studies, Stone (2001) acknowledged, "measuring the extent to which people are attached to formally constituted social groups of one or another is a method frequently employed for the measure of group based relations in social capital research" (p. 14).

In measuring the content dimension of social capital, which includes quantifying measures of trust and reciprocity, Stone (2001) offered the following observation: "like the measurement of trust, norms of reciprocity can be investigated either through asking directly about perceived norms, or by investigating behavioral outcomes which result from and demonstrate the norm of reciprocity 'at work'" (p. 34). However, it is difficult to measure directly trust and reciprocity because survey or interview questions must be crafted in such a way as to elicit a response that addresses a specific feeling, and many surveys are not administered with trust and reciprocity as the primary identified data elements. Putnam (2000) expressed this obstacle in developing measures for social capital, and he stated, "our exploration of social change is inevitably constrained by the fact that…no one thought ahead to collect the really perfect evidence that we now need" (p. 415). Narayan and Cassidy (2001) likewise suggest that

operational measures that capture the various dimensions of social capital "are invariably indirect surrogates of their associated constructs" (p. 61) given the difficulty in obtaining direct measures of social capital.

Operationalizing Measurement

With respect to the third consideration of operationalizing the measures of social capital for empirical analyses, it is important to note that measures of social capital may or may not have a single value. Each empirical exercise must consider the context and dimensions of social capital that are theoretically relevant for the respective analyses. For example, Putnam (2000) constructed an index to measure social capital using multiple sources, justifying its use by asserting "no single source of data is flawless, but the more numerous and diverse the sources, the less likely that they could all be influenced by the same flaw" (p. 415). While Putnam (2000) argued that it is necessary to use more than one measure to capture the multidimensional nature of social capital, Halpern (2005) suggested "the answer to a simple question can go a long way to capture the quality of an individual's supportive network" (pp. 35-36).

Operationalizing Strong and Weak Social Ties for Innovative Firms

Reflecting on the aforementioned social capital measurement issues and how they relate to innovative firms, measures of social capital should emanate from the structure and content dimensions of social relationships. The structural component consists of informal and formal networks among employees of the firm and between the firm and outside groups, respectively and the content dimension must encapsulate the trust and reciprocity that are built within each network structure. As such, it can perhaps be reasoned that for innovative firms, informal networks develop norms of trust and reciprocity within a more familial group, such as among

employees, and formal networks provide the structure to promote trust and reciprocity with external parties through active engagement.

With respect to informal networks, measures of the structure and content dimensions for innovative firms include the quantification of strong social ties that embody the culture, institutional knowledge, depth of working relationships and internal collaborations, and the propensity to innovate and be productive as a result of a firm's expectations of the social norms of trust and reciprocity. Narayan and Cassidy (2001) suggested the general level of "togetherness" of people, including how well individuals get along, is a valid measure of the cohesiveness and cultural strength cultivated through shared experiences within a group (p. 77). One approach to quantifying the strong social ties of "togetherness" is assessing the extent to which employees engage in collaborations with their coworkers because participation in shared projects or research efforts is very likely to build trust and reciprocity among those employees.

Zucker, Darby, Brewer, and Peng (1995) develop a model of internal collaboration among scientists based on trust using a collaborator's value to the overall research effort. The authors state,

> Production of trust…involves information boundaries that are at least partially constructed by collaborating within the same organization (university, research institute/hospital, or firm). We in fact demonstrate that specific characteristics of other scientists, generally those indicating the potential value of their discoveries, lead them to be included more often in scientific collaborations and be more often in collaborations with scientists working in the same organization (p. 93).

Zucker et al. (1995) measured the value of these collaborations through pairs of researchers, and these authors found that as researchers realized the benefits from collaborating, they participated more fully in the research, which generated trust and reciprocity. Thus, as employees observe incremental successes, the propensity for internal collaboration also increases,

and strong social ties develop because employees realize that there is common goal which is mutually beneficial.

To operationalize internal collaboration as a measure of strong social ties, a level of collaboration must be quantified. To follow the logic of Zucker et al. (1995), as employees engage in projects that become successful, new projects will garner more interest and internal collaboration. Therefore, firms with a history of innovative project successes should expect to see higher levels of collaboration, which build trust and reciprocity among the employees working on those projects; thus, new innovations are promoted.

With respect to formal networks, weak social ties for innovative firms are developed where a structure is in place to promote trust and reciprocity with external parties through active engagement. For example, Carayannis, Alexander, and Ioannidis (2000) advanced the idea that trust and reciprocity build among unaffiliated organizations through formal engagement of cooperation, and these authors noted,

> The synthesis of disparate tacit knowledge across organizational borders is not accomplished through the 'transfer' of…intangible assets. Rather, the organizations must cooperate to create mutually reinforcing processes of learning-by-doing and learning-by-learning, where the individual members of each organization participate in a shared social setting (such as an alliance organization) to develop and absorb knowledge in a common context. This socialization process then leads to the growth in social capital across organizations in the alliance, which in turn facilitates greater sharing and exchanges of knowledge.

In addition to information sharing with outside organizations, engagement with external investors is another component in achieving innovative output because it builds trust and reciprocity between the entrepreneurs and current and potential future investors, such as venture capitalists. Shepherd and Zacharakis (2001) theorized that the development of weak social ties between entrepreneurs and venture capitalists must be grounded in trust. Often there is asymmetric information between entrepreneurs and venture capitalists, which can result in

skepticism or mistrust among the parties as one side may attempt to obtain leverage over the other and is typically addressed through contractual control mechanisms. However, the authors asserted that trust among entrepreneurs and venture capitalists, which is developed through signals of commitment and frequent communication, is important to maximize cooperation and to achieve mutually beneficial goals. Lim and Cu (2010) evaluated relationship characteristics between an entrepreneurial firm and its venture capital firm, and they found the stronger the social tie between the two parties, the higher the trust and an increase in the likelihood that advice will be given by the venture capitalist to the entrepreneur. Hsu (2004) showed that entrepreneurs value this exchange of information and trust and will pay a premium (i.e., accept less favorable financial terms relative to other venture capitalists) to engage with venture capitalists that have better reputations of trust.

Narayan and Cassidy (2001) asserted that intergroup or interpersonal interactions are dimensions of social capital that can be measured by the number of memberships (or engagements) with outside groups, the contribution of money and the sources of group funding, and the participation in decision making. Following this logic, operationalizing weak social tie measures for innovative firms involves the identification of formal agreements with outside parties where trust and reciprocity can accumulate not only through active engagement and shared decisions but also through the receipt of objective feedback, and funding arrangements with information flow. These types of engagements build weak social ties for innovative firms through inter-organization collaboration, the sharing of ideas, and by cultivating trustworthy business relationships to bring efficiently new technologies to market. Examples of agreements that promote the development of weak social ties include those with researchers at universities and other organizations that enhance research efforts through collaboration and provide guidance and certification of an innovation, R&D and commercialization alliances that mutually benefit the

firm, its business partners, and financing relationships with venture capitalists where information, ideas, and best practices are actively communicated.

Summary

In summary, the measurement of social capital requires identifying the dimensions of social capital associated with innovative firms, articulating the approach to the measurement of each dimension, and operationalizing the measures. Following Stone (2001), the two core dimensions of social capital are structure and content. The approach to quantifying the structural dimension of social capital rests on the identification of the formal and informal networks cultivated by innovative firms. Then, the measurement of the content dimension includes assessing the extent of the norms of trust and reciprocity within the networks.

Finally, to operationalize the dimensions of social capital for an innovative firm, measures of the level of trust and reciprocity within formal and informal networks need to be obtained. For example, firms that receive financial awards to fund new innovations have cultivated informal networks of internal researchers that collaborate on projects. These awards represent the cumulative effect of trust and reciprocity built through internal collaborations on new innovations. Formal networks where norms of trust and reciprocity are developed include engagements with external organizations that collaborate on research, provide feedback and guidance on product development, pool resources to improve the prospects of commercialization success, and share ideas and best practices. Engagements with universities, regulatory authorities, research and commercialization business partners, and venture capital investors indicate the existence of such formal networks for innovative firms where trust and reciprocity can flourish.

CHAPTER IX

EMPIRICAL ANALYSIS

As discussed in Chapter I, this dissertation makes three contributions to the literature. The prior chapters addressed the first two contributions by first conceptualizing social capital as an input into production, and second by describing the measurement of social capital in the context of innovation production. This chapter provides the third contribution, which is an empirical investigation of social capital as an input into innovation output.

Specifically, the following three research questions are intended to evaluate the relationship between social capital inputs and innovation outputs. The three innovation output measures of production and the related inputs into production necessary to answer these research questions are described in the following sections.

1. Are there dimensions of social capital that benefit an innovative firm in the pursuit of developmental (i.e., late-stage) funding?
2. Are there social capital characteristics of an innovative firm that are associated with realizing sales resulting from the commercializable technology? And,
4. Are there certain types of social capital associated with the probability than an innovative firm experiences growth-related activities, such as through the execution of an IPO, as a spin-off into a financially independent organization, a firm sale, a firm merger, a joint venture agreement or a licensing agreement?

Data

The data used in the empirical analysis are based on responses to survey questions on the NRC survey. The NRC survey data are appropriate to address empirically the three research questions noted above for two reasons. First, a legislated purpose of the SBIR program is to "[i]ncrease private sector commercialization of innovation derived from Federal research/R&D, thereby increasing competition, productivity and economic growth" (SBA, 2014, p. 3). The NRC survey asks several questions about the firm conducting the funded research bringing new innovative products and services to market, and the NRC survey also asks about a variety of innovation-related outputs. Second, an element of the SBIR program evaluation process is the extent to which the proposed research will include other organizations. Through collaboration, social capital accumulates as trustworthy relationships and expectations of reciprocity are developed. The NRC survey includes questions related to collaborative activities that are closely associated with social capital, and thus the survey responses to these questions provide a vehicle for measuring the social capital within an innovative firm.

The 2005 NRC survey was mandated through the 2000 reauthorization of SBIR by Congress as previously discussed. The NRC randomly sampled Phase II projects funded from 1992 through 2001 through awards from the DoD, the NIH, DOE, NASA, and NSF.

The NRC conducted two separate surveys for each project. One survey related to the firm that received the Phase II award, and the other survey related to the project itself completed by a firm designate. The firm survey includes questions regarding the nature of the organization, including characteristics of its founders; the firm's history of obtaining SBIR awards; and the IPO and spin-off experience of the firm. The project survey asks more detailed questions about the Phase II project award, including, but not limited to, sales and licensing revenue realized from the project, commercialization outcomes, engagements with third parties for funding and

collaboration, the extent of prior SBIR awards related to the project, and intellectual property (e.g., patents) resulting from the project.

The NRC survey of NIH-funded projects was selected as a starting point to explore he relationship between social capital and innovation outcomes due to the sizable participation of NIH in the SBIR program and the diversity in types of projects funded by NIH. To create the dataset used in this dissertation from the NRC database, the NIH firm survey data file and project survey file were merged based on a unique firm identifier. As Table 4 shows, the steps followed conclude with a sample of 315 projects for consideration in this dissertation.

Table 4. NRC Survey Projects in Dataset

Population of Projects[32]	2,497
Survey Population[33]	1,680
Random Survey Population[34]	1,677
Survey Respondents	496
Survey Respondents Reporting all Relevant Information[35]	315

The survey data is limited in terms of understanding the entire population of firms that were able to respond to the NRC survey. There is a valid argument that the sample is self-selected since there is not visibility on outputs related to firms that did not respond to the survey. It is possible that the firms that did not respond have a different set of characteristics, which could be one reason for the lack of response. Given the absence of counterfactuals associated with

[32] Link and Scott (2010), Table 2.
[33] National Research Council, 2009, p.247
[34] Link and Scott (2010), Table 2.
[35] Respondents reporting relevant information include those that completed Phase II and projects that were not discontinued at the time of the survey. Further project reduction was due to missing responses to questions used in the empirical analysis in this dissertation.

those that did not respond or had limited responses to the questions, this sample data set is potentially not fully representative of the firms receiving SBIR Phase II funding from the NIH.

Dependent Variables

Table 5 lists the variables selected from the SBIR survey data which encapsulate each of the three innovation outputs. Each row corresponds with the three research questions outlined in the beginning of this chapter. The table includes a variable name plus the question on the SBIR survey that most closely reflects the innovation output measure.

Table 5. Dependent Variables

Output	Variable	Survey Question[36]
Additional Developmental Funding	Firm Received Additional Development Funding for the Funded Project	Have you received or invested any additional developmental funding in this project?
Commercialization	Firm Reported Commercialization of Product, Process or Service Sales	Has your firm and/or licensee had any actual sales of Products/Processes/Services incorporating the technology developed during this project?
Growth-Related Activity	Firm Experienced Growth-Related Activity, such as an IPO, a Spin-off Firm, Sale, Merger, Joint Venture, or Licensing Agreement	As a result of the SBIR program, did your firm make an initial public offering? Establish one or more spin-off companies? As a result of the technology developed during this project, [licensing agreements, sale of the firm, firm merger, and/or joint venture agreement] describe[s] your firm's activities with other firms and investors?

[36] For consistency, the word 'firm' is used in place of 'company' where it appears in survey questions.

The first innovation output shown in Table 5 is an indicator of the firm's receipt of additional developmental funding, or Phase III funding, for the project. This is a binary response variable that equals 1 if the firm responded "yes" to the question of whether it received additional developmental funding for the project subject to the survey and 0 if the response was "no." The SBIR survey defines additional developmental funding as "non-SBIR funds from federal or private sector sources, or from your own company, used for further development and/or commercialization of the technology developed during this Phase II project."

The second innovation output shown in Table 5 is the realization of sales from the innovation. The sales variable used to measure the second innovation output is a combination of responses from the SBIR survey related to sales of the firm and/or its licensee. The dependent variable equals 1 if the firm responded "yes" to any sales incorporating the Phase II-funded technology and 0 otherwise. The SBIR survey defines sales as "all sales of a product, process, or service, to federal or private sector customers resulting from the technology developed during this Phase II project…[including] licensing, the sale of technology or rights, etc."

The third innovation output shown in Table 5 is whether the firm experienced growth-related activities resulting from award funding through the SBIR program. There are several potential measures of firm growth-related activities.[37] In 2002, when the NIH conducted their own survey of its SBIR program, one of the assessments sought in the survey was the extent to which awardees grew their firms because of "the product, process, or service developed under the SBIR-funded project" (National Institutes of Health, 2003, p. 3-44). The NIH survey question related to this assessment asked specifically whether the firm experienced debt financing, private

[37] Initial versions of the dissertation only considered IPOs and planned IPOs for the firms in the NRC survey. However, the NIH has published many statistics on "growth-related activities," which include IPOs, so the output measurement was expanded to include those activities of interest to the NIH.

placement (angels, VC, relatives), public offering, set up one or more spin-off companies, entered into a joint venture (academic or commercial), sold the firm, merged the firm, or had a licensing agreement.

National Research Council (2009) presented the results of this NIH survey question to compare with results of the 2005 NRC survey questions in an analysis of the impact of SBIR on a firm's growth-related activities and stated its intent of assessment through the following statement: "[t]he NRC Phase II Survey explored several ways in which equity-related activities might be finalized or underway at surveyed projects" (p. 104). Given the explicit interest of the NRC and NIH in the assessment of firm growth through SBIR awards and the responses crafted to measure this output, the third innovation output in this dissertation is the measurement of growth-related activities of the firm. Using the NIH survey question responses as the basis, the questions and responses from the NRC survey that most closely match the question and responses from the NIH survey are presented in Table 6.

Table 6. Growth-Related Activity Survey Questions

	NIH 2002 Survey[38]	NRC 2005 Survey[39]	
Assessment	Growth of Small Business Concerns	Sales of Equity and other Corporate-level Activities	
Survey Question	Which, if any, of the following has your firm experienced because of the product, process, or service developed during this project?	Which, if any, of the following has your firm experienced as a result of the SBIR program?	As a result of the technology developed during this project, which of the following describes your firm's activities with other firms and investors?
Survey Responses	***1. IPO*** ***2. Spin-off Firm(s)*** ***3. Joint Venture Agreement*** ***4. Sale of Firm*** ***5. Firm Merger*** ***6. Licensing Agreement*** 7. Debt Financing 8. Private Placement	***1. IPO*** ***2. Spin-off Firm(s)***	***3. Joint Venture Agreement*** ***4. Sale of Firm*** ***5. Firm Merger*** ***6. Licensing Agreement*** 7. Marketing Agreement 8. Manuf. Agreement 9. R&D Agreement 10. Customer Alliance 11. Partial Sale of Firm 12. Sale of Tech. Rights 13. Other

To create a variable for the third innovation output, the responses to the NRC questions that include the same or similar responses to the NIH question are noted in Table 6. The NIH survey question provided eight growth-related activity responses, and six of the eight responses are present in the NRC survey through two survey questions. Therefore, the six growth-related activity responses to the NRC survey questions are combined into a composite innovation output variable that represents growth-related activities of the firm resulting from the SBIR program. The variable equals 1 if the firm reported at least one growth-related activity as a result of the SBIR program and 0 otherwise.

[38] National Institutes of Health, 2003, p. 3-44-3-46.
[39] National Research Council, 2009, p. 104-106.

Dependent Variable Descriptive Statistics

Descriptive statistics associated with the dependent variables are presented in Table 7. Each of the dependent variables are coded as binary responses.

Table 7. Dependent Variable Descriptive Statistics

Output	Yes	%	No	%
Additional Developmental Funding	223	70.79	92	29.21
Commercialization	202	64.13	113	35.87
Growth-Related Activity	120	38.1	195	61.9

Approximately 71% of the respondents received additional developmental, or Phase III, funding to support the project. Also, 64% of the projects commercialized from their funding project. The last dependent variable is an innovation output that is a combination of survey questions as noted in Table 6. The combined "yes" responses result an approximate 38% of projects executing a growth-related activity.

Regarding the responses to the innovation output of commercialization, Table 8 shows that of those projects that reported "yes" to the sales question, 38% projects realized sales of products only, 1% reported sales of processes only, 3% reported sales of service only, and 3% reported sales of other technology only. Although product sales represent the majority of the overall type of sales resulting from the project, there are many projects in the survey that reported sales in more than one category. For example, about 17% of the projects reported sales of products as well as sales in at least one other category. The implication is that there are multiple revenue channels resulting from SBIR-funded projects, which may be driven by certain inputs into production, including social capital inputs.

Table 8. Commercialization by Sales Type

Sales of Product(s)	Sales of Process(es)	Sales of Service(s)	Other Sales of Technology	Frequency of Sales of Products, Processes, or Services	%
No	No	No	No	113	35.87
			Yes	10	3.17
		Yes	No	10	3.17
			Yes	6	1.9
	Yes	No	No	3	0.95
		Yes	No	1	0.32
			Yes	1	0.32
Yes	No	No	No	118	37.46
			Yes	13	4.13
		Yes	No	23	7.3
			Yes	7	2.22
	Yes	No	No	1	0.32
		Yes	No	6	1.9
			Yes	3	0.95
			Total	315	100.00

With respect to innovation output of growth-related activities, Table 9 shows that about 38% of the projects experienced at least one type of firm growth activity. While there is some overlap in the responses (i.e., some firms indicated more than one type of growth activity), 16% of the projects executed licensing agreements only, 12% experienced a spin-off firm only, and 2% entered into a joint venture. Only a handful of projects resulted in an IPO, a firm sale, or a firm merger. These questions are combined into one response variable to provide a broader view of the effect of capital inputs, and in particular social capital, on the firm's growth-related activities that are the result of projects funded through the SBIR program.

Table 9. Firm Growth-Related Activities

IPO	Spin-off Firm	Firm Sale	Firm Merger	Joint Venture	Licensing Agreements	Frequency of Firm Growth Activities	%
No	No	No	No	No	No	195	61.9
					Yes	50	15.87
				Yes	No	6	1.9
					Yes	3	0.95
			Yes	No	Yes	1	0.32
		Yes	No	No	No	2	0.63
	Yes	No	No	No	No	37	11.75
					Yes	16	5.08
				Yes	Yes	1	0.32
		Yes	No	No	No	1	0.32
					Yes	1	0.32
Yes	No	No	No	No	Yes	2	0.63
					Total	315	100.00

As discussed in an earlier chapter, the NRC survey was administered at one point in time (i.e., in 2005), and the questions on the survey did not ask about the timing of specific outputs relative to others related to the SBIR project. As such, the NRC survey data is treated as contemporaneous in this dissertation. However, it is reasonable to argue that certain outputs may be related to each other. For example, firms that have received additional developmental funding for the project may be more likely to commercialize the technology from the funded project if those financial resources provide necessary capital to bring the product to market.

To begin to evaluate the potential correlation between the dependent variables, Table 10 lists a cross-tabulation of each innovation output relative to the others. To get sense of correlation, both the “yes” / “yes”/ “yes” and “no” / “no” / “no” boxes visualize the degree to which outputs move together. The “yes” / “no” boxes indicate the degree to which the outputs

diverge. The intersection of the "yes" and "no" boxes show that one (or more) of the outputs was produced while one (or more) was not for the project.

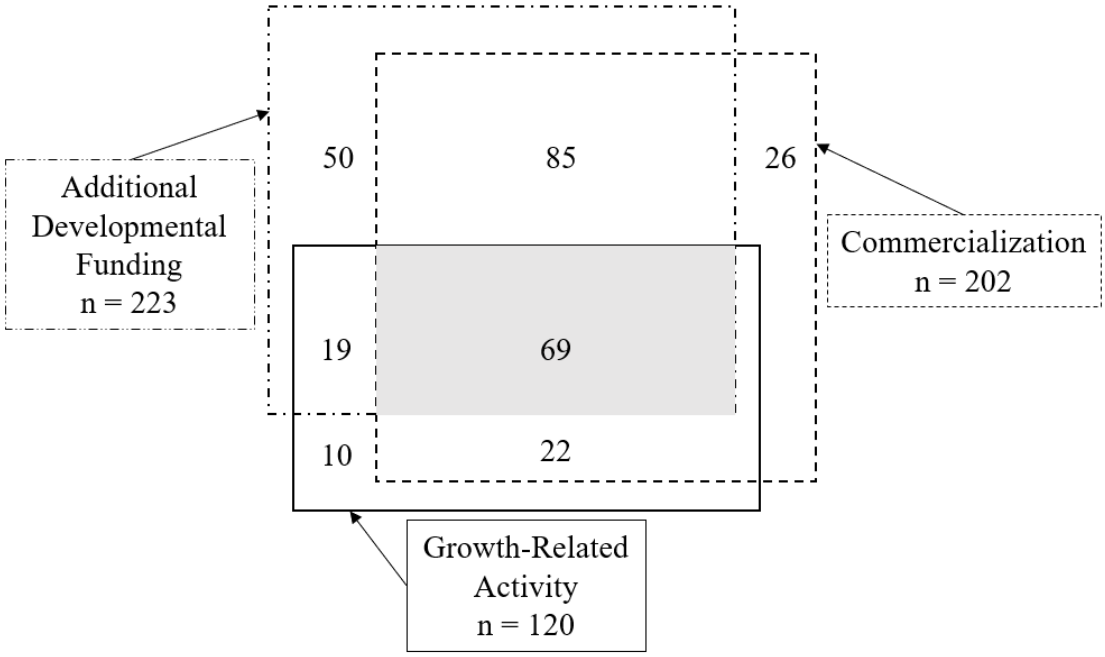
The "yes" / "yes" / "yes" boxes in Table 10 show that about 22% of the projects sampled experienced all three innovation outputs while the "no" / "no" / "no" boxes indicate that approximately 11% of the projects did not realize any of the innovation outputs. Interestingly, nearly 50% of the projects produced additional developmental funding and commercialization of the project, which may indicate correlation between the outputs. Further, about 27% of the projects received additional developmental funding and experienced a firm growth-related activity. Lastly, over 28% of the projects commercialized a project and experienced a firm growth-related activity.

Table 10. Cross Tabulation of Innovation Outputs

Firm Received Additional Development Funding for the Funded Project	Firm Reported Commercialization of Product, Process, Service Sales	Firm Experienced Growth-Related Activity, such as an IPO, a Spin-off Firm, Sale, Merger, Joint Venture, or Licensing Agreement	Frequency of Innovation Outputs	%
No	No	No	34	10.79
		Yes	10	3.17
	Yes	No	26	8.25
		Yes	22	6.98
Yes	No	No	50	15.87
		Yes	19	6.03
	Yes	No	85	26.98
		Yes	69	21.9
		Total	315	100.00

Figure 3 provides a different visual of the overlap in "yes" responses to the three innovation outputs. The combined 281 "yes" responses (i.e., at least one of the three innovation outputs was realized) indicates that nearly 90% of the projects resulted in one or more of the innovation outputs described in this dissertation, Out of those, 69 projects reported that all three occurred, and as noted above, there is significant overlap between each pair of innovation outputs.

Figure 3. Overlap of "Yes" Responses to Innovation Outputs
(n = 281 Combined "Yes" Responses)



Independent Variables

The independent variables in the empirical analysis fall into one of three broad categorical vectors: Strong and Weak Social Ties, Other Forms of Productive Capital, and Firm Characteristics, which control for inter-firm differences in abilities to execute Phase II projects. A description of the variables in each vector follows.

Strong and Weak Social Ties

As defined in Chapter II, social capital is the stock of wealth created from the ability to create, foster, and leverage social interactions into economic action. Social capital is accumulated through the cultivation of relationships with others within a network and through development of social content, which includes the norms of trust and reciprocity. Strong social ties are characterized by tight connections and close social networks with those individuals sharing institutional (homogeneous) knowledge while weak social ties are characterized by acquaintances and a heterogeneous information set across social networks. Chapter VIII outlined an approach to measurement of social capital. Applying this approach, responses to the NRC survey are used to arrive at the social capital measures used in this dissertation. The remainder of this section discusses the development of each strong and weak social tie variable.

The SBIR program acknowledges the importance of an environment that supports the cultivation of strong and weak social ties through collaborative activities. In fact, in the review of SBIR award applications at the NIH, one of the five key considerations by peers reviewing the application is the environment within which the innovation is being developed.[40] The NIH provides the following guidelines for evaluating the innovation environment:

> Does the scientific environment in which the work will be done contribute to the probability of success? Do the proposed experiments take advantage of unique features of the scientific environment or *employ useful collaborative arrangements*? *Is there evidence of institutional support*?

[40] See (5) in 'Background' section on https://grants.nih.gov/grants/guide/notice-files/not97-010.html.

By asking these questions during the review process, NIH effectively requires a level of review and scoring of the amount of collaboration within and outside the firm developing the innovation. Collaboration by applicant firms is an important criterion for the determination of an SBIR award by the NIH. The benefit of this evaluation criterion is that the NRC survey includes questions that attempt to identify the collaborative environment and activities of innovative firms and their projects and it provides a set of data for evaluating the impact of social capital building activities and innovation output.

The collaborative environment that is conducive to innovation and the extent of interactions that build social capital are measured in several survey questions through multiple dimensions. As noted in Chapter VIII, Putnam (2000) argued that it is necessary to use more than one measure to capture the multidimensional nature of social capital, so it is reasonable to justify that no single measure or survey question can adequately measure the level of social capital within a firm. Therefore, the following constructs of social capital (i.e., the trust and reciprocity within formal and informal networks) are explored in the survey data to arrive at a comprehensive measure of elements that define strong and weak social ties within a firm:

1. the shared experiences and interaction of the employees to win funding for the firm's innovations;
2. the extent of collaboration that generates publishable and patentable research;
3. the environment established by its founders to encourage innovation;
4. the interpersonal connections and guidance received from the firm's investors; and
5. the extent of engagement with external parties to bring new products/services to market.

With respect to the first element of shared experiences and interaction to win funding for innovative projects, the SBIR survey asks about the extent of success of receiving financial awards. Firms with a history of winning funding awards for new technologies have a track record

of "selling" the potential commercial success of innovative projects to potential funders due in part to the trust built through collaborative efforts within the firm. Zucker et al. (1995) investigated the impact of trust-building through internal research collaboration, and their results suggest that trust encourages engagement, and collaboration will increase when there is an expectation of future success. Following this logic, with each incremental innovation award the researchers at the firm obtain, other employees observe these outcomes and will want to participate in innovative projects that are likely to succeed, which perpetuates a culture of trust through collaboration. Therefore, the level of prior innovation awards indicates a stock of strong social ties built through the number of internal collaborations on prior innovation projects. The greater the number of internal collaborations on innovation projects, the more trust and reciprocity is built, which strengthens the institutional knowledge, the cultural ethos, the shared identity through a common goal, and internal network within the firm. In short, the incidence and intensity of prior innovation achievements are a measurement of strong social ties within a firm.

It is also important to understand the intent of NIH when funding projects. The receipt of prior SBIR awards indicates the NIH, based on their review criteria, has considered the collaborative environment within which the firm operates in awarding funds to the firm.[41] It might therefore be inferred that firms that have been awarded numerous prior SBIR awards, and particularly Phase II awards, have already been evaluated positively with respect to the level of collaboration associated with those projects. Implicitly, the level of SBIR awards received through collaborative efforts is a manifestation of the trust built among the researchers within the firm. It follows then that the explicit SBIR review criteria of the collaborative environment, in

[41] See (5) in 'Background' section on https://grants.nih.gov/grants/guide/notice-files/not97-010.html.

combination with the incentive of employees to collaborate internally on innovative projects where funding has been awarded provide a theoretical argument to operationalize prior funding awards as one measure of the trust and reciprocity cultivated in networks of coworkers within innovative firms. There are further social capital benefits of multiple SBIR awards since the NIH provides mentoring and other consulting programs (i.e., the Niche Assessment Program and the Commercial Accelerator Program) to assist the awardee firm's researchers in achieving their innovation goals.

The NRC survey asks firms how many Phase II SBIR awards they received prior to the Phase I award that led to the project with the Phase II award associated with the survey. The number of prior Phase II SBIR awards provides an indication of the overall collaborative nature of the firm and the internal social networks developed by the intensity of the innovative projects that have successfully received exploratory SBIR funding.

The second element of social capital measurement is the collaboration that generates publishable and patentable research. The development of research among researchers within the same firm is a trust-building endeavor and a manifestation of the level of internal collaboration. Zucker and Darby (1996) found that research authored by "star" researchers garners interest from other researchers, which builds trust through collaboration and leads to powerful results:

> The extent of collaboration by a firm's scientists with stars is a powerful predictor of its success: for an average firm, 5 articles coauthored by an academic star and the firm's scientists result in about 5 more products in development, 3.5 more products on the market, and 860 more employees (p. 12709).

Thus, the extent of the scientific publications and patents within innovative firms and the propensity to produce new innovations to patent provide foundational measures of the level of trust embedded within the organization resulting from internal collaborative activity.

The NRC survey includes questions that seek to measure the degree of collaborative intensity by inquiring about the level of scientific research and patents the firm. The number of scientific studies submitted for publication and the number of patent applications submitted for approval related to the SBIR-funded technology quantifies the innovative priorities of the firm that are generated through trustworthy, collaborative research.

The third social capital element explored in the NRC survey data is the environment established by its founders to encourage innovation. A culture of collaboration and innovation within a firm is one that emanates from management. When a firm provides an environment for workers to be innovative, it becomes natural to discuss ideas with coworkers and to establish connections to others that have similar interests. Within a cultural environment that encourages creative exploration in pursuit of shared goals, these interactions lead to the cultivation of trust and expectations of reciprocity, which are tenets of social capital. It follows then that the more prior experience the founders of a firm have with establishing innovative firms, the more collaboration and innovation exploration occurs, and thus the greater the strong social ties within the firm(s) founded by those individuals.

The NRC survey includes a question about the number of firms the founders have started, which is a quantification of the relationship building and new product development skills of the firm's founders that may influence the innovative culture of the firm. While this question does not specifically target the measurement of trust and reciprocity among employees at the firm, the intent of the question is to ascertain the extent of the firm's experience in research, collaboration, and execution of innovative research, all of which are trust-building interactions among its employees.

The fourth social capital element is the interpersonal connections and guidance received from the firm's investors. For those firms where investors, and in particular venture capitalists,

participate financially, social capital benefits, such as receiving advising and mentoring related to product commercialization and financial markets, can accrue to the firm and provide invaluable insight and direction in the commercialization of a new innovation. These interpersonal connections encourage the sharing of ideas, research, and product knowledge as well as adding industry expertise to the project, potentially enhancing the commercial prospects for the innovation.

The NRC survey asks about the firm's engagement with a variety of potential funding sources. The survey asks specifically whether prior to the Phase II award associated with survey, the firm received funds for research or development of the technology in the project from venture capitalists and private investors. This question provides insight into the network afforded by venture capital and other private investors and the resulting guidance and knowledge received stemming from those connections, which builds social capital at the firm.

The fifth element of social capital considered in the NRC survey is the engagement with external parties to bring new products/services to market. Pursuing strategic agreements with third parties enables the firm to develop trustworthy external relationships and generate dialogue on best practices for successful product commercialization and future innovation development.

The NRC survey includes questions about a variety of activities in which the firm may be engaged with other firms or investors. Two key arrangements where the exchanging of ideas and the cultivation of trust is critical are R&D agreements and marketing and distribution agreements. With respect to those two activities, the survey asks whether the firm has negotiated agreements with U.S.-based and/or foreign companies and investors to provide assistance in R&D and marketing/distribution of the technology developed during the project. Quantifying the number of finalized agreements is R&D and marketing partners provides an indicator of the social capital building expertise by the firm. It is noted, however, that the NRC survey data do not contain a

timing dimension, so it is possible that these agreements occur after the three innovation outputs analyzed in this dissertation. Nonetheless, these agreements provide a starting point to quantify a firm's social capital with external parties.

Table 11 lists the questions on the NRC survey that correspond to the aforementioned social capital elements. The capital type indicates the type of social tie (strong or weak), the descriptive name of the variable, and the actual question on the survey. For clarity, the NRC survey does not use the terms "social capital," "strong social ties," or "weak social ties." The information in this table asserts that these are operationalized measures of social capital.

An argument can be made that these measures are not social capital measures at all and are instead other forms of innovation output. While not with merit, the selection of these measurements is not rote. The intent is to understand and develop theories around the root causes for these measurements that are social capital based. It would be perfunctory to not account for the variation in firms' social capital as it relates to innovative behaviors. These strong and weak social ties are intended to deepen the understanding of how social capital underpins quantifiable measures.

Table 11. Social Capital Variables

Capital Type	Variable	Survey Question
Strong Social Tie	Number of Phase II SBIR Awards Received	How many Phase II SBIR awards did your firm receive prior to the Phase I that led to this Phase II?
Strong Social Tie	Number of Scientific Publications Submitted	What is the number of Scientific Publications submitted as a result of this [Phase II] project?
Strong Social Tie	Number of Patent Applications Submitted	What is the number of Patents applied for as a result of this [Phase II] project?
Strong Social Tie	Number of Firms Founded by the Funded-Firm's Founders	Number of other companies started by one or more of the founders
Weak Social Tie	Receipt of Project Funds Prior to Phase II from Venture Capital, Other Private Company, or Private Investor	Prior to this SBIR Phase II award, did your firm receive funds for research or development of the technology in this project from Venture Capital, Other Private Company, or Private Investor?
Weak Social Tie	Marketing/Distribution Agreements in Place	As a result of the technology developed during this [Phase II] project, your firm's activities with U.S. and/or foreign companies and investors includes finalized marketing/distribution agreements.
Weak Social Tie	Research/Development Agreements in Place	As a result of the technology developed during this [Phase II] project, your firm's activities with U.S. and/or foreign companies and investors includes finalized R&D agreements.

Social Capital Descriptive Statistics

Descriptive statistics associated with the strong and weak social tie measures discussed above are presented in Table 12. The strong social ties variables are continuous variables and the weak social tie variables are binary response variables. Given that there is a distribution of the

strong social tie variables, a second table, Table 13, is also provided to delve into the intensity of these social capital measures.

Table 12. Social Capital Descriptive Statistics
(n = 315)

Independent Variables – Strong and Weak Social Ties	Mean	StdDev	Min	Max
Strong Social Tie - Number of Phase II SBIR Awards Received	2.273	7.93	0	79
Strong Social Tie - Number of Scientific Publications Submitted	3.181	10.96	0	165
Strong Social Tie - Number of Patent Applications Submitted	1.162	2.41	0	25
Strong Social Tie - Number of Firms Founded by the Funded-Firm's Founders	1.238	2.06	0	18
Weak Social Tie - Receipt of Project Funds Prior to Phase II from Venture Capital, Other Private Company, or Private Investor	0.194	0.4	0	1
Weak Social Tie - Marketing/Distribution Agreements in Place	0.251	0.43	0	1
Weak Social Tie - Research/Development Agreements in Place	0.175	0.38	0	1

Table 13. Strong Social Ties Frequencies
(n = 315)

Strong Social Ties								
	Number of Phase II SBIR Awards Received		Number of Scientific Publications Submitted		Number of Patent Applications Submitted		Number of Prior Firms Founded by the Funded-Firm's Founders	
Number	Freq	%	Freq	%	Freq	%	Freq	%
0	170	53.97	135	42.86	179	56.83	143	45.4
1	66	20.95	47	14.92	62	19.68	74	23.49
2	22	6.98	43	13.65	29	9.21	57	18.1
3	14	4.44	23	7.3	18	5.71	16	5.08
4	13	4.13	20	6.35	7	2.22	13	4.13
5	6	1.9	16	5.08	8	2.54	3	0.95
6	6	1.9	1	0.32	3	0.95	6	1.9
7	2	0.63	3	0.95	2	0.63		
8	3	0.95	4	1.27				
9	1	0.32	3	0.95				
10			5	1.59	3	0.95		
11-20	6	1.9	9	2.86	3	0.95	3	0.95
21-50	2	0.63	4	1.27	1	0.32		
51-100	4	1.27	1	0.32				
> 100			1	0.32				

With respect to the strong social ties of employee networks cultivated through the development of trust and shared goals and that propel the firm to win funding for innovations, the average number of Phase II awards received prior to the Phase I award leading to the project is 2.3. Further, Table 13 shows that approximately 46% reported at least one prior Phase II funding, which implies that many of the firms in the survey are serial innovators that use the SBIR program to tactically fund their early stage R&D projects. By winning multiple SBIR awards, a

firm has demonstrated to the NIH that it has created an environment where collaboration within a firm's internal network can occur and where working relationships among its researchers can be fruitful, supporting the hypothesis that prior awards are accomplished through the cultivation of strong social ties.

For the strong social ties of collaborative research as observed through intellectual property development, projects in the survey have submitted on average over three scientific publications for approval and applied for 1 patent. It is noteworthy that 57% of the projects submitted at least one scientific publication and nearly one-quarter of the projects submitted more than one patent application, so there are projects with significant research resources and social capital building collaboration that result to intellectual property development. Further, these survey questions only ask about scientific publications and patents related to the specific Phase II project, and an average of over three scientific research papers submitted for publication and one patent submitted for approval related to a single technology represents, on average, meaningful innovative capabilities and research collaboration within the firm.

The environment and the culture that is created by the firm's founders to develop innovations are important in the cultivation of social capital. For the projects in the survey, the average number of firms started by the firm's founders is slightly more than one. It can be reasoned that founders with experience in starting up companies bring a culture to their new ventures that encourage innovation production through collaborative, social capital building activity. In this sample, over 30% of the projects surveyed had founders that started two or more companies, which imbues those firms with experience in innovation culture development and social capital accumulation.

Regarding the weak social ties of trust and reciprocity measured through the interpersonal connections, transfer of information, and shared ideas through financing arrangements, the survey

data indicate that approximately 19% of the projects received venture capital, other private company, or private investor funding prior to the Phase II award associated with the project subject to the survey. Participation of a venture capitalist or private investor in a firm's project can provide valuable insight and guidance related to the commercialization of a technology and create social capital through the ongoing dialogue and feedback to achieve mutually beneficial outcomes.

Also, engagement in strategic relationships with third parties to bring products and services to market is a direct measure social capital building and provides the firm a platform to exchange ideas and pursue best practices to achieve a common goal. Firms may choose to enter into these agreements to cultivate relationships that benefit the firm by leveraging resources and to reduce the time to commercialize their technologies. The nature of the survey question and the response solicited provide insight into the type, occurrence, partner domicile, and stage of agreement in which the firm is engaged for the project (but not the total number of agreements within each type of arrangement)[42]. Approximately 25% of the projects in the survey finalized a marketing/distribution agreement with a U.S. or foreign company/investor. Additionally, 18% of the projects finalized an agreement with a U.S. or foreign company/investor to perform R&D. The existence of finalized agreements may indicate the firm has a network of partners to facilitate development, commercialization, and other innovative potential resulting from the technology. These agreements allow for the social capital of the firm to grow as trust and expectations of reciprocity are cultivated through strategic relationships with third parties.

[42] For the survey question regarding the existence of activities with companies and investors, it is possible for a firm with an SBIR-funded project to respond 'yes' to engagement in multiple types of agreements, so one project may have agreements with both U.S. and foreign companies/investors that are finalized and in ongoing negotiations.

To see the potential correlations among the variables used in the empirical analysis, a correlation matrix is provided in Table 14. The top value is the correlation value and the bottom value in parentheses is the p-value under the null hypothesis of zero correlation between the two variables. A low p-value indicates a statistically significant correlation among the two variables (i.e., the probability of rejecting the null when it is true is low).

The correlation matrix indicates that the output variables of additional developmental funding and commercialization is statistically significant at the 0.01 level. Additionally, commercialization and firm growth-related activities are positively correlated and statistically significant at the 0.01 level. These correlations imply that there may be similar factors driving both outputs, which raises the potential issue of cross-equation error correlations due to unobserved factors associated with the outputs.

With respect to the social capital independent variables that are correlated, the magnitude to the correlations varies considerably, but many are statistically significant. Of the correlations with larger values, the correlation between patent applications and receipt of project funds prior to Phase II from venture capital, other private company, or private investor, which is 0.16 and significant at the 0.01 level. Additionally, the correlation between the number of publication submissions and the existence of marketing/distribution agreements is 0.14 and significant at the 0.05 level. Lastly, the correlation between research agreements and patent applications is 0.13; the correlations between research agreements and receipt of project funds prior to Phase II from a private investor is 0.13; and the correlation between research agreements and marketing agreements is 0.14, and each of these correlations is significant at the 0.05 level. While not large correlation values, these positive and statistically significant correlations suggest some of the social capital variables derived from the NRC survey questions may be related to some extent, so a discussion of the pros and cons of variable reduction is provided later in this chapter.

Table 14. Correlation Matrix
(n = 315)

		1	2	3	4	5	6	7	8	9	10	11	12	13
1	Output A - Firm Received Additional Development Funding	1.000												
2	Output B - Firm Reported Incidence of Product, Process, or Service Sales	0.160 (0.004)	1.000											
3	Output C - Firm Experienced Growth-Related Activity	0.044 (0.438)	0.191 (0.001)	1.000										
4	Strong Social Tie - Number of Phase II SBIR Awards Received	-0.071 (0.207)	-0.007 (0.904)	0.131 (0.020)	1.000									
5	Strong Social Tie - Number of Scientific Publications Submitted	0.092 (0.102)	0.104 (0.066)	0.095 (0.094)	-0.041 (0.463)	1.000								
6	Strong Social Tie - Number of Patent Applications Submitted	0.162 (0.004)	-0.038 (0.504)	0.135 (0.017)	-0.039 (0.496)	0.067 (0.238)	1.000							
7	Strong Social Tie - Number of Firms Founded by the Funded-Firm's Founders	0.105 (0.063)	-0.094 (0.098)	0.103 (0.068)	0.114 (0.042)	0.041 (0.465)	0.072 (0.200)	1.000						

8	Weak Social Tie - Receipt of Project Funds Prior to Phase II from Private Investor	0.120	-0.035	0.161	-0.101	-0.002	0.161	0.041	1.000					
		(0.033)	(0.531)	(0.004)	(0.073)	(0.979)	(0.004)	(0.470)						
9	Weak Social Tie - Marketing/Distribution Agreements in Place	0.211	0.372	0.104	0.030	0.137	0.034	0.001	-0.043	1.000				
		(0.000)	(0.000)	(0.065)	(0.596)	(0.015)	(0.546)	(0.990)	(0.451)					
10	Weak Social Tie - Research/Development Agreements in Place	0.185	0.117	0.328	-0.074	0.012	0.126	0.077	0.134	0.139	1.000			
		(0.001)	(0.037)	(0.000)	(0.191)	(0.839)	(0.026)	(0.174)	(0.017)	(0.014)				
11	Physical Capital - Percentage Category of Firm Growth Due to SBIR	-0.034	0.059	0.063	0.053	0.002	-0.053	-0.027	-0.114	0.034	0.020	1.000		
		(0.544)	(0.300)	(0.267)	(0.344)	(0.977)	(0.345)	(0.632)	(0.044)	(0.549)	(0.725)			
12	Human Capital - Number of Employees when Phase II Proposed	-0.092	0.035	-0.038	0.263	-0.039	-0.061	-0.026	-0.022	0.020	0.041	-0.337	1.000	
		(0.105)	(0.537)	(0.501)	(0.000)	(0.486)	(0.283)	(0.641)	(0.692)	(0.722)	(0.467)	(0.000)		
13	Firm was Established for SBIR Awards	-0.032 (0.572)	0.032 (0.569)	0.131 (0.020)	0.171 (0.002)	-0.036 (0.524)	-0.022 (0.698)	0.054 (0.337)	-0.081 (0.149)	-0.009 (0.880)	0.001 (0.983)	0.258 (0.000)	-0.033 (0.565)	1.000

Other Forms of Productive Capital

The other forms of productive capital that have been theorized in this dissertation as direct inputs into production are physical capital and human capital. Physical capital, such as machines, equipment, and laboratories, is used in innovation production as it is often the physical structure(s) through or within which an innovation is developed and produced. Human capital, which includes the education, experience, and training of a firm's workers, deploys the physical capital in the development and manufacturing of products and services.

With respect to measures of physical capital, the SBIR survey does not directly ask about the amount of a firm's physical capital. Nevertheless, the survey does include a measure of the growth of the firm since its first SBIR award, which can be viewed as an indicator of the asset growth of the firm since it began submitting applications for SBIR awards. While perhaps imprecise, firm growth is assumed to proxy the physical assets accumulated by the firm over time.

For human capital, the survey asks about the size of the workforce when the Phase II project proposal was submitted. For an innovative firm that is striving to commercialize a new technology, the number of employees at the firm provides an aggregated measure of the overall education and experience working on the innovation. By evaluating the number of workers before the Phase II award, a more precise measure of the human capital used to work on Phase II of the project emerges. Conversely, selecting the current number of employees at the point of the survey measures the human capital after the project is complete and would not be the best theoretical predictor of innovation output.

The variables and survey questions used to measure both physical capital and human capital are detailed in Table 15. The physical capital variable is a categorical response to question of the percentage of firm growth attributable to the SBIR program after the firm received

its first SBIR award. The responses are split in to ascending order quartiles (1-4) by 25% increments. The human capital measure is the discrete number of employees of the firm when the Phase II proposal was submitted.

Table 15. Physical Capital and Human Capital Variables

Capital Type	Variable	Survey Question
Physical	Percentage Category of Firm Growth Due to SBIR (1-4 groups)	What percentage of your firm's growth would you attribute to the SBIR program after receiving its first SBIR award? 1= < 25%, 2= 25%-50%, 3= 51%-75%, 4= > 75%
Human	Number of Employees when Phase II Proposed	Number of employees (if known) when Phase II proposal was submitted.

Descriptive Statistics on Other Forms of Productive Capital

Descriptive statistics on the other forms of productive capital are displayed in Table 16. Since physical capital is a categorical variable, the average value of 2.5 is difficult to interpret. A more meaningful interpretation of the variable is in Table 17, which shows the number of projects responding within each category. There is not a uniform distribution of responses, but there is somewhat of a bipolar or barbell effect in that the largest number of responses are in the lowest and highest categories. Interestingly, the survey reported that nearly a third of the firms attributed 75% or more of their overall growth to the SBIR program. The key assumption in using this variable to measure physical capital is that SBIR-funded growth results in additional physical resources used to generate innovation output, so this segment of the sample (greater than 75% growth) will be considered to have a higher level of physical capital.

Table 16. Physical Capital and Human Capital Descriptive Statistics
(n=315)

Independent Variables – Other Forms of Productive Capital	Mean	StdDev	Min	Max
Physical Capital - Percentage Category of Firm Growth Due to SBIR	2.511	1.22	1	4
Human Capital – Number of Employees when Phase II Proposed	19.498	39.58	1	300

Table 17. Physical Capital Distribution
(n = 315)

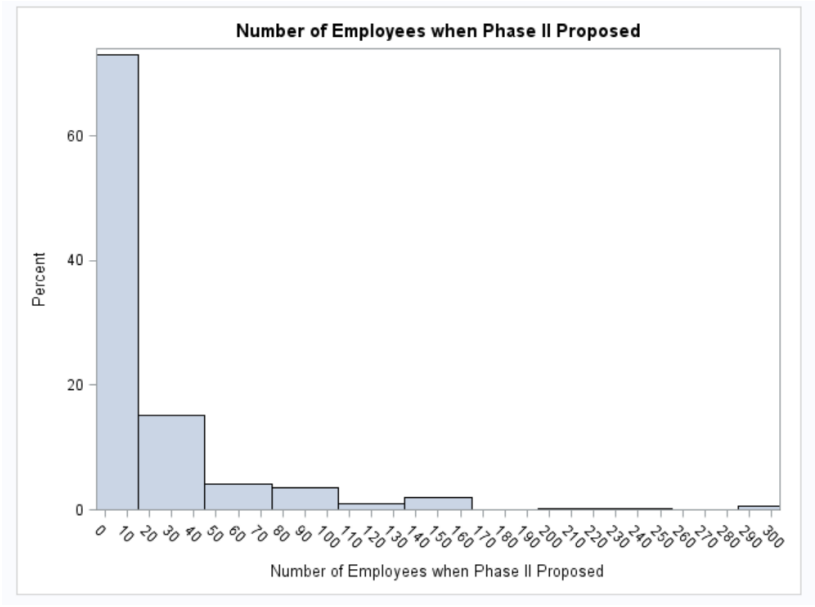
Percentage Category of Firm Growth Due to SBIR		
Response	Freq	%
Less than 25%	92	29.21
25%-50%	71	22.54
51%-75%	51	16.19
Greater than 75%	101	32.06

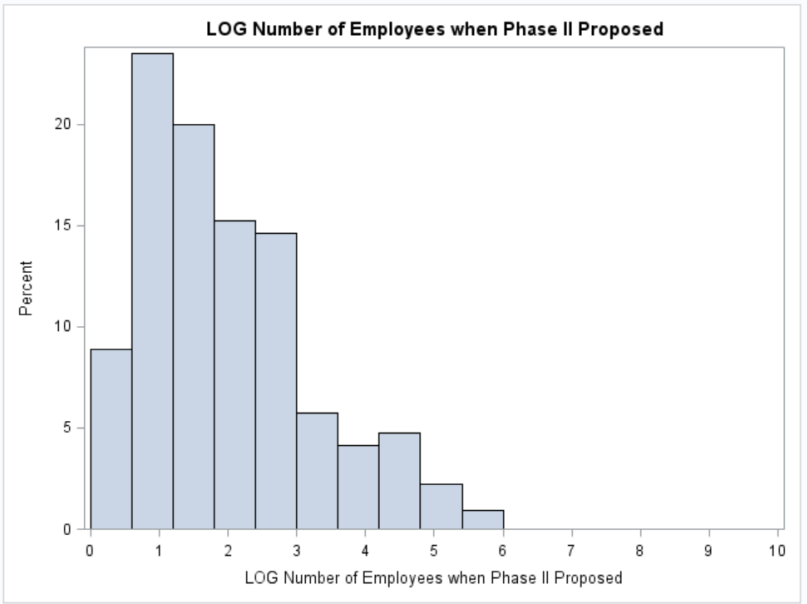
The human capital variable shows that projects in the survey had on average nearly 20 employees when the Phase II proposal for the project was submitted. There are a few notable items about the human capital variable. First, there are a small number of projects that reported "0" employees at the point of Phase II proposal submission. Since Phase II funding is preceded by or in conjunction with Phase I funding and NIH review of SBIR applications involves at least one principal investigator associated with the firm, it is reasonable to assume that there is at least one employee. As such, any "0" response to this question is changed to "1."

Second, there are some projects with a significant number of employees—about two dozen projects have over 100 employees with a couple projects reporting 300 employees. Figure 4 provides a visualization of the distribution of the human capital variable. Relative to the number of projects in the survey, the number of projects with hundreds of employees is small.

Nonetheless, it has been suggested that firms that have received five or more awards are SBIR "mills" whose primary purpose is to employ individuals to win additional SBIR awards. It has been determined, however, that frequent award winners at the NIH are not a significant concern to commercialization potential (National Research Council, 2008, pp. 220-222).

Figure 4. Human Capital Distribution
(n = 315)





Lastly given the distribution of the human capital measure, for modeling purposes, the log of the variable is used as a model input to moderate the potential influence of the firms with higher levels of employees as the point of the Phase II proposal submission. The second

histogram chart in Figure 4 shows how taking the log creates a more normally distributed variable relative to the raw employee count in the first histogram chart.

Firm Characteristics

To account for other dimensions of a firm and/or project that potentially influence innovation output, other covariates are considered in the empirical analysis. Certain productive capital measures incorporated into the model pick up potential differences between firms, such as human capital (employee growth) and physical capital (firm growth). However, the firm's relative inexperience in conducting SBIR-eligible research may also be a significant covariate of innovation output since those firms that have more experience in research and development may be more experienced in commercializing new technologies. Following the logic of Gicheva and Link (2016), a firm is considered "nascent" based on two conditions. First, the firm must be founded because of the SBIR program, and second, the firm must not have received any prior Phase II SBIR awards related to the surveyed Phase II technology. Table 18 outlines the variable name and the question on the survey used to derive the indicator.

Table 18. Firm Characteristic Variables

	Variable	Survey Questions
Firm Characteristic	Nascent	Was the firm founded because of the SBIR Program? How many Phase II awards has the firm received that are related to the project/technology supported by this Phase II award?

Firm Characteristics Descriptive Statistics

As Table 19 shows, less than 6% of the projects are related to nascent firms, which implies that the vast majority of the firms in the survey are relatively experienced with respect to SBIR-eligible funded projects.

Table 19. Firm Characteristics Frequencies
(n = 315)

Firm Characteristics - Nascent		
Response	Freq	%
No	298	94.6
Yes	17	5.4

Variable Transformation Discussion

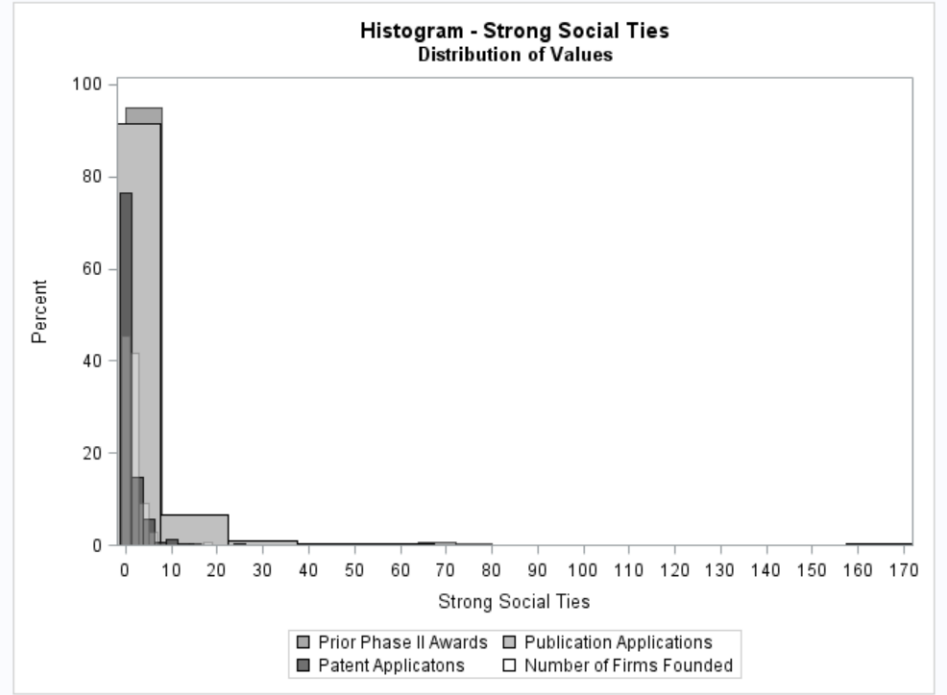
As described earlier in this chapter, several of the social capital measures, and particularly the strong social tie variables as outlined in Table 13, span a range of response values and are not all scaled the same. This could make interpretation of model results challenging since social capital marginal effects will be evaluated on multiple scales, which may not give an intuitive interpretation of a social capital variable's importance relative to other social capital variables in the model. One method to address this potential issue and to retain outliers in the

analysis is to standardize the values to be measured on the same scale, such as z-scores or percentiles. Standardization of the strong social capital variables was initially considered given the reasons above, but it was ultimately not pursued given the overwhelming benefit of interpretability of the model results using the raw variables relative to standardization.

Figure 5 shows the distribution of strong social ties. The scale is skewed right due to the relatively large observation values related to a handful of projects with patents and prior Phase II awards received. Top coding those strong social tie variables above a threshold, such as 25 or 50 slightly alters the distribution, but, as Table 13 shows, there are fairly large concentrations of each variable at 0 and 1. As such, in the absence of a compelling reason to alter the raw data for certain observations, top coding is not applied to the strong social tie variables.[43]

[43] For completeness, all the models in this dissertation were run with a top coding of 25 and 50 for the Number of Phase II SBIR Awards Received and Number of Scientific Publications Submitted variables. The results did not indicate any material difference in the coefficient estimates or significance other than the Number of Phase II SBIR Awards Received in Equation [3], which becomes more negative and significant at lower top code points. It is not clear why artificially capping prior Phase II awards at a low level would create this result since it only affects a handful of observations, so the top code approach is not pursued as it may result in an unnecessary measurement bias.

Figure 5. Strong Social Ties Histogram



With respect to the other independent variables, the weak social ties variables are not transformed as they are all in the same scale (binary responses). The physical capital variable is not transformed either since it is a categorical response that will be a class variable in the model. Likewise, the nascent firm indicator is binary and is not transformed. Lastly, the human capital variable is transformed by taking its log.

Variable Reduction Discussion

In addition to considering variable standardization, there are reasons to also consider variable reduction for the social capital variables. First, as noted in this chapter, several social capital dimensions that are present in the NRC survey data, and there may be correlations among the variables measuring social capital. In fact, the correlation matrix in Table 14 details the correlation coefficients across each dependent and independent variable, and it indicates there are

several correlations among the social capital variables that are statistically significant. Variable reduction would create a smaller set of variables that account for most of the variation in the social capital measures. There also could be reasons that the strong social ties are correlated that cannot be fully explained, such as an unintended interpretability of the survey questions by the responding firm or a conflation of the meaning of certain survey questions, which may result in a similar level of response value to different questions. Second, it has been asserted in this dissertation that social capital is best measured through the development of multiple indicators. Reducing multiple social capital measures into a smaller set may produce a more holistic and simpler method to capture the level of a firm's social capital. To evaluate the potential benefit of using variable reduction, a test for multicollinearity is performed on all the raw independent variables.

Greene (2003, p. 56) and Cameron and Trivedi (2005, p. 350) suggest using the condition number of the information matrix (**X'X**, scaled to have 1's on the diagonal) to check for multicollinearity. The condition number of the information matrix is derived from the eigenvalues for each independent variable and is the square root of the ratio of the largest eigenvalue to the smallest of the information matrix. Since a high ratio implies certain components may account for the most variability, one rule of thumb is that a final condition number of greater than 100 indicates a concerning level of multicollinearity (Cameron and Trivedi, 2005, p. 350).

This collinearity test was performed in SAS using the 'collin' option in the model statement with the first innovation output, the receipt of additional developmental funding, as the dependent variable in an ordinary least squares (OLS) regression and all the raw independent variables included on the right-hand side. Since the test is a measure of collinearity among the

independent variables, the dependent variable used in the test is not relevant as the test results are the same.[44]

The results from the test are shown in Table 20, which include the name of each independent variable and its associated eigenvalue and condition value from the collinearity test plus the variance inflation factor.

Table 20. Results from Test of Multicollinearity

Independent Variable	Eigenvalue	Condition Value	VIF
Intercept	3.84	1.00	0.0
Strong Social Tie - Number of Phase II SBIR Awards Received	1.25	1.75	1.17
Strong Social Tie - Number of Scientific Publications Submitted	0.97	1.89	1.03
Strong Social Tie - Number of Patent Applications Submitted	0.95	2.01	1.05
Strong Social Tie - Number of Firms Founded by the Funded-Firm's Founders	0.80	2.19	1.04
Weak Social Tie - Receipt of Project Funds Prior to Phase II from Venture Capital, Other Private Company, or Private Investor	0.70	2.34	1.07
Weak Social Tie - Marketing/Distribution Agreements in Place	0.68	2.37	1.05
Weak Social Tie - Research/Development Agreements in Place	0.66	2.41	1.07
Physical Capital - Percentage Category of Firm Growth Due to SBIR	0.57	2.59	1.26
Human Capital - Number of Employees when Phase II Proposed	0.50	2.76	1.27
Firm was Established for SBIR Awards	0.07	7.51	1.11

[44] For completeness, a Variance Inflation Factor (VIF) value for each independent variable is also calculated using SAS with the 'vif' option in the model statement. The VIF provides the level, or inflationary impact, of a variable on the variance of its coefficient estimate. High VIFs indicate that a variable may be driving a significant amount of the variation (i.e. high standard error of the estimate), which may signal collinearity with other right-hand side variables.

From an interpretation standpoint, the final condition value of 7.51 does not indicate a concerning level of multicollinearity among the independent variables. If the value was close to 100, then a closer review of the pairwise proportion of variation among each of the independent variables would need to be completed to determine the extent of collinearity. Likewise, while the VIF calculation does not have an upper bound, a VIF of 1 for each predictor variable indicates the absence of multicollinearity (i.e., none of the other covariates help explain the variation in the variable). As such, the VIFs for each of the raw independent variables, which range from 1.03 to 1.27, imply that multicollinearity is not a concern for this set of explanatory variables.

While the formal tests for multicollinearity do not indicate a concern with the independent variables used in this dissertation, there are a priori considerations about variable redundancy. First, there exists several statistically significant pairwise correlations in the correlation matrix from Table 14 that include social capital measures. Second, since the social capital measures are obtained through the NRC survey questions, it is possible the questions overlap in context with respect to the measurement of the dimensions of social capital. Third, the dimensions of social capital are difficult to measure through one survey question, and a combined or unified measure may result in a more robust measure. Even with those considerations, the marginal benefit of using the raw variables significantly outweighs these concerns and is further supported by the formal tests of multicollinearity.

For completeness and to verify the appropriateness of the raw variable approach, principal component analysis (PCA) was performed on the social capital independent variables used in the empirical analysis to evaluate any potential benefit of variable reduction. PCA creates a set of new variables that are a linear combination of the initial set of variables that captures the variation among those variables. PCA creates components through the estimation of weights assigned to each variable. This weighting is the optimal combination that accounts for the

variance in the social capital variables loaded onto the fewest components (O'Rourke and Hatcher, 2013). While PCA may address issues with the data, the most significant downside to using PCA is the loss in interpretation of the principal components used as independent variables in the model. Since the principal components are artificial variables generated to account for the variance in the social capital variables, the marginal effect associated with a principal component independent variable is not directly related to a change in one social capital variable. Instead, the interpretation is one of significance (or not) of the factor loading associated with each principal component.

To begin PCA, the set of variables to be reduced are selected. For this evaluation, two separate PCA analyses are completed—one on the strong social tie variables and the other on the weak social tie variables. The reasoning for the split is the theoretical motivation to conceptualize and measure strong and weak social ties separately. Additionally, there are certain correlations in the correlation matrix in Table 14 which may indicate some redundancy in each type of social capital.

Next, PCA estimates the weights that are assigned to each observed variable to create the first principal component that accounts for the maximum variance among all potential linear combinations of the variable set. This process is repeated with new weights associated with a second principal component until the number of principal components created equals the number of observed variables included in the PCA vector.

Since the purpose of PCA is to reduce the number of variables, not all principal components should be kept for future use. The ideal number of principal components to select is based on the degree to which the principal components account for the variation in the observed variables. A common method to determine the number of principal components retained is an eigenvalue cutoff of one, which is the amount of variance that is accounted for by a given

component,[45] Table 21 lists the eigenvalues associated with the strong social tie variables used in the PCA in descending order along with proportion of variation accounted for by each component. For example, the first component has an eigenvalue of 1.13, which is 0.03 higher than the next component and accounts for 28% of the variation in the strong social tie variables. Given the first two components have eigenvalues greater than one and account for 56% of the variation (as noted in the Cumulative column in Table 21), the strong social tie variables are reduced to two components. Once retained, rotated factor loadings are derived, which allows for an easier interpretation of the types of variables loading on each principal component and ensuring that the components are uncorrelated.

Table 21. Strong Social Tie Eigenvalues from PCA

Component	Eigenvalue	Difference	Proportion	Cumulative
1	1.13	0.03	0.28	0.28
2	1.10	0.16	0.27	0.56
3	0.93	0.09	0.23	0.79
4	0.84		0.21	1.00

Table 22 shows the results from the rotated factors, which indicate that certain strong social ties are associated with one factor. For example, the social capital measures of a working environment that encourages innovation and interactions of the firm's employees in winning funding for innovations are more closely associated with Factor 1. Similarly, the social capital

[45] A detailed discussion of PCA and a reference used for this dissertation is the first chapter from O'Rourke & Hatcher (2013) titled *Principal Component Analysis* (http://support.sas.com/publishing/pubcat/chaps/55129.pdf).

developed through researcher collaboration in the pursuit of intellectual property is loaded onto Factor 2.

Table 22. Strong Social Tie Rotated Factor Pattern from PCA

	Factor 1	Factor 2
Number of Prior Phase II SBIR Awards Received	76 *	-29
Number of Scientific Publications Submitted	-6	66 *
Number of Patent Applications Submitted	7	70 *
Number of Firms Founded by the Funded-Firm's Founders	73 *	31

Printed values are multiplied by 100 and rounded to the nearest integer
Values greater than 0.35 are flagged by an '*'

Using PCA is both art and science. The science part is described above. The art is in determining whether PCA should be considered at all, and if it is a consideration, how many principal components to select. One measure of whether PCA should be initially considered is Kaiser's Measure of Sampling Adequacy (MSA), which attempts to quantify the usefulness of factor analysis. An overall MSA of 0.80 or higher is considered a good candidate for PCA[46]. With respect to PCA on the strong social tie variables, the overall MSA is 0.49, which based on the scale, is considered a poor candidate for PCA. To obtain a higher MSA score, variables should be removed, or others added to the analysis. Additionally, PCA is more impactful when at least three variables are loaded on to one principal component, which is not the case with the strong social tie variables. Considering both the art and science of PCA, the theoretical

[46] The Kaiser MSA is not the only test of PCA factor grouping. Bartlett's test of sphericity was also performed. The null hypothesis of no common factors was rejected in favor of the alterative of at least one common factor.

motivation for using a variable reduction technique, such as PCA, is not very compelling for the strong social tie variables.

PCA was also performed on the weak social tie variables. Since each of these variables are dichotomous responses, a tetrachoric correlation matrix was used to derive the PCA estimates ('polychoric' option in SAS correlation matrix generation). Table 23 shows the eigenvalues and the proportion of variation that accounted for each component while Table 24 highlights the factor loadings on each of the components. The tables show that the three weak social tie variables loaded onto two principal components. The Kaiser MSA value is 0.42, which is low, so variable reduction to this group of variables is not compelling.[47]

Table 23. Weak Social Tie Eigenvalues from PCA

Component	Eigenvalue	Difference	Proportion	Cumulative
1	1.32	0.24	0.44	0.44
2	1.09	0.50	0.36	0.80
3	0.59		0.20	1.00

[47] Cronbach's Alpha, which is a reliability estimate for the degree of correlation or "internal consistency" among a set of variables potentially measuring the same concept (Ritter 2010), was also calculated for the set of the raw strong social tie variables and the raw weak social tie variables. The standardized Cronbach Alpha for the strong social ties is 0.13 and 0.20 for the weak social tie variables. The interpretation is that the closer the Cronbach Alpha is to 1.0, the higher the correlation of the standardized variables. The correlation does not appear to be strong, which further supports the use of the raw social capital variables in the empirical analysis.

Table 24. Weak Social Tie Rotated Factor Pattern from PCA

	Factor 1	Factor 2
Receipt of Project Funds Prior to Phase II from Private Investor	90 *	-14
Marketing/Distribution Agreements in Place	-14	90 *
Research/Development Agreements in Place	61 *	61 *

Printed values are multiplied by 100 and rounded to the nearest integer
Values greater than 0.35 are flagged by an '*'

Model Specification

Given the binary responses associated with each of the three innovation output dependent variables described in this chapter, the model to estimate the impact of the type of capital (social capital, physical capital, human capital) on those outcomes must accommodate discrete (binary) outcomes. The most significant issue in selecting a model is whether to view each innovation output independently or to consider the potential correlation among each of the outputs.

As discussed in Chapter V, there is not a predetermined sequence of innovation outputs measured in the NRC survey data. Further, innovation output as defined in this dissertation as additional developmental funding, commercialization of a product/service, and the execution of a growth-related activity, do not necessarily have to follow a strict path. Innovation is fluid, and there are not specific hurdles or conditions that are necessary to realize an innovation output as defined in this dissertation. Nonetheless, there could be unobserved and unmeasurable factors that are common to innovation outputs. Therefore, selecting individual independent models to characterize innovation outputs may not be the appropriate course since the assumption of independence may be violated. To begin the analysis, however, individual probit models are estimated first to initially assess the potential impact of social capital on the three innovation

outputs as described in equations [3], [4], and [5]. The results are presented in Tables 25, 26, and 27.[48]

[48] All the models in this dissertation were run in NLOGIT 6.

Table 25. Probit Results from Equation 3
Output: Firm Received Additional Developmental Funding for the Funded Project
(n = 315)

Inputs	Estimate	StdError	t-stat	p-value		ME at Avg of ME	ME StdError	ME t-stat	ME p-value	
Intercept	0.273	0.253	1.08	0.282						
Strong Social Tie - Number of Phase II SBIR Awards Received	-0.013	0.010	-1.23	0.218		-0.004	0.003	-1.24	0.215	
Strong Social Tie - Number of Scientific Publications Submitted	0.030	0.022	1.39	0.165		0.010	0.007	1.40	0.162	
Strong Social Tie - Number of Patent Applications Submitted	0.152	0.061	2.49	0.013	**	0.049	0.019	2.55	0.011	**
Strong Social Tie - Number of Firms Founded by the Firm's Founders	0.098	0.055	1.79	0.073	*	0.032	0.017	1.82	0.069	*
Physical Capital - Percentage of Firm Growth Due to SBIR – < 25%	0.000	.	.	.						
Physical Capital - Percentage of Firm Growth Due to SBIR – 25%-50%	0.089	0.231	0.39	0.699		0.028	0.072	0.39	0.695	
Physical Capital - Percentage of Firm Growth Due to SBIR – 51%-75%	0.205	0.267	0.77	0.442		0.064	0.079	0.80	0.423	
Physical Capital - Percentage of Firm Growth Due to SBIR – > 75%	-0.120	0.225	-0.53	0.595		-0.039	0.074	-0.53	0.598	
Human Capital – Log Number of Employees when Phase II Proposed	-0.006	0.072	-0.08	0.936		-0.002	0.023	-0.08	0.936	
Firm was Established for SBIR Awards (yes/no)	-0.060	0.342	-0.18	0.860		-0.019	0.112	-0.17	0.862	

McFadden's Pseudo R^2 = 0.064, Likelihood Ratio = 24.36	significance levels: * = < 0.10, ** = < 0.05, *** = < 0.01

Table 26. Probit Results from Equation 4
Output: Firm Reported Commercialization of Product, Process or Service Sales
(n = 315)

Inputs	Estimate	StdError	t-stat	p-value		ME at Avg of ME	ME StdError	ME t-stat	ME p-value	
Intercept	-0.255	0.246	-1.04	0.298						
Weak Social Tie - Receipt of Project Funds Prior to Phase II from Venture Capital, Other Private Company, or Private Investor (yes/no)	-0.101	0.202	-0.50	0.618		-0.032	0.064	-0.50	0.620	
Weak Social Tie - Marketing/Distribution Agreements in Place (yes/no)	1.522	0.257	5.92	0.000	***	0.400	0.042	9.58	0.000	***
Weak Social Tie - Research/Development Agreements in Place (yes/no)	0.265	0.223	1.19	0.235		0.082	0.067	1.22	0.222	
Physical Capital - Percentage of Firm Growth Due to SBIR – < 25%										
Physical Capital - Percentage of Firm Growth Due to SBIR – 25%-50%	0.558	0.234	2.39	0.017	**	0.168	0.064	2.61	0.009	***
Physical Capital - Percentage of Firm Growth Due to SBIR – 51%-75%	0.181	0.246	0.74	0.460		0.056	0.074	0.76	0.450	
Physical Capital - Percentage of Firm Growth Due to SBIR – > 75%	0.285	0.229	1.25	0.212		0.089	0.069	1.28	0.200	
Human Capital – Log Number of Employees when Phase II Proposed	0.044	0.068	0.65	0.517		0.014	0.021	0.65	0.516	
Firm was Established for SBIR Awards (yes/no)	0.210	0.373	0.56	0.574		0.065	0.112	0.58	0.563	

McFadden's Pseudo R^2 = 0.151, Likelihood Ratio = 62.06	significance levels: * = < 0.10, ** = < 0.05, *** = < 0.01

Table 27. Probit Results from Equation 5
Output: Firm Experienced Growth-Related Activity, such as an IPO, a Spin-off Firm, Sale, Merger, Joint Venture, or Licensing Agreement
(n = 315)

Inputs	Estimate	StdError	t-stat	p-value	ME at Avg of ME	ME StdError	ME t-stat	ME p-value
Intercept	-1.076	0.255	-4.22	0.000 ***				
Weak Social Tie - Receipt of Project Funds Prior to Phase II from Venture Capital, Other Private Company, or Private Investor (yes/no)	0.528	0.198	2.67	0.008 ***	0.180	0.068	2.64	0.008 ***
Weak Social Tie - Marketing/Distribution Agreements in Place (yes/no)	0.256	0.177	1.45	0.148	0.085	0.060	1.42	0.155
Weak Social Tie - Research/Development Agreements in Place (yes/no)	1.050	0.208	5.04	0.000 ***	0.375	0.069	5.40	0.000 ***
Physical Capital - Percentage of Firm Growth Due to SBIR – < 25%								
Physical Capital - Percentage of Firm Growth Due to SBIR – 25%-50%	0.281	0.225	1.25	0.211	0.093	0.075	1.24	0.215
Physical Capital - Percentage of Firm Growth Due to SBIR – 51%-75%	0.759	0.248	3.06	0.002 ***	0.259	0.083	3.14	0.002 ***
Physical Capital - Percentage of Firm Growth Due to SBIR – > 75%	0.128	0.234	0.54	0.586	0.041	0.076	0.54	0.587
Human Capital – Log Number of Employees when Phase II Proposed	0.062	0.068	0.92	0.358	0.020	0.022	0.92	0.356
Firm was Established for SBIR Awards (yes/no)	1.018	0.364	2.80	0.005 ***	0.344	0.112	3.08	0.002 ***

McFadden's Pseudo R^2 = 0.139, Likelihood Ratio = 58.28	significance levels: * = < 0.10, ** = < 0.05, *** = < 0.01

The results suggest that under the assumption of error independence among the three output functions, social capital does indeed significantly impact innovation output. While not all of the social capital coefficients and their associated marginal effects are significant, there appears to be certain measures of strong and weak social ties that increase the probability of the firm receiving additional developmental funding, commercialization new innovations, and executing a growth strategy.

For example, the measures of strong social ties that reflect the collaborative environment of the firm through patentable research and the culture of innovation that the firm's founders bring through the establishment of other innovative firms are positively related to the firm receiving additional developmental funding for the project. Additionally, the weak social tie measure of entering into marketing and distribution agreements with third parties is positive and significant as well. The margin effect suggests that the probability of commercialization increases by 0.40 when there is a marketing agreement in place relative to no marketing agreement. This strong relationship has to be considered in light of the nature of the survey data, however. Since there is not a time dimension to the data, it is possible that marketing agreements may be negotiated as the firm is close to commercializing the project, so it would be inaccurate to conclude that there is some causal effect happening, Also noteworthy is that the weak social tie of receipt of funds by a private investor is not statistically significant,, which does not support the hypothesis discussed in Chapter V of financial capital working indirectly to commercialize the technology.

While not significant in Equation [4], Table 27 does show that financial capital may work indirectly to produce a growth-related activity. The marginal effect on the weak social tie of receipt of project funds prior to Phase II from a venture capitalist or other private company or investor increases the probability of executing a growth-related activity by 0.18. Further, firms

that enter into research agreements with third parties increase the probability of a growth-related activity by 0.38. Since the weak social tie measures are binary variables, the marginal effect represents the difference in probabilities when the value of each independent binary variable is 1 and when it is 0. Taken together, the results indicate a strong relationship between weak social ties and the achievement of a firm IPO, spin-off, firm sale or merger, a joint venture, or a licensing agreement.

Notwithstanding the statistical significance of many of the social capital measures in producing innovation output, it is reasonable to assume that there may be unobservable factors that drive multiple innovation outputs that are not directly measured. These factors are theoretically captured in the error term within each model, so a presumption of strict independence of each innovation output functions may not be appropriate. Therefore, a model that is able to incorporate the potential correlation among error terms is necessary to properly estimate parameters. The model framework must also accommodate different vectors of independent variables based on the theoretical motivation of differing strong and weak social ties associated with each innovation output. The ability to incorporate a separate set of independent variables for each output is critical to accurately specify the model.

The Model

Considering these requirements, a system of equations model where coefficient estimates on vectors of independent variables corresponding to different outcomes that can be estimated jointly is the approached taken in this dissertation. Greene (2003, p. 710) and Wooldridge (2010, p. 595) describe the use of a multivariate probit model in cases like this to allow for correlated error terms in the estimation of multiple equations with discrete choice outcomes. The multivariate probit is an extension of the probit model to incorporate a joint probability density

and allow for error correlation. While the multivariate probit considers correlation in the errors of the system of equations, it also assumes a zero mean of the error term and variance of one for each equation, conditional on the vectors of independent variables for all equations. It follows then that if error correlation equals zero, the system of equations simply consists of independent probit equations. Estimation of a multivariate probit through maximum likelihood results in the same number of estimates as estimating the parameters as separate equations. Through the estimation process, an error correlation value is also estimated and can be tested under the null hypothesis of the error correlation equal to zero.

For simplicity, the multivariate probit model of the probability of all three innovation outputs being produced is shown in Equation [6]. There are potentially eight combinations of innovation outputs associated with the joint probability, but just one of the eight equations (where all y_j =1) is depicted in the equation for discussion purposes following the notation in Greene (2003).

[6] $P\ (y_1=1, y_2=1, y_3=1) = P(\varepsilon_1 < \beta_1'X_1, \varepsilon_2 < \beta_2'X_2, \varepsilon_3 < \beta_3'X_3) = \Phi_3(\beta_1'X_1, \beta_2'X_2, \beta_3'X_3, \rho)$

Each of the y_j dependent variables in equation [6] is an indicator of innovation output as noted in Table 4 in this dissertation. The first output, which is a "yes" or "no" value, indicates the receipt (or not) of additional developmental funding of the Phase II SBIR funded project. The second output is a generated indicator ("yes" / "no") of whether the firm commercialized the SBIR funded project. The third output is a generated indicator ("yes" / "no") of whether the firm experienced a growth-related activity, such as executing an IPO, creating a firm spin-off, realizing a firm sale or merger, or entering into a joint venture or licensing agreement.

The vector of independent variables varies by each y_j. All three X_j (for j=1,2,3) vectors use the same physical capital and human capital independent variables as well as an indicator that

identifies whether a firm is considered nascent. However, the independent social capital variables are not the same.

With respect to the first output of receiving additional developmental funding, strong social ties are expected to be related to the receipt of additional developmental funding. The vector X_1 funding includes the strong social ties that are measures of an imbued culture of innovation propagated by the firm's founders with experience in starting new companies. Also included is a measure of employee interactions resulting in cutting edge research worthy of publication or patents. The other strong social tie measure is most closely associated with the social capital derived from collaboration on innovations and a shared interest in furthering the goals of the firm, including winning early-stage funding.

The vector X_2 includes the measurement of weak social ties, which are expected to be related to the commercialization of the innovation. Weak social ties are those relationships that are formed with third parties outside the firm that bring new ideas, encourage the sharing of information, and that build trust, such as those relationships developed with venture capitalists and engagements with strategic partners. The weak social ties measures include the private funding relationships cultivated to develop the Phase II project associated with the survey and the two measures of engagement with other firms and investors to research and market the SBIR funding Phase II technology. Additionally, it is theorized that the financial capital acquired through weak social tie relationships with private investors will have an indirect impact on innovation output of commercialization.

Lastly, it is theorized that the execution of a firm growth-related activity is driven in part by the connections with third parties to establish strategic agreements and to obtain guidance from experienced investors. These weak social ties build credibility and set expectations of reciprocity that put the firm on a path to continue the innovation trajectory and establish a

platform from which to leverage the firm's core competencies in innovation into future products and firm longevity. Therefore, vector X_3 includes weak social tie measures to incorporate these engagements.

Model Results

Table 28 shows the results from the multivariate probit model and the correlations (rho or ρ) between all pairs of equations. For each output, estimates, standard errors, t-statistics, and p-values are provided. The marginal effects of the independent variable and their associated standard errors, t-statistics, and p-values are presented in Table 29.

Additionally, the bottom of Table 28 displays the estimates of the correlation of the error terms between two of the models (three pairs all together). When the p-values of individual t-statistics of the correlation estimate are less than 0.10%, it would imply that the correlations are significantly different than zero. The test results indicate a correlation between the outputs of the firm receiving additional developmental funding and commercialization of the project and the outputs of commercialization and the execution of firm growth-related activity as both are statistically significant and lead to a rejection of the null hypothesis of $\rho = 0$.

Table 28. Multivariate Probit Results from Equation 6
(n = 315)

Inputs	Estimate	StdError	t-stat	p-value	
Output - Firm Received Additional Developmental Funding for the Funded Project					
Intercept	0.263	0.273	0.97	0.334	
Strong Social Tie - Number of Phase II SBIR Awards Received	-0.010	0.010	-1.00	0.316	
Strong Social Tie - Number of Scientific Publications Submitted	0.027	0.025	1.09	0.277	
Strong Social Tie - Number of Patent Applications Submitted	0.164	0.066	2.49	0.013	**
Strong Social Tie - Number of Firms Founded by the Firm's Founders	0.118	0.069	1.70	0.090	*
Physical Capital - Percentage of Firm Growth Due to SBIR – < 25%	0.000				
Physical Capital - Percentage of Firm Growth Due to SBIR – < 25%	0.073	0.252	0.29	0.772	
Physical Capital - Percentage of Firm Growth Due to SBIR – 25%-50%	0.183	0.293	0.63	0.532	
Physical Capital - Percentage of Firm Growth Due to SBIR – 51%-75%	-0.117	0.246	-0.48	0.633	
Physical Capital - Percentage of Firm Growth Due to SBIR – > 75%	-0.014	0.075	-0.19	0.848	
Human Capital – Log Number of Employees when Phase II Proposed	-0.092	0.343	-0.27	0.789	
Firm was Established for SBIR Awards (yes/no)	-0.010	0.010	-1.00	0.316	
Output - Firm Reported Commercialization of Product, Process or Service Sales					
Intercept	-0.226	0.256	-0.88	0.38	
Weak Social Tie - Receipt of Project Funds Prior to Phase II from Venture Capital, Other Private Company, or Private Investor (yes/no)	-0.116	0.214	-0.54	0.59	
Weak Social Tie - Marketing/Distribution Agreements in Place (yes/no)	1.476	0.302	4.88	0.00	***
Weak Social Tie - Research/Development Agreements in Place (yes/no)	0.194	0.229	0.85	0.40	
Physical Capital - Percentage of Firm Growth Due to SBIR – < 25%	0.000	.	.	.	
Physical Capital - Percentage of Firm Growth Due to SBIR – 25%-50%	0.558	0.248	2.25	0.02	**
Physical Capital - Percentage of Firm Growth Due to SBIR – 51%-75%	0.185	0.256	0.72	0.47	
Physical Capital - Percentage of Firm Growth Due to SBIR – > 75%	0.283	0.247	1.15	0.25	
Human Capital – Log Number of Employees when Phase II Proposed	0.043	0.071	0.61	0.54	
Firm was Established for SBIR Awards (yes/no)	0.255	0.402	0.64	0.53	
Output - Firm Experienced Growth-Related Activity, such as an IPO, a Spin-off Firm, Sale, Merger, Joint Venture, or Licensing Agreement					
Intercept	-1.069	0.270	-3.96	0.00	***
Weak Social Tie - Receipt of Project Funds Prior to Phase II from Venture Capital, Other Private Company, or Private Investor (yes/no)	0.536	0.213	2.52	0.01	**
Weak Social Tie - Marketing/Distribution Agreements in Place (yes/no)	0.296	0.185	1.60	0.11	

Weak Social Tie - Research/Development Agreements in Place (yes/no)	1.093	0.224	4.88	0.00	***
Physical Capital - Percentage of Firm Growth Due to SBIR – < 25%	0.000	.	.	.	
Physical Capital - Percentage of Firm Growth Due to SBIR – 25%-50%	0.268	0.229	1.17	0.24	
Physical Capital - Percentage of Firm Growth Due to SBIR – 51%-75%	0.751	0.261	2.87	0.00	***
Physical Capital - Percentage of Firm Growth Due to SBIR – > 75%	0.098	0.255	0.38	0.70	
Human Capital – Log Number of Employees when Phase II Proposed	0.059	0.072	0.82	0.41	
Firm was Established for SBIR Awards (yes/no)	1.028	0.405	2.54	0.01	**

Correlations

Rho: Additional Funding & Commercialization	0.191	0.113	1.68	0.09	*
Rho: Additional Funding & Firm Growth-Related Activity	-0.148	0.118	-1.26	0.21	
Rho: Commercialization & Firm Growth-Related Activity	0.290	0.109	2.66	0.01	***

significance levels: * = < 0.10, ** = < 0.05, *** = < 0.01

Table 29. Marginal Effects from Multivariate Probit

`Inputs	ME	StdError	t-stat	p-value	
Marginal Effect of $E[I_A = 1 \mid I_B = 1, I_C = 1, X]$ and Computed at the Mean of all Right-Hand Side Variables $Pr(I_A = 1 \mid I_B = 1, I_C = 1) = 0.721$					
Strong Social Tie - Number of Phase II SBIR Awards Received	-0.004	0.057	-0.06	0.951	
Strong Social Tie - Number of Scientific Publications Submitted	0.009	0.056	0.17	0.866	
Strong Social Tie - Number of Patent Applications Submitted	0.056	0.082	0.69	0.491	
Strong Social Tie - Number of Firms Founded by the Firm's Founders	0.040	0.074	0.55	0.585	
Physical Capital - Percentage of Firm Growth Due to SBIR – < 25%					
Physical Capital - Percentage of Firm Growth Due to SBIR – 25%-50%	-0.029	0.307	-0.10	0.924	
Physical Capital - Percentage of Firm Growth Due to SBIR – 51%-75%	0.516	0.348	1.48	0.138	
Physical Capital - Percentage of Firm Growth Due to SBIR – > 75%	-0.095	0.274	-0.35	0.730	
Human Capital – Log Number of Employees when Phase II Proposed	0.018	0.211	0.09	0.932	
Firm was Established for SBIR Awards (yes/no)	0.587	0.468	1.25	0.210	
Marginal Effect of $E[I_B = 1 \mid I_A = 1, I_C = 1, X]$ and Computed at the Mean of all Right-Hand Side Variables $Pr(I_B = 1 \mid I_A = 1, I_C = 1) = 0.688$					
Weak Social Tie - Receipt of Project Funds Prior to Phase II from Venture Capital, Other Private Company, or Private Investor (yes/no)	0.338	0.178	1.90	0.058	*
Weak Social Tie - Marketing/Distribution Agreements in Place (yes/no)	0.528	0.207	2.55	0.011	**
Weak Social Tie - Research/Development Agreements in Place (yes/no)	0.784	0.400	1.96	0.050	**
Physical Capital - Percentage of Firm Growth Due to SBIR – < 25%					
Physical Capital - Percentage of Firm Growth Due to SBIR – 25%-50%	0.314	0.353	0.89	0.374	
Physical Capital - Percentage of Firm Growth Due to SBIR – 51%-75%	0.571	0.279	2.05	0.040	**
Physical Capital - Percentage of Firm Growth Due to SBIR – > 75%	0.116	0.184	0.63	0.529	
Human Capital – Log Number of Employees when Phase II Proposed	0.048	0.227	0.21	0.833	
Firm was Established for SBIR Awards (yes/no)	0.744	0.349	2.13	0.033	**
Marginal Effect of $E[I_C = 1 \mid I_A = 1, I_B = 1, X]$ and Computed at the Mean of all Right-Hand Side Variables $Pr(I_C = 1 \mid I_A = 1, I_B = 1) = 0.395$					
Weak Social Tie - Receipt of Project Funds Prior to Phase II from Venture Capital, Other Private Company, or Private Investor (yes/no)	0.214	0.076	2.81	0.005	***
Weak Social Tie - Marketing/Distribution Agreements in Place (yes/no)	0.042	0.043	0.97	0.330	
Weak Social Tie - Research/Development Agreements in Place (yes/no)	0.415	0.155	2.67	0.008	***
Physical Capital - Percentage of Firm Growth Due to SBIR – < 25%					
Physical Capital - Percentage of Firm Growth Due to SBIR – 25%-50%	0.079	0.109	0.72	0.469	

Physical Capital - Percentage of Firm Growth Due to SBIR – 51%-75%	0.290	0.114	2.55	0.011	**
Physical Capital - Percentage of Firm Growth Due to SBIR – > 75%	0.019	0.125	0.16	0.876	
Human Capital – Log Number of Employees when Phase II Proposed	0.020	0.065	0.31	0.755	
Firm was Established for SBIR Awards (yes/no)	0.384	0.108	3.56	0.000	***

significance levels: * = < 0.10, ** = < 0.05, *** = < 0.01

Discussion of Results

In broad perspective, the results of the model suggest that certain measures of social capital are statistically significant inputs into the production of innovation outputs of obtaining additional developmental funding, commercializing an innovation, and executing a growth-related activity stemming from an innovation. The results from the multivariate probit mirror fairly closely the results from the individual probits even though the correlation tests indicate there may be some noise in the error terms that is driving more than one of the innovation outputs.

Specifically, the correlation section at the bottom of Table 28 shows a positive and significant correlation between the error terms associated with the outputs of additional developmental funding and commercialization and the outputs of commercialization and a firm growth-related activity. A low p-value in the correlation section indicates the probability of rejecting the null hypothesis of zero correlation when it is true is low. These positive error correlations are consistent with the hypothesis that the unobserved factors that are driving additional developmental funding may also be driving commercialization. Likewise, the results imply that unobserved factors that are driving commercialization may be driving the firm's growth-related activities. While the errors in the additional developmental funding and the growth-related activity equations are not significantly correlated, the other significant error correlations suggest the use of the multivariate probit is appropriate.

In terms of interpreting the results and beginning with the innovation output of receiving additional developmental funding, strong social ties as measured by the collaborative activity of the firm in the development of patentable technologies and the innovative environment that is cultivated by founders who have experience in start-up firms are correlated with the acquisition of R&D funding. The results also indicate that the weak social ties developed through the establishment of marketing and distribution agreements with third parties are statistically significant in the innovation output of commercialization Additionally, the weak social ties built through financial arrangements with private investors, such as venture capitalists, as well as the relationships with external research partners (and the associated information sharing and common goal setting) have a positive and significant relationship to whether the firm achieves important growth-related milestones, such as an IPO, spin-off, firm merger or sale, a joint venture, or licensing agreement.

Tempering these results is the possibility that there could be other forces a play in the realization of innovation output other than the capital inputs theorized in this dissertation. For example, the very strong correlation between the measure of weak social ties (the existence of marketing agreements) and commercializing the project could be due to timing. A firm that believes it is close to commercializing a new technology may have engaged with their third-party partner towards the end of the development process, so a marketing agreement may just be a natural progression of the commercialization process instead of a driver. While this scenario is quite plausible, relationship building with trustworthy partners is not something that is created over time. Even if an agreement is signed immediately before sales occur, there is very likely some level of idea sharing and collaboration that is inherent in such an arrangement, so the strong statistical results are consistent with the theory of the importance of weak social ties in producing innovation output.

Regarding the impact of weak social ties on firm growth-related activities, there is a legitimate argument that the statistically significant measures of the receipt of funding from private investors and the creation of R&D agreements coincide with certain firm growth activities instead of driving them. The potential list of growth-related activities as spelled out by the NIH is quite broad. As such, for firms receiving Phase II SBIR funding, there could be an existing group of external parties that are shepherding the firm through the R&D process in anticipation of a executing a variety of options to monetize their investment versus these relationships just providing support though the innovation process. However, similar to the prior counterargument, significant firm events, such and IPO or spin-off, do not just occur suddenly. There are multiple relationships developed centered around trust building that a firm must cultivate to realize important milestones. The weak social ties that are created through these strategic financial and R&D arrangements are critical for that level of success.

In terms of the other forms of capital inputs, there also appears to be a relationship between higher levels of physical capital measure and the commercialization of the innovation and executing a growth-related activity. The measurement of physical capital in the NRC survey is the degree of growth in the firm resulting from the SBIR program, which is a less than ideal measure but one that inherently captures the extent of the physical resources available to produce innovations. Since the physical capital measure is an ordered categorical variable, the model uses "< 25%" as the base value from which to interpret the other coefficients. By evaluating estimates relative to the base value, statistically significant values of the estimated coefficients at each value above the base imply that as firms realize growth from the SBIR program, the probability of sales from product commercialization or a growth-related activity increases.

Regarding the measure of human capital, which is the log of the number of employees when the Phase II proposal was submitted, there does not appear to be any significant relationship

(positive or negative) between this measure and any of the innovation outputs. Lastly, there is a positive and significant relationship between firm's that were established for the purpose of SBIR and the execution of growth-related activities.

While the estimates of the multivariate probit show a latent propensity of the independent variables to increase the probability of an innovation output, the marginal effect of an independent variable provides the expected change in the probability of an innovation output relative to change in the variable and conditioned on the other independent variables. As noted earlier in this chapter, in a three-equation multivariate probit, there are eight possible combinations of outputs in the joint probability. To interpret the marginal effects of the independent variables associated with one of the innovation outputs, an assumption must be made regarding the expectation of the other innovation outputs as well as the average values of the other independent variables. It can get unwieldly to evaluate every possible combination, so Table 29 presents marginal effects conditioned on the expectation that the other two innovation outputs equal one. The reason this combination is selected is that generally interest is in the expectation of the innovation output occurring.

Under this scenario, the marginal effects provide an interesting result. For example, while the coefficient estimates in the innovation output of additional developmental funding indicate certain measures of strong social ties are statistically significant, the marginal effects of those same independent variables are not statistically significant assuming the other two innovation outputs are expected to be achieved. However, since the marginal effects are conditioned on the expectation of the other innovation outputs and an assumption of the value of the other independent variables, the interpretation is limited to the scope of the conditions and may not provide a complete view of the potential impact of the independent variables. One possible interpretation for this result is changes in the strong social ties in the additional

developmental funding equation do not significantly increase the probability of the output assuming a positive result of the other innovation outputs, but they may be significantly correlated to additional development funding without the assumption of the occurrence of the other innovation outputs.

For the innovation outputs of commercializing a technology and the firm experiencing a growth-related activity, the statistical significance of the marginal effects associated with the weak social ties measures more closely resemble the statistical significance of the estimated coefficients. For example, the marginal effect of the firm's relationships cultivated with marketing partners is statistically significant in commercializing the technology and the coefficient estimate is also statistically significant. In this example, the existence of a marketing agreement increases the probability of commercialization by 0.53, conditioned on the other innovation outputs equal to one and evaluated at the mean of the all the right-hand side variables. In the innovation output of a firm growth-related activity, both the coefficient estimate and the marginal effect associated with the weak social tie measure of a firm's relationships with private investors are positive and statistically significant. The marginal effect indicates that a firm that received project funds from a private company, such as a venture capitalist, increases the probability of a firm growth-related activity by 0.21, conditional on the other innovation outputs equal to one. With respect to firm-related characteristics, for a nascent firm, the marginal effect indicates that probability of commercializing the technology and realizing a growth activity increases by 0.74 and 0.38 , respectively, and each is statistically significant.[49]

[49] As mentioned earlier in this chapter, the variable of firm age was considered for a control variable. While not used, for completeness, the models were run including the age of the firm, but it was not significant in any of the three innovation output equations, and the overall results did not materially change.

Robustness Check

While the results suggest the existence of a relationship between social capital and innovation output, there are potentially other interpretations and limitations of the results, which may be partially addressed in a robustness check of the model. Most significantly, there are several social capital variables that may be endogenous to the model. For example, in the equation for the innovation output of additional developmental funding, the strong social tie measures of scientific publications submitted for approval and patent applications submitted are related only the project subject to the survey. Since there is not a time dimension in the data to discern the sequence of events, it is not unreasonable to posit that scientific publications and patents may occur as a result of receiving additional developmental funding instead of those social capital measures driving additional funding. Similarly, in the innovation output equations of commercializing the technology and the firm realizing a growth-related activity, the weak social tie measures of firm marketing and research agreements may actually occur at the time or after realizing of the innovation output. The potential endogeneity of these social capital measures presents a limitation in the empirical analysis as it may not be clear which variables are truly independent.

To partially address these concerns, a robustness check is performed where the social tie variables are limited to those that have occurred before the project subject to the survey. By limiting the social capital variables in this manner, the argument of endogeneity is attenuated as this reduced variable model effectively creates a time dimension with respect to the observation of the social tie measures and the subsequent occurrence of the innovation outputs. However, this robustness test does resolve the endogeneity issue as it merely reduces the number of variables to focus on exogenous variables.

Appendix C includes a table with the results from a multivariate probit using only two of the strong social tie variables—the number of prior Phase II awards received, and the number of firms started by the firm's founders—in the equation for the innovation output of additional developmental funding. Similarly, only one of the weak social tie variables—receipt of funds from private firms prior to the Phase II award—is included in the innovation output equations of commercializing the technology and a firm growth-related activity. Since all three of the social tie measures are associated with activities prior to the Phase II funding, it is assumed that there is some passage of time between the activity and the innovation output.

The results from this reduced variable model are encouraging as coefficient estimates on social capital measures in two of the three equations are positive and significant. The strong social tie of the number of firms started by the firm's founders, which is a measure of the firm's collaborative culture infused into the firm by its founders, increases the probability of the firm receiving additional developmental funds. Similarly, the weak social tie measure of the receipt of funds from a private investor, which provides a platform to develop relationships with third parties that share information and to work towards common goals, increases the probability of a firm experiencing a growth-related activity. However, this weak social tie measure is not significant in the innovation output of commercialization, which is a similar result to the model when all the social capital variables were included. It should also be noted the coefficient estimates on the physical capital and firm characteristic variables that are statistically significant in the model with all the social capital variables are also significant in the robustness check.

While not conclusive, the robustness check provides some additional support for the use of social capital variables in the production of innovation output. When the potentially endogenous social capital regressors are removed from the model, the selected exogenous social

capital measures and the other covariates substantially retain the extent of their explanatory power.

Alternative Interpretations and Limitations

Notwithstanding these results, there remain limitations on the interpretability of the empirical analysis. First, as noted above, the potential endogeneity of several of the social capital measures can be interpreted as the model is missing other social capital measures or measurement error with respect to the existing social capital variables. This is not an unreasonable interpretation, and it has been discussed in this dissertation that measurement of social capital is a significant research challenge. Future research on this topic should consider enhanced social capital measures.

Second, it can be interpreted that the innovation outputs that have been presented in this dissertation are limited in the context of innovation production. Innovation is a process and there are many types of outputs that are important within that process, so the selection of these three outputs may not fully represent the breadth of innovation. Also, the three innovation outputs of additional developmental funding, commercialization, and a firm growth-related activity tested in the empirical analysis seem to follow a sequence. As discussed throughout this dissertation, the three outputs are intended to measure significant milestones, but it is not a necessary condition that one output must precede another. Regardless, the absence of a time dimension in the NRC survey data limits the ability to consider the potential sequence of innovation outputs for an innovating firm in this empirical analysis.

Lastly, the theoretical model includes physical capital, human capital, social capital, and financial capital as inputs into innovation output. This dissertation focuses primarily on the social capital dimension to the model, but it can be interpreted that the empirical analysis lacks adequate

measures of the other forms of capital inputs. Further, the endogeneity concern addressed above with respect to the social capital variables can be extended to the other forms of capital in the form of omitted variable bias. The primary limitation is the availability of other capital measures in the NRC survey, and any extension of this research should address this shortcoming.

CHAPTER X

CONCLUSION AND IMPLICATIONS

It is argued that social capital is a form of productive capital in the development of innovation output. A theoretical model has been proposed to suggest the role social capital can play in three innovation outputs: obtaining additional developmental funding for the innovation, realizing sales from the innovation, and executing a growth-related activity, such as an IPO or spin-off, as a result of a technology developed with an SBIR award.

While the empirical results presented in the previous chapter, and summarized again below, do support the premises set forth in this dissertation, this dissertation should still be viewed as an exploratory exercise intended to suggest a path forward from which to evaluate the impact of social capital that is cultivated in innovative firms. It is estimated this effort, albeit exploratory, is the first attempt to systematically set forth a path for future inquiries on the relationship between firm social capital and the innovation process.

Social capital is difficult to directly quantify, but an attempt has been completed to develop measures with data obtained from innovative firms that encapsulate the structural and content dimensions of social capital. The empirical analysis suggests that strong social ties may be correlated with late-stage funding and weak social ties are correlated with selling a new innovation in the marketplace and executing firm growth strategies. The modeling approach taken to estimate the coefficients on the vector of explanatory variables is a multivariate probit, which is useful to consider in light of the potential correlation of unobserved variables captured in each equations error term.

The implications of the analysis are noteworthy. First, conceptualizing and developing a theoretical economic model of innovation output and the associated social capital and other capital inputs provides a foundational analysis to begin to review other innovation outputs. Second, quantifying values for social capital, and particularly those targeting the extent of internal collaboration, are useful in establishing standards in the measurement of intangible capital in economic analyses. Third, social capital is often deemed irrelevant in economic studies due to the measurement issues and varying definitions. This paper empirically demonstrates using data from firms that are in the process of creating new innovations that social capital is productive and does represent an intangible, yet important component of a firm's overall capital structure.

Whether firms think about social capital in economic terms or not, many firms are beginning to recognize the importance of social interaction and collaboration in the workplace. In an increasingly competitive and information-driven business climate, the "innovate or die" motto has never been as resounding. There are numerous recent examples of firms that have begun to shun remote work arrangements in favor of face-to-face office time. The vision on this trend is clear: firms that do not innovate will become irrelevant, and innovation does not happen individually. If firms want to increase profits by creating new products and services, they must find ways to create a culture that builds trust and reciprocity among its employees and strives for constant innovation. In short, the firms that will be the most innovative will have successfully cultivated social capital.

REFERENCES

Acs, Z. J., Braunerhjelm, P., Audretsch, D. B., & Carlsson, B. (2009). The knowledge spillover theory of entrepreneurship. *Small Business Economics,* 32, 15-30. http://dx.doi.org/10.1007/s11187-008-9157-3

Aghion, P., Akcigit, U., Hyytinen, A., & Toivanen, O. (2017). *The Social Origins of Inventors* (No. w24110). National Bureau of Economic Research.

Åstebro, T. (2003). The return to independent invention: evidence of unrealistic optimism, risk seeking or skewness loving?. *The Economic Journal*, 113(484), 226-239.

Audretsch, D. B., & Lehmann, E. (2005). The effects of experience, ownership, and knowledge on IPO survival: Empirical evidence from Germany. *Review of Accounting and Finance,* 4, 13-33. http://dx.doi.org/10.1108/eb043435

Baptista, R., Karaöz, M., & Mendonça, J. (2014). The impact of human capital on the early success of necessity versus opportunity-based entrepreneurs. *Small Business Economics*, 42(4), 831-847.

Becker, G. S. (1964). *Human capital: A theoretical and empirical analysis, with special reference to education.* New York, NY: Columbia University Press for the National Bureau of Economic Research New York.

Becker, G. S. (1993). *Human capital: A theoretical and empirical analysis, with special reference to education (3rd Edition).* The University of Chicago Press.

Bell, A., Chetty, R., Jaravel, X., Petkova, N., & Van Reenen, J. (2018). Who becomes an inventor in America? The importance of exposure to innovation. *The Quarterly Journal of Economics*, 134(2), 647-713.

Bilton, N. (2016, September 6). Exclusive: How Elizabeth Holmes's House of Cards Came Tumbling Down. Retrieved September 9, 2016 from http://www.vanityfair.com/news/2016/09/elizabeth-holmes-theranos-exclusive.

Bonardo, D., Paleari, S., & Vismara, S. (2011). Valuing university-based firms: The effects of academic affiliation on IPO performance. *Enterprise Theory and Practice*, 35, 755-776. http://dx.doi.org/10.1111/j.1540-6520.2010.00369.x

Bourdieu, P. (1977). *Outline of a theory of practice*. Cambridge, U.K: Cambridge University Press.

Burt, R. S. (2005). Brokerage and Closure : An Introduction to Social Capital. Oxford, GBR: Oxford University Press, UK. Retrieved from http://www.ebrary.com.

Cameron, A. C., & Trivedi, P. K. (2005). Microeconometrics: Methods and Applications. Cambridge University Press.

Carayannis, E. G., Alexander, J., & Ioannidis, A. (2000). Leveraging knowledge, learning, and innovation in forming strategic government–university–industry (GUI) R&D partnerships in the US, Germany, and France. *Technovation*, 20(9), 477-488.

Carreyrou, J. (2015, October 16). Hot Startup Theranos Has Struggled With Its Blood-Test Technology. Retrieved September 9, 2016 from http://www.wsj.com/articles/theranos-has-struggled-with-blood-tests-1444881901.

Chatzkel, J. L. (2002). *Intellectual Capital*. Oxford, U.K: Capstone Pub.

Chou, Y. K. (2006). Three simple models of social capital and economic growth. *The Journal of Socio-Economics*, 35(5), 889-912.

Claridge, T., (2004). Social Capital and Natural Resource Management: An important role for social capital? *Unpublished Thesis, University of Queensland, Brisbane, Australia*.

Coleman, J. S.. (1988). Social Capital in the Creation of Human Capital. *American Journal of Sociology*, *94*, S95–S120. Retrieved from http://www.jstor.org/stable/2780243.

Cooke, P., & Wills, D. (1999). Small firms, social capital and the enhancement of business performance through innovation programmes. *Small Business Economics*, 13, 3, 219-234.

Cragg, J. G. (1971). Some statistical models for limited dependent variables with application to the demand for durable goods. *Econometrica: Journal of the Econometric Society*, 829-844.

crowdfunding.com (2018). *Infographic: History of Crowdfunding*. Retrieved on October 19, 2018 from https://blog.crowdfunder.com/infographics/the-history-of-crowdfunding/.

Crowdnetic (2015, September 23). *Crowdnetic's Quarterly Private Companies Publicly Raising Data Analysis, Title II Turns Two*. Retrieved on November 4, 2015 from http://www.crowdnetic.com/reports/sep-2015-report.

D'Este, P., Rentocchini, F., & Vega-Jurado, J. (2014). The role of human capital in lowering the barriers to engaging in innovation: Evidence from the Spanish Innovation Survey. *Industry and Innovation*, 21, 1-19. http://dx.doi.org/10.1080/13662716.2014.879252

Dolan, B. (2013, August 13). Fitbit raises $43 million from three new investors. Retrieved on December 14, 2016 from http://www.mobihealthnews.com/24667/fitbit-raises-43-million-from-three-new-investors/.

Farag, H., Mallin, C., & Ow-Yong, K. (2014). Governance, ownership structure, and performance of entrepreneurial IPOs in AIM companies. *Corporate Governance: An International Review*, 22, 100-115. http://dx.doi.org/10.1111/corg.12049

Feld, B. (2010, September 28). Foundry Group Invests in Fitbit. Retrieved on December 14, 2015 from http://www.foundrygroup.com/blog/2010/09/foundry-group-invests-in-fitbit/.

Fitbit (2013, August 13). Fitbit Raises $43M in Series D Funding. Retrieved on December 14, 2016 from https://investor.fitbit.com/press/press-releases/press-release-details/2013/Fitbit-Raises-43M-in-Series-D-Funding/default.aspx.

Fitbit (2015, May 7). Form S-1 Registration Statement. Retrieved on December 14, 2016 from https://www.sec.gov/Archives/edgar/data/1447599/000119312515176980/d875679ds1.htm#rom875679_30.

Fitbit (2016). Who We Are. Retrieved on December 15, 2016 from https://www.fitbit.com/about.

Fountain, J. E. (1998). Social capital: Its relationship to innovation in science and technology. *Science and Public Policy*, 25(2).

Fukuyama, F. (1995). Social Capital and the Global Economy. *Foreign Affairs*, 74(5), 89-103.

Gallié, E.-P., & Legros, D. (2012). Firms' human capital, R&D and innovation: A study on French firms. *Empirical Economics*, 43, 581-596. http://dx.doi.org/10.1007/s00181-011-0506-8

Gicheva, D., & Link, A. N. (2016). On the economic performance of nascent entrepreneurs. *European Economic Review*, 86, 109-117.

Gimmon, E., & Levie, J. (2010). Founder's human capital, external investment, and the survival of new high-technology ventures. *Research Policy*, 39, 1214-26. http://dx.doi.org/10.1016/j.respol.2010.05.017

Giménez, G., López-Pueyo, C., & Sanaú, J. (2015). Human capital measurement in OECD countries and its relation to GDP growth and innovation. *Revista de Economía Mundial*, 39, 77-107. Retrieved from https://login.libproxy.uncg.edu/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=bth&AN=103213840&site=ehost-live

Gompers, P., Kovner, A., Lerner, J., & Scharfstein, D. (2008). Venture capital investment cycles: The impact of public markets. *Journal of Financial Economics*, *87*(1), 1-23.

Granovetter, M. S. (1973). The Strength of Weak Ties. American Journal of Sociology, 78(6), 1360–1380. Retrieved from http://www.jstor.org/stable/2776392

Greene, W. H. (2003). Econometric Analysis (5th). Ed.. *Upper Saddle River, NJ.*

Grilli, L., & Murtinu, S. (2015, March 31). Selective subsidies, entrepreneurial founders' human capital, and access to R&D alliances (Working Paper). http://dx.doi.org/10.2139/ssrn.2592408

Grossman, M. (1972). On the concept of health capital and the demand for health. *Journal of Political Economy*, *80*(2), 223-255.

Gulati, R., & Higgins, M. C. (2003). Which ties matter when? The contingent effects of interorganizational partnerships on IPO success. *Strategic Management Journal*, 24, 2, 127-144.

Halpern, D. (2005). *Social Capital*. Cambridge, U.K: Polity Press.

Hanifan, L. J. (1916). The rural school community center. *Annals of the American Academy of political and social science*, *67*, 130-138.

Herper, M. (2016, June 1). From $4.5 Billion To Nothing: Forbes Revises Estimated Net Worth Of Theranos Founder Elizabeth Holmes. Retrieved from http://www.forbes.com/sites/matthewherper/2016/06/01/from-4-5-billion-to-nothing-forbes-revises-estimated-net-worth-of-theranos-founder-elizabeth-holmes/#5981e60f2f29.

Hofmann, I. (2007, August). Innovative Healthcare systems on their way to the market: How to cope with commercialization barriers. In *Engineering in Medicine and Biology Society, 2007. EMBS 2007. 29th Annual International Conference of the IEEE* (pp. 5160-5161). IEEE.

Hsu, D. H. (2004). What do entrepreneurs pay for venture capital affiliation?. *The Journal of Finance*, 59(4), 1805-1844.

Hsu, D. H. (2007). Experienced entrepreneurial founders, organizational capital, and venture capital funding. *Research Policy*, 36, 5, 722.

Hsu, D. K., Haynie, J. M., Simmons, S. A., & McKelvie, A. (2014). What matters, matters differently: A conjoint analysis of the decisions of angel and venture capital investors. *Venture Capital*, 16, 1-25. http://dx.doi.org/10.1080/13691066.2013.825527

Jonsson, S., & Lindbergh, J. (2013). The Development of Social Capital and Financing of Entrepreneurial Firms: From Financial Bootstrapping to Bank Funding. *Entrepreneurship Theory and Practice*, 37, 4, 661-686.

Jones, A. M. (1989). A double-hurdle model of cigarette consumption. *Journal of Applied Econometrics*, 4(1), 23-39.

Kaplan, S. N., Sensoy, B. A., & Stromberg, P. (2005). What are firms? Evolution from birth to public companies (No. 11581). NBER Working Paper. Retrieved from http://www.nber.org/papers/w11581.pdf

Krackhardt, D. (1992). The strength of strong ties: The importance of philos in organizations. In N. Nohria & R.G. Eccles (Eds.), *Networks and organizations: Structure, form, and action, 216*-239. Boston: Harvard Business School Press.

Landry, R., Amara, N., & Lamari, M. (2002). Does social capital determine innovation? To what extent?. *Technological Forecasting & Social Change*, 69, 7, 681-701.

Landry, R., Amara, N., & Rherrad, I. (December 01, 2006). Why are some university researchers more likely to create spin-offs than others? Evidence from Canadian universities. *Research Policy*, 35, 10, 1599.

Leenders, R. T., & Dolfsma, W. A. (2016). Social networks for innovation and new product development. *Journal of Product Innovation Management*, 33(2), 123-131.

Lehmann, E. E., Braun, T. V., & Krispin, S. (2012). Entrepreneurial human capital, complementary assets, and takeover probability. *Journal of Technology Transfer*, 37, 589-608. http://dx.doi.org/10.1007/s10961-011-9225-8

Leyden, D. P., & Link, A. N. (2014). Toward a theory of the entrepreneurial process. *Small Business Economics*, 44, 475-484. http://dx.doi.org/10.1007/s11187-014-9606-0

Lim, K., & Cu, B. (2012). The effects of social networks and contractual characteristics on the relationship between venture capitalists and entrepreneurs. *Asia Pacific Journal of Management*, 29(3), 573-596.

Link, A. N., & Scott, J. T. (2009). Private Investor Participation and Commercialization Rates for Government-sponsored Research and Development: Would a Prediction Market Improve the Performance of the SBIR Programme?. *Economica, 76*, 302, 264.

Link, A. N., & Scott, J. T. (2010). Government as entrepreneur: Evaluating the commercialization success of SBIR projects. *Research Policy, 39*(5), 589-601.

Link, A. N., & Siegel, D. S. (2007). *Innovation, entrepreneurship, and technological change*. Oxford University Press, USA.

Marx, K. (1858). The emancipation question. *New-York Daily Tribune*, January 17 and 22. http://hiaw.org/defcon6/works/1858/12/31.html

Marx, K. (1906). *Capital: A Critique of Political Economy, Vol. I. The Process of Capitalist Production.* Frederick Engels, Ernest Untermann, eds. Samuel Moore, Edward Aveling, trans. Part II, Chapter VI, Paragraph 12. Library of Economics and Liberty. http://www.econlib.org/library/YPDBooks/Marx/mrxCpA6.html

Mincer, J. (1958). Investment in human capital and personal income distribution. *The Journal of Political Economy*, 66, 281-302.

Narayan, D., & Cassidy, M. F. (March 01, 2001). A dimensional approach to measuring social capital: Development and validation of a social capital inventory. *Current Sociology, 49*, 2, 59-108.

National Institutes of Health. (2003). *National Survey to Evaluate the NIH SBIR Program, Final Report.* National Institutes of Health Office of Extramural Research.

National Research Council. (2008). *An Assessment of the SBIR Program*. National Academies Press.

National Research Council. (2009). *An Assessment of the SBIR Program at the National Institutes of Health*. National Academies Press.

National Academies of Sciences, Engineering, and Medicine. (2015). *SBIR/STTR at the National Institutes of Health*. National Academies Press.

NIH SBIR Criteria: https://grants.nih.gov/grants/guide/notice-files/not97-010.html

O'Rourke, N., & Hatcher, L. (2013). A Step-by-Step Approach to Using SAS® for Factor Analysis and Structural Equation Modeling, Cary, NC: SAS Institute.

Ozmel, U., Robinson, D. T., & Stuart, T. E. (2013). Strategic alliances, venture capital, and exit decisions in early stage high-tech firms. *Journal of Financial Economics*, 107, 655-670. http://dx.doi.org/10.1016/j.jfineco.2012.09.009.

Parloff, R. (2014, June 12). This CEO is Out for Blood. Retrieved from http://fortune.com/2014/06/12/theranos-blood-holmes.

Pérez-Luño, A., Medina, C. C., Lavado, A. C., & Rodríguez, G. C. (2011). How social capital and knowledge affect innovation. Journal of Business Research, 64, 12, 1369.

Primack, D. (2013, August 13). Fitbit raises $43 million in new funding. Retrieved on December 14, 2016 from http://fortune.com/2013/08/13/fitbit-raises-43-million-in-new-funding/.

Profatilov, D. A., Bykova, O. N., & Olkhovskaya, M. O. (2015). Crowdfunding: Online Charity or a Modern Tool for Innovative Projects Implementation?. *Asian Social Science*, *11*(3), 146.

Putnam, R. D. (1995). Bowling alone: America's declining social capital. *Journal of democracy*, *6*(1), 65-78.

Putnam, R. D. (2000). *Bowling Alone*. New York: Simon & Schuster.

Putnam, R. D. (2002). *Democracies in flux: The evolution of social capital in contemporary society*. Oxford University Press.

Ritter, N. L. (2010). Understanding a Widely Misunderstood Statistic: Cronbach's α. Paper presented at the annual meeting of the Southwest Educational Research Association, New Orleans, February 18, 2010. Retrieved April 2, 2019 from https://files.eric.ed.gov/fulltext/ED526237.pdf.

Robison, L. J., Schmid, A. A., & Siles, M. E. (2002). Is social capital really capital?. *Review of Social Economy*, 60(1), 1-21.

SBIR (2013). Small Business Innovation Research and Small Business Technology Transfer Annual Report Fiscal Year 2013. Retrieved June 15, 2016 from https://www.sbir.gov/sites/default/files/annual_reports/FY13_SBIR_STTR_AR_Final.pdf.

Schultz, T. W. (1961). Investment in Human Capital. *The American Economic Review*, *51*(1), 1–17.

Scopus Citations. Retrieved on December 18, 2016 from https://www-scopus-com.libproxy.uncg.edu/term/analyzer.uri?sid=2AFFE3844F27E0A2AAAFF114E6FF7631.wsnAw8kcdt7IPYLO0V48gA%3a10&origin=resultslist&src=s&s=TITLE-ABS-KEY%28social+capital%29&sort=plf-f&sdt=b&sot=b&sl=29&count=41557&analyzeResults=Analyze+results&txGid=2AFFE3844F27E0A2AAAFF114E6FF7631.wsnAw8kcdt7IPYLO0V48gA%3a6

"SEC Adopts Rules to Permit Crowdfunding. (2015, October 30)." In *SEC.gov*. Retrieved November 15, 2015 from http://www.sec.gov/news/pressrelease/2015-249.html

Sevilir, M. (2010). Human capital investment, new firm creation and venture capital. *Journal of Financial Intermediation*, 19, 483-508. http://dx.doi.org/doi:10.1016/j.jfi.2009.08.002

Shepherd, D. A., & Zacharakis, A. (2001). The venture capitalist-entrepreneur relationship: control, trust and confidence in co-operative behaviour. *Venture Capital: an international journal of entrepreneurial finance*, 3(2), 129-149.

Small Business Administration, Office of Investment and Innovation (2014, February 14). Small Business Innovation Research (SBIR) Program Policy Directive. Retrieved June 14, 2016 from https://www.sbir.gov/sites/default/files/sbir_pd_with_1-8-14_amendments_2-24-14.pdf

Smith, A., (1976). *An inquiry into the nature and causes of the wealth of nations*. Oxford, UK: Oxford University Press. Original published 1776.

Spence, M. (1973). Job market signaling. *The Quarterly Journal of Economics*, 87, 355-374.

Stiglitz, J. E. (1975). The theory of "screening," education, and the distribution of income. *The American Economic Review*, 65, 283-300.

Stone, W. (2001). Measuring social capital. *Australian Institute of Family Studies, Research Paper*, *24*.

Uzzi, B. (1999). Embeddedness in the making of financial capital: How social relations and networks benefit firms seeking financing. *American Sociological Review*, 64, 4, 481-505.

van der Zwan, P., Thurik, R., Verheul, I., & Hessels, J. (2016). Factors influencing the entrepreneurial engagement of opportunity and necessity entrepreneurs. *Eurasian Business Review*, 6(3), 273-295.

Weisman, J. (2012, March 8). With November in Mind, House Passes a Jobs Bill. Retrieved November 15, 2015 from http://www.nytimes.com/2012/03/09/us/politics/house-passes-jobs-act-by-large-margin.html?_r=0.

Williams, N., & Williams, C. C. (2014). Beyond necessity versus opportunity entrepreneurship: some lessons from English deprived urban neighbourhoods. *International Entrepreneurship and Management Journal*, 10(1), 23-40.

Wooldridge, J. M. (2010). *Econometric analysis of cross section and panel data*. MIT press.

Zucker, L. G., Darby, M. R., Brewer, M. B., & Peng, Y. (1995). *Collaboration structure and information dilemmas in biotechnology: Organizational boundaries as trust production* (No. w5199). National Bureau of Economic Research.

Zucker, L. G., & Darby, M. R. (1996). Star scientists and institutional transformation: Patterns of invention and innovation in the formation of the biotechnology industry. *Proceedings of the National Academy of Sciences of the United States of America*, 93, 23, 12709-12716.

APPENDIX A

SOCIAL CAPITAL AND INNOVATION SUCCESS – FITBIT

Fitbit was founded in 2007 with the intent to build a wearable device that provides consumers with key healthcare information (Fitbit, 2016). The company astutely identified the trend towards real-time feedback associated with physical activity before other healthcare technology firms. The vision of the company's founders, James Park and Eric N. Friedman, was to leverage revolutionary technology to put healthcare information in the hands of consumers. They note "…we started Fitbit with the vision that sensors, data, and amazing software could transform the way people think about health and fitness" (Fitbit, 2015). In just 8 years, Fitbit was able to obtain outside funding to finance their innovation, create a market-ready wearable healthcare device, generate successive years of increasing sales, and issue an IPO.

The success of Fitbit can be traced to the development of their social capital and the production of innovation output. First, Fitbit was able to obtain multiple external fundings from several venture capitalists. In announcing their initial financial participation in Fitbit, one of the first venture capital firms to invest in Fitbit noted the strength of the firm's expertise in the core technology, "…we bought numerous products in a search for the best company in a market – human instrumentation – that we believe will explode over the next decade. With Fitbit, we believe we have found it" (Feld, 2010). An investor in a subsequent round of financing for Fitbit indicated their investment was encouraged by the need to continue building expertise at the firm and mentioned, "The business is growing really fast…[Fitbit is] a device, which means that it really requires a good deal of working capital, unlike all these software apps venture capitalists are usually funding" (Primack, 2013). Within the same financing round, another investor echoed Fitbit's success in leveraging prior funding into R&D success by explaining, "Companies like Fitbit are attracting investors because it is one of the earliest companies to attract a massive user

base that continues to grow at a rapid rate" (Dolan, 2013). In their press release related to the venture capital funding, Fitbit acknowledges the investment will be used to build strong social ties as it will "accelerate hiring of the best hardware and software engineers, designers, product managers, data analysts and marketers" (Fitbit, 2013). With the strong social ties Fitbit cultivated through its skillful and knowledgeable workforce, it has successfully obtained incremental rounds of venture capital by signaling early investment successes, culminating in obtaining outside developmental financing in the innovation process.

Second, Fitbit's sales from their innovation continue to increase. According to the company's IPO prospectus, revenue in 2011, 2012, 2013, and 2014, accelerated from $14.5 million in 2011 to $76.4 million in 2012, $271.1 million in 2013, and $745.4 million in 2014 (Fitbit, 2015). The increase in sales can also be tied to social capital. Customers who buy a Fitbit are likely influenced by experiences of prior customers given the relative newness and novelty of wearable fitness technology. Additionally, those experiences can be shared and enhanced through the connectivity of the devices with other devises. Fitbit recognized the need to collaborate with outside development to provide an expanded menu of applications that allow the sharing of Fitbit experiences. Fitbit describes the benefit of these third-party relationships (Fitbit, 2015),

> …we extend the value of our platform through our open application programming interface, or API, which enables third-party developers to create health and fitness apps that interact with our platform…[through] our open platform and our large community of users, we have established a growing ecosystem that includes thousands of third-party health and fitness apps that connect with our products and enhance the Fitbit experience…The size of our user community increases the likelihood that our users will be able to find and engage with friends and family, creating positive network effects that reinforce our growth and user retention. In addition, data from our large community enables us to enhance our product features, provide improved insights, and offer more valuable guidance for our users.

With the opportunity to enhance the experience through additional applications from outside developers, Fitbit has been able to continuously introduce new products to an expanding user base. Fitbit states, "To date, product introductions have had a significant, positive impact on our operating results due primarily to increases in revenue associated with sales of the new products in the quarters following their introduction" (Fitbit, 2015). The weak social capital ties cultivated through the relationship building with external application developers has contributed to increased sales of Fitbit products, resulting in commercialization success.

Third, Fitbit's commercial success along with the increasingly competitive market for wearable health technology led the firm down the path to an IPO. The success of the IPO can be linked to the strong social ties developed by Fitbit as demonstrated in their ability to continue to innovate. The propensity to innovate emanates from the firm's dedication to invest in knowledge as explained by the importance of R&D funding (Fitbit, 2015),

> We are passionate about developing innovative products and services that empower our users to reach their health and fitness goals. We believe our future success depends on our ability to develop new products and features that expand the versatility and performance of our existing platform and we plan to continue to invest significant resources to enhance performance, functionality, and convenience and style for our users.

In the case of Fitbit, a signal for this investment is the depth of intellectual property owned. The firm notes (Fitbit, 2015),

> As the leader in the fast-growing market for connected health and fitness devices, we have developed a significant patent portfolio to protect certain elements of our proprietary technology. As of March 31, 2015, we had 77 issued patents and 132 patent applications pending in the United States. We continually review our development efforts to assess the existence and patentability of new intellectual property.

The strong and weak social ties cultivated by Fitbit in the relatively short time between founding and IPO underscores the importance of social capital in the innovation process. In fact,

the three innovation outputs additional developmental funding, commercialization of products, and executing and IPO achieved by Fitbit's are summed by the company's founders in a letter to prospective IPO investors (Fitbit, 2015),

> Thanks to the employees of Fitbit who believed in the vision and who have worked passionately to create something incredible out of nothing. Thanks to our users who have trusted our products and our company to improve their lives. Thanks to our investors who believed in us and the opportunity. The journey is not over and, in fact, it is just beginning. This [IPO] offering is just one milestone among the many that we have reached in the past and will reach in the future.

APPENDIX B

SOCIAL CAPITAL AND INNOVATION FAILURE - THERANOS

Theranos, a Silicon Valley-based health technology company, set out to revolutionize the multi-billion-dollar blood diagnosis industry by using in-house developed technology and just a finger prick amount of blood to provide a panel of laboratory tests. The potential disruption in the status quo of a large and staid industry coupled with a young female CEO with a drive to change the healthcare world created a large amount of interest by the venture capital community as well as the media. The result was an estimated $9 billion valuation of Theranos, a "unicorn" investment in venture capital parlance (Parloff, 2014). Theranos, by all measures, successfully produced the innovation output of obtaining outside funding through the development of perceived deep institutional (strong tie) knowledge.

While Elizabeth Holmes, the founder and CEO of Theranos, had an audacious vision, her company was not able to fully commercialize its main product due to misjudgment of her firm's social capital, which ultimately resulted in innovation failure. Holmes viewed Theranos as a technology company and not as a healthcare firm, so she sought out and surrounded herself with advisors and leaders with very little healthcare knowledge or experience in navigating the laborious and tedious regulatory process typically associated with new healthcare products. In fact, Bilton (2016) notes the make-up of Theranos' board, which included several high profile politicians at the initial point of assemblage, was "…a board that was better suited to decide if America should invade Iraq than vet a blood-testing company." This lack of expertise and industry knowledge within Theranos' social network, which manifested itself in questionable signals of success and laboratory inconsistencies, led to an inability to support their claims around blood testing procedures.

As scrutiny of their expertise in laboratory practices intensified, Theranos summarily dismissed concerns of competency and played victim to calls for openness, stating their "methods for preparing samples for analysis are trade secrets and cannot be revealed" (Carreyrou, 2015). The outcome was heavy skepticism and ultimately findings of misrepresentation around the true nature of their products, laboratory proficiency, and in-house knowledge, resulting in sanctions by the government related to Theranos' laboratory practices and Holmes herself. Further, Herper (2016) notes that due to a lack of proven efficacy of its product and eroded confidence in the firm's ability to resolve its business practices, including actively engaging third-party reviews, Theranos's value plummeted from $9 billion to $800 million, and Holmes' 50% ownership is now worthless. As further scrutiny intensified and more became known about the relationship destruction and distrust perpetuated by its CEO, Theranos ultimately failed as a company.

While failure can be attributed to any number of issues, it is clear Theranos misjudged the importance of cultivating a successful social network to include weak social ties (credible advisors and outside reviewers), and as a result, the company was not able to deliver a commercializable product. Theranos' weak social tie of non-healthcare advisors hampered instead of helped its success. The measures of social capital strength that Theranos signaled in an attempt to demonstrate their breakthrough technology and leadership backfired and instead signaled social capital weakness. Bilton (2016) even notes that a potential investment from Google Ventures evaporated once their due diligence revealed inconsistencies in Theranos' claims of product ingenuity.

While clearly flawed, the logic for overweighting Theranos' group of advisors with high-profile politicians perhaps stemmed from the belief that those types of individuals would signal to regulators, investors and customers that the firm had access to a wide range of resources and contacts to successfully commercialize their blood testing innovation. By misjudging the social

capital signal of the optimal number of healthcare advisors, the CEO put only 1 individual on the board with healthcare experience and 11 individuals with significant political backgrounds (and little healthcare experience) to serve on the board of directors and as company advisors (Bilton, 2016).[50] For Theranos, the CEO did not correctly assess the number of healthcare advisors it needed to cultivate the appropriate level of social capital to bring the product to market, and the company was not able to convince regulators, investors, or consumers that their product, and ultimately the firm, was viable.

[50] Bilton (2016) notes "As [Elizabeth] Holmes started to assemble her board of directors, she chose a dozen older white men, almost none of whom had a background in anything related to health care…(Bill Frist, the former Senate majority leader, and former cardiovascular doctor, was an exception.)"

APPENDIX C

ROBUSTNESS CHECK ON INDEPENDENT VARIABLES

Multivariate Probit Results with Selected Independent Variables (n = 315)

Inputs	Estimate	StdError	t-stat	p-value	
Output - Firm Received Additional Developmental Funding for the Funded Project					
Intercept	0.456	0.253	1.80	0.071	*
Strong Social Tie - Number of Phase II SBIR Awards Received	-0.014	0.009	-1.58	0.114	
Strong Social Tie - Number of Scientific Publications Submitted					
Strong Social Tie - Number of Patent Applications Submitted					
Strong Social Tie - Number of Firms Founded by the Firm's Founders	0.130	0.063	2.06	0.040	**
Physical Capital - Percentage of Firm Growth Due to SBIR – < 25%	0.000				
Physical Capital - Percentage of Firm Growth Due to SBIR – < 25%	0.092	0.243	0.38	0.704	
Physical Capital - Percentage of Firm Growth Due to SBIR – 25%-50%	0.285	0.286	0.99	0.320	
Physical Capital - Percentage of Firm Growth Due to SBIR – 51%-75%	-0.135	0.245	-0.55	0.583	
Physical Capital - Percentage of Firm Growth Due to SBIR – > 75%	-0.017	0.071	-0.25	0.806	
Human Capital – Log Number of Employees when Phase II Proposed	-0.075	0.343	-0.22	0.826	
Firm was Established for SBIR Awards (yes/no)	0.456	0.253	1.80	0.071	*
Output - Firm Reported Commercialization of Product, Process or Service Sales					
Intercept	0.018	0.229	0.08	0.94	
Weak Social Tie - Receipt of Project Funds Prior to Phase II from Venture Capital, Other Private Company, or Private Investor (yes/no)	-0.164	0.187	-0.87	0.38	
Weak Social Tie - Marketing/Distribution Agreements in Place (yes/no)					
Weak Social Tie - Research/Development Agreements in Place (yes/no)					
Physical Capital - Percentage of Firm Growth Due to SBIR – < 25%	0.000				
Physical Capital - Percentage of Firm Growth Due to SBIR – 25%-50%	0.587	0.223	2.63	0.01	***
Physical Capital - Percentage of Firm Growth Due to SBIR – 51%-75%	0.183	0.246	0.75	0.46	
Physical Capital - Percentage of Firm Growth Due to SBIR – > 75%	0.336	0.218	1.54	0.12	
Human Capital – Log Number of Employees when Phase II Proposed	0.054	0.064	0.85	0.40	
Firm was Established for SBIR Awards (yes/no)	0.128	0.364	0.35	0.72	

Output - Firm Experienced Growth-Related Activity, such as an IPO, a Spin-off Firm, Sale, Merger, Joint Venture, or Licensing Agreement					
Intercept	-0.919	0.260	-3.53	0.00	***
Weak Social Tie - Receipt of Project Funds Prior to Phase II from Venture Capital, Other Private Company, or Private Investor (yes/no)	0.568	0.189	3.01	0.00	***
Weak Social Tie - Marketing/Distribution Agreements in Place (yes/no)					
Weak Social Tie - Research/Development Agreements in Place (yes/no)					
Physical Capital - Percentage of Firm Growth Due to SBIR – < 25%	0.000				
Physical Capital - Percentage of Firm Growth Due to SBIR – 25%-50%	0.365	0.223	1.64	0.10	
Physical Capital - Percentage of Firm Growth Due to SBIR – 51%-75%	0.772	0.256	3.01	0.00	***
Physical Capital - Percentage of Firm Growth Due to SBIR – > 75%	0.213	0.236	0.91	0.36	
Human Capital – Log Number of Employees when Phase II Proposed	0.084	0.070	1.20	0.23	
Firm was Established for SBIR Awards (yes/no)	0.904	0.372	2.43	0.02	**
Correlations					
Rho: Additional Funding & Commercialization	0.304	0.095	3.19	0.00	***
Rho: Additional Funding & Firm Growth-Related Activity	0.011	0.110	0.1	0.92	
Rho: Commercialization & Firm Growth-Related Activity	0.320	0.091	3.53	0.00	***
significance levels: * = < 0.10, ** = < 0.05, *** = < 0.01					