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Origins and outcomes: Success of technology spin-offs from universities, firms, and government research centers and laboratories

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Abstract

Spin-off firms originate from several sources such as universities, existing firms, and government research centers. Thus far, work on spin-off activity has focused on factors that influence the creation and performance of corporate spin-offs, with recent attention concentrating on those from universities. Spin-offs from government laboratories and research centers have largely been overlooked. Thus, little is known about the comparative success of the different spin-off types. Using a database of all nanotechnology firms founded between 1981 and 2001, this study examines academic, corporate and government spin-offs and de novo start-ups in terms of firm cessation, acquisition, liquidation, bankruptcy, and funding. The data show that lineage does influence outcomes; however, each type of firm origin has provocative distinctions. Implications for technology transfer and entrepreneurship are discussed.

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ABSTRACT

Spin-off firms originate from several sources such as universities, existing firms, and government research centers. Thus far, work on spin-off activity has focused on factors that influence the creation and performance of corporate spin-offs, with recent attention concentrating on those from universities. Spin-offs from government laboratories and research centers have largely been overlooked. Thus, little is known about the comparative success of the different spin-off types. Using a database of all nanotechnology firms founded between 1981 and 2001, this study examines academic, corporate and government spin-offs and de novo start-ups in terms of firm cessation, acquisition, liquidation, bankruptcy, and funding. The data show that lineage does influence outcomes; however, each type of firm origin has provocative distinctions. Implications for technology transfer and entrepreneurship are discussed.

Firms that develop from other organizations, often called spin-offs or spin-outs, are a mainstay in industry creation, market growth, innovation, employment and economic development (Callan, 2001). Spin-offs are created when intellectual property (IP) or knowledge is transferred from one source, such as a firm, university or government research center, to form a new organization (Clarysse & Moray, 2004; Parhankangas & Arenius, 2003). High-technology industries are particularly prone to spin-off activity (Agarwal, Echambadi, Franco, & Sarkar, 2004) where funding for R&D helps support innovation. For example, much of the early semiconductor industry in Silicon Valley was created through spin-offs from Fairchild Semiconductor (Saxenian, 1994). As such, spin-offs are important to economic growth and the development, diffusion, and commercialization of nascent technologies.

Parent organizations play a large role in the founding conditions, resource stocks, and strategies of their progeny spin-offs. It follows that a firm’s lineage is important for its performance (Burton, Sørensen & Beckman, 2002; Shrader & Simon, 1997). Indeed, the resources capabilities provided to spin-offs at founding from their parents influence the spin-offs' ability to survive (e.g. Powers & McDougall, 2005; Klepper, 2002). But not all parental organizations are the same; a wide range of organizations create spin-off firms. Spin-offs can be created when IP or knowledge, codified or tacit, is moved from one organization and used as the basis of a start-up organization (Clarysse & Moray, 2004; Parhankangas & Arenius, 2003). As such, a spin-off depends on the IP or knowledge on which it is founded, the organization from which the IP is transferred, and the team transferring the IP and starting the new firm. Each of these provides opportunities for heterogeneity in the resulting spin-offs. For example, IP can be cutting edge, market driven, or incremental. Parent organizations vary from private firms to public institutions. Founding teams can include a range of people including professors, serial entrepreneurs, and researchers. However, much of the current research tends to either examine spin-offs as a relatively uniform group or focuses on either academic or corporate spin-offs.

Only recently has literature emerged that compares the attributes and performance of different types of spin-offs. This stream of research has focused on the knowledge-based view that specifies that the foundation of knowledge imprinted on spin-offs by their parent organizations at the beginning influences their outcomes (Lockett, Siegel, Wright, & Ensley, 2005). For example, Zahra, Van de Velde, and Larraneta (2007) find that academic and corporate spin-offs differ in knowledge conversion capabilities, which leads to differences in productivity, profitability and revenue growth. Wennberg, Wiklund, and Wright (2011) argue that the commercial knowledge inherited by corporate spin-offs results in higher growth and survival rates when compared to academic spin-offs lacking such experience. Similarly, Clarysse, Wright, and Van de Velde (2011) argue that since academic spin-offs lack market knowledge, they may benefit from having a broad technology with many applications, while corporate spin-offs use their superior industry knowledge to benefit from narrow technologies targeting specific markets.

This work has provided insight into the knowledge-based differences and similarities of academic and corporate spin-offs; however, many questions remain. For instance, organizations other than universities and firms spin out companies. Yet, there is a dearth of research on spin-offs from other types of organizations. For example, government research centers and laboratories generate technology and IP that is used to establish new firms (Mowery & Ziedonis, 2001). In 2014, the U.S. federally funded 25 R&D centers, 10 systems analysis centers, and six systems engineering centers (National Science Foundation, 2014b). Annual federal funding for these R&D centers ranges from about $3 million to $2.3 billion (National Science Foundation, 2014a). These research centers and labs explore a wide range of technologies, but do not seek commercialization, leaving that objective to their spin-offs. Examples of such spin-offs include Amtech from Los Alamos National Laboratory, MEMX from Sandia National Laboratory, and Sion Power from Brookhaven National Laboratory. In fact, between 1997 and 2008, Los Alamos National Laboratory enabled over 50 spin-offs (Engardio, 2008). However, spin-offs from government facilities have been treated as the same as other spin-offs or generally neglected in the literature. Given their active role in entrepreneurship and technology transfer, government spin-offs warrant additional consideration.

To address these challenges, this study examines the characteristics and outcomes of de novo firms and three types of spin-offs: those from universities, firms, and the government. The article begins with a review of work on academic and corporate spin-offs. The insights from these literature streams are integrated with findings from the limited work on government spin-offs. Then, I empirically examine the primary research question of how a firm's origins influence its outcomes using a database of nanotechnology firms founded between 1981 and 2001. The data are analyzed using five types of firm outcomes: closure, acquisition, liquidation/bankruptcy, venture capital and government grants. The findings indicate that academic spin-offs are more likely to obtain venture capital and government grants while government spin-offs are more likely to be acquired. Start-up firms with a high proportion of former business executives on the founding team are more likely to close, while university spin-offs are more likely to obtain venture capital funding. The findings suggest that, indeed, the characteristics of a firm's lineage influence its success, however in distinct and provocative ways that are not well explained by current theory.

This study makes several contributions to both theory and practice. Research tends to focus on a single type of spin-off with few studies comparing different types. The dearth of comparative empirical work in this area limits our understanding of factors that influence a firm's success, particularly those related to technology and knowledge transfer. The inclusion of government spin-off activity in this study further develops the entrepreneurship literature that has largely neglected these firms. Comparing the influence of lineage on firm success provides empirically based insight into decision-making by investors with spin-off related opportunities. Furthermore, understanding spin-off outcomes has implications for government and university policy makers with regard to initiatives that influence technology transfer and entrepreneurship. Using multiple measures of firm success provides new insight into how firm origins influence their longevity. Thus, this study informs our understanding of knowledge and technology transfer, with important implications for university and government policy regarding entrepreneurship. The study also builds our understanding of the recent developments to support technology transfer and entrepreneurship by parent organizations, such as university technology transfer offices and corporate intrapreneurship programs.

BACKGROUND

Spin-off firms can be distinguished by the sources and types of resources and capabilities that help them survive (Wright, 2014). Three categories of resources and capabilities that are particularly salient when comparing spin-off firms are their intellectual property (IP), parent organizations, and people. First, spin-offs are often defined by the source of the technology or knowledge on which the firm is based including patents, trade secrets, processes, and tacit information. As technology and knowledge are inherently intertwined, these can be thought of as the *IP* on which the firm is founded. Second, in addition to IP, parent firms often support spin-off firms with other assets such as financing (Mustar, Renault, Colombo, Piva, Fontes, Lockett, Wright, Clarysse, & Moray, 2006), experience, routines (Stinchcombe, 1965; Romanelli, 1989), cultures, infrastructure, systems (Moray & Clarysse, 2005) and networks. Indeed, spin-off success is directly influenced by the resources and capabilities enabled by the *parent* organization (e.g. Powers & McDougall, 2005; Klepper, 2002). Third, spin-offs are also defined by their founding team's human capital in terms of social actors and knowledge transfer agents. The category of *people* captures the team and individual contributions of human capital. Using these three categories as a framework, the following section more closely reviews work on three types of spin-offs: academic, corporate, and government. Table 1 uses this framework to summarize the literature.

Insert Table 1 about here

Academic Spin-offs

Universities are fountainheads of innovation and technology. Increasingly, universities are using a variety of technology transfer mechanisms to benefit from internally generated IP (Friedman & Silberman, 2003). The enactment of the Bayh-Dole Act in 1980 gave universities and research organizations the right to own the inventions generated through government funding. Since then, many universities have supported the creation of spin-offs to commercialize these inventions. Thus, academic spin-offs have been a key element in the transfer of technology and knowledge from universities into industry. Academic spin-offs have become important contributions to not only university funding and technology development, but also the economic health of nations (Vincett, 2010; Friedman & Silberman, 2003).

Intellectual Property (IP). Academic spin-offs are often founded on IP generated from university research in the hard sciences, which affords several advantages and disadvantages. For example, the IP on which academic spin-offs are founded is often cutting-edge (Wennberg *et al.*, 2011), which provides a competitive advantage in the market, particularly in emerging domains of technology. Cutting-edge IP may also provide the basis for technology standards on which a nascent market is derived. Spin-off firms can use such IP to achieve market dominance and a first-mover advantage (Lieberman & Montgomery, 1988). At the same time, pioneering technology can be too far ahead of its time if a supporting supply chain has not been developed (Woolley, 2010; 2014). Cutting-edge IP also may be far from ready to commercialize (Jensen & Thursby, 2001; Rothaermel & Thursby, 2005; Shane, 2000; Thursby, Jensen, & Thursby, 2001), which hinders a firm's ability to enter the market or survive. Additionally, academic spin-offs are based on ideas created in a non-commercial environment (Bathalt, Kogler, & Munro 2010) that is not typically oriented toward profit-seeking activities (Wennberg *et al.*, 2011). Furthermore, university-based inventions are considered high-risk (Rothaermel & Thursby, 2005), which may deter investors who view corporate spin-offs more positively (Schipper & Smith, 1983; Seward & Walsh, 1996). Being perceived as riskier than other ventures in the market reduces a firm's ability to raise funding needed for survival.

Parent Organization. Academic spin-offs can benefit from a relationship with a university parent in several regards. Parent universities often provide their progeny with access to university facilities, expertise and resources that increase their resource stocks at founding and provide a competitive advantage (Powers & McDougall, 2005; Grandi & Grimaldi, 2003). Furthermore, academic spin-offs often use other university resources such as student labor, faculty consulting (Mian, 1996), labs and libraries (Quintas, Wield, & Massey, 1992), which reduces their capital expenditures. Similarly, technology transfer offices at universities can provide invaluable services and support to academic entrepreneurs such as facilitating IP use agreements and providing templates for legal documentation (Clarysse, Wright, Lockett, Mustar, & Knockaert, 2007; Clarysse, Tartari, & Salter, 2011). Likewise, the social networks of universities have been shown to benefit academic entrepreneurship in terms of idea exchange and learning (Lindelof & Lofsten, 2004). These interactions can help the founders to develop their business models and products. University affiliations also provide signals of legitimacy (Stuart & Ding, 2006; Ding & Choi, 2011; Mian, 1996; Rothaermel & Thursby, 2005), which is critical for obtaining resources and customers, especially in nascent markets. Similarly, firms affiliated with universities have more access to government subsidies, research programs (Colombo & Delmastro, 2002) and knowledge resources (Clarysse et al., 2011b; Zahra et al., 2007). In sum, a university parent can provide progeny with access to a portfolio of resources and capabilities that facilitate long-term success.

Hand in hand with benefits is an array of drawbacks for academic spin-offs. Academic parents do not have business routines to pass on to their progeny. In fact, the operating procedures of universities often conflict with for-profit strategies. For example, a university's direct involvement in the commercialization of its IP is often problematic. As the main goal of universities is to create knowledge, they are less supportive of profit-generation activities (Vohora, Wright & Lockett, 2004; Lockett & Wright, 2005; Siegel, Waldman, Atwater, & Link, 2003; Shane, 2004). The multiple stakeholders of academic spin-offs, from students, professors, and researchers to administration, governing boards, and donors, differ greatly in their objectives (Clarysse, *et al.*, 2007; Jensen & Thursby, 2001), bureaucracy, and resource control. These differences create conflicts that may inhibit growth of academic spin-offs (Vohora *et al.,* 2004). For example, the value of university technology transfer offices' services is limited by their employees' perception of the IP's value to the school (Lockett & Wright, 2005). Although universities have increased their support of entrepreneurial activities (Rothaermel, Agung, & Jiang, 2007), they have relatively little experience in market assessment, technology evaluation, and transfer. Thus, their technology transfer officers' assessment of the IP's value to the university may be unrealistic and their services to the spin-off may not be useful, or even at times harmful. It is common for technology transfer offices to value university IP much differently than potential external investors. When these evaluations differ greatly, the spin-off may lose crucial funding from these investors that is needed for their survival.

The role of the university in protecting technology can also be contentious (Clarysse *et al.,* 2007). While building technology transfer support, few universities allow faculty ownership of the IP created at the school, regardless of funding source (Thursby *et al.*, 2001). Consequently, conflicts about technology ownership arise. Continued ownership of the IP by a university after it is spun off into a new firm often requires the involvement of the school's legal department, which can prevent academic spin-offs from protecting themselves through traditional legal means. This continued relationship and influence by the university limits the firm's competitive advantage gains from the technology. The venture capital community is less supportive of academic spin-offs (Munari & Toschi, 2011; Watson, Stewart & Barnir, 2003; Wright, Lockett, Clarysse, & Binks, 2006), in part due to such contentious relationships.

People. Academic spin-offs benefit from having professors and researchers on their founding team. Academic founders bring advanced education (Burton, *et al.*, 2002; Wennberg, et al., 2011; Watson et al., 2003; Sapienza & Grimm, 1997) and in-depth technology knowledge (Ding & Choi, 2011; Clarysse et al., 2011b). In fact, academic founders are often the inventors of the technology on which academic spin-offs are based. This education and tacit knowledge about the firm's foundational technology helps to establish a competitive advantage in the market and to sustain further product development. Academic founders also bring their network ties that are particularly rich in R&D knowledge (Lofsten & Lindelof, 2005) and social capital (Murray, 2004). Academic entrepreneurs may act as facilitators of pre-commercialization research that traditionally does not fit either the role of the university nor the commercial firm. This is a scarce skillset that benefits the spin-off.

While academic founders provide skills and knowledge that can create a competitive advantage, they may constrain the start-up activity. For one, by being among the few people to understand the important tacit IP on which the firm is founded, they are embedded in the fabric of the firm and their continued involvement is required. If the technology on which a firm is founded is controlled by one academic founder, the firm's growth prospects are limited. Also, academic founders often lack industry experience, which limits market knowledge (e.g Ensley & Hmieleski, 2005; Zahra *et al.*, 2007). For example, academic inventors, due to commercial inexperience, may overemphasize the technical aspects of the innovation instead of business viability leading to inefficient resource expenditures. Academic founding teams often lack entrepreneurial experience, which can limit their opportunity recognition or exploitation skills and impede the firm's development (Duchesneau & Gartner, 1990; Franklin, Wright, & Lockett, 2001; Stuart & Abetti, 1990). Similarly, academic founders often lack the commercial goals and incentives to bring inventions to market, particularly if they remain employed at the university (Ensley & Hmieleski, 2005; Clarysse & Moray, 2004; Roure & Keeley, 1990). All of these deficiencies can be the source of conflicts between founders and investors and slow product development, thus impeding a firm's likelihood of success.

Academic spin-offs tend to have homogeneous founding teams in terms of characteristics such as education and experience, which leads to lack of diversity in knowledge and skills (Beckman, Burton, & O'Reilly, 2007; Ensley & Hmieleski, 2005; Fesser & Willard, 1990; Ruef, Aldrich, & Carter, 2003). Such founding team homogeneity can reduce the efficacy of their decision making. Visintin and Pittino (2014) find that heterogeneity in the founding team of university spin-offs exhibit superior employee and sales growth. Academic entrepreneurs often lack an industry network (Zahra et al., 2007; Shane & Stuart, 2007; Walter, Auer, & Ritter, 2006; Mosey & Wright, 2007) and have difficulty developing social capital in the market (Corrolleur, Carrere, & Mangematin, 2004; Mosey & Wright, 2007; Mustar et al., 2006; Nicolaou & Birley, 2003). A lack of industry ties and social capital impedes a firm's ability to obtain resources needed for developing and commercializing products. Thus, academic spin-offs can be hindered by the very people that make them special.

Corporate Spin-offs

Spin-offs form from existing firms for several reasons. The knowledge-based view of entrepreneurship emphasizes the role of corporate spin-offs in providing incumbent firms the opportunity to transfer a technology to a new firm where it can be explored outside of the confines of the existing organizational structure (Agarwal et al, 2004). These spin-offs are often backed by the resources and support of the parent firm (Bruneel, Van de Velde, & Clarysse, 2013). Employees are also driven to start new firms based on the knowledge that they gain at their employers that is not deemed appropriable by the parent firm (Agarwal et al, 2004). Other corporate spin-offs are formed when disruptions such as management changes, mergers, or disagreements prompt employees to seek new employment and start new firms (Klepper & Sleeper, 2005; Garvin, 1983).

Intellectual Property (IP). In contrast to academic spin-offs, the IP on which corporate spin-offs are founded tends to be applied R&D (Singh, Tucker, & House, 1986) and created with the market in mind. Thus, this IP tends to be closer to commercialization (Chatterji, 2009; Wennberg *et al.,* 2011). As such, technology on which corporate spin-offs are based is perceived as being less risky (Schipper & Smith, 1983; Seward & Walsh, 1996). However, this IP is not risk-free. For example, firm-based IP is often generated with little outsider perspective. A lack of external input can result in a product that does not meet the needs of the end user, thus limiting its prospects for adoption. Also, firms divest IP into new ventures when it is believed that the resulting products have small markets or insufficient opportunities for value capture. These ideas may be deemed as inferior and, thus, not worth further expenditures (Bruneel et al., 2013). Spin-offs based on IP that another firm has determined to be inferior may struggle with its commercialization.

Parent Organization. Start-ups spun out of corporate parents benefit directly and indirectly from their previous experience and resources. Corporate spin-offs inherit routines or operating procedures that have been vetted in the market by their parents (e.g. Nelson & Winter, 1982; Romanelli, 1989; Aldrich & Pfeffer, 1976; Phillips, 2002) and their existing supply chain relationships (Semadeni & Cannella, 2011). By preserving the relationship with its parent, a corporate spin-off combines the advantages of being a small start-up while utilizing the assets of a larger corporation (Teece, 1988). For instance, parent firms often contribute resources and infrastructure (Scott, 2003), such as funding and IP. In some cases, spin-off firms maintain relationships with their parent firms and obtain support through that affiliation (Zahra, 1996) and legitimacy (Stuart, Hoang, & Hybels, 1999). If the parent firm maintains ownership of the spin-off, the parent may continue oversight (Semadeni & Cannella, 2011). As such, corporate spin-offs spend less of their time and resources building infrastructure, market analysis methods, routines, and supply chains than other start-up firms.

Some of the benefits of corporate lineage may also be disadvantages. For example, the parents' routines imprinted on spin-offs may constrain the flexibility and ingenuity on which nascent firms thrive (Amburgey, Kelly, & Barnett, 1993; Romanelli, 1989; Klepper & Sleeper, 2005). Similarly, parental oversight can deprive the spin-off of autonomy or independence (Semadeni & Cannella, 2011) needed for growth. Furthermore, an overreliance on parent resources can retard a firm's ability to create its own set of skills and capabilities. Thus, relationships with corporate parents must be carefully evaluated and managed.

People. Several characteristics of corporate spin-offs' founding teams can help their start-up. The founding teams of corporate spin-offs tend to be more heterogeneous than those at academic progeny. This heterogeneity can lead to better decision making by including a wider range of voices (e.g. Ensley & Hmieleski, 2005; Ruef et al., 2003; Beckman et al., 2007). The founding teams of corporate spin-offs also have industry experience (e.g. Colombo & Grilli, 2005; Colombo & Piva, 2012; Fesser & Willard, 1990; Klepper & Simons, 2000) that generates market knowledge benefiting their spin-offs (Klepper & Sleeper, 2005; Agarwal *et al.,* 2004).

Corporate spin-offs also benefit from the networks of their founding teams. Founders from firms are more likely to have industry-related networks (Higgins & Gulati, 2003; Yli-Renko, Autio, & Sapienza, 2001), including social ties with former co-workers (Sapienza, Parhankangas, & Autio, 2004) and the venture capital community (Shane & Stuart, 2002). Academic founders are more likely to have R&D-related networks (Lofsten & Lindelof, 2005; Murray, 2004). Although both types of networks can be useful, corporate spin-offs benefit commercially from relationships with customers and market knowledge from their parent firms. Similarly, corporate spin-off founders often have social capital related to industry (Shane & Stuart, 2002). Thus, corporate spin-offs have a higher likelihood of success than those from universities (Lindholm Dahlstrand, 1997).

Spin-offs from Government Research Centers and Laboratories

Spin-off activity from government research centers and labs (herein "government spin-offs") has little representation in the entrepreneurship literature, despite its prevalence (Carayannis, Rogers, Kurihara, & Allbritton, 1998). As entrepreneurship activity is tied to knowledge production, and government research centers and labs generate extensive knowledge and IP, it follows that government spin-offs are not uncommon (Carayannis *et al.*, 1998; Rogers, Takegami, & Yin, 2001). In fact, Smith and Ho (2006) found more spin-offs from public labs than from universities in the Oxford area of the U.K. When included in entrepreneurship research studies, government spin-offs tend to be grouped with university start-ups (e.g. Carayannis *et al.*, 1998; Rogers *et al.*, 2001; Malo, 2009). However, universities and government organizations differ greatly in their goals, technology transfer policies, and publication activities. As a result of grouping them together, much less is known about government spin-offs compared to those from universities and corporations. The next section reviews work on government spin-offs and applies our knowledge of academic and corporate spin-offs to clarify the similarities and differences of the types of spin-offs.

Intellectual Property (IP). Government labs are involved in a range of R&D projects from fundamental sciences to commercially oriented research. Thus, government research centers and labs create technology with elements from both university and corporate R&D. On one hand, government labs are less likely to view basic research as part of their core mission compared to university labs (42 percent versus 70 percent, respectively; Bozeman, 2000, p. 634). While basic science lays the foundation for government R&D, government projects tend to build applications of basic science work, usually based on a proof of concept to get government funding (Rogers *et al.*, 2001). Thus, these projects are closer to commercialization than academic projects based on foundational scientific research. On the other hand, government labs are oriented more toward basic research than corporate labs (Bozeman, 2000).

Government projects tend to address complex and large-scale problems that are considered high risk (Hruby, Manley, Stoltz, Webb, & Woodard, 2011). Although this specialization may limit the market to which the technology can be applied, government spin-offs can benefit from insight into the sizeable existing government market and the project support process. For example, through the funding application process, government research centers' technologies and their applications are vetted through the government audience. In doing so, firms spun from these labs gather market information and feedback before launch. This is particularly important for start-ups that target specialized government markets. However, in some cases, the process of getting government funding and support can focus the development of the technology on government applications that differ from those in the general market (Rogers *et al.*, 2001). While the quality of patents from government organizations has improved over time (Jaffee & Lerner, 2001), these patents are typically focused on government customers and may not be adaptable to other markets (Rogers *et al.*, 2001).

Parent Organization. The government is a unique parent. Government spin-offs are provided little business guidance compared to corporate and academic spin-offs that have technology transfer support. However, as discussed, government spin-offs targeting government customers may not need the same business guidance as other firms. Spin-offs that target government customers need knowledge of the routines and protocols regarding government contracts, procurement and logistics, which vary from traditional market routines. Becoming a supplier to the government is a complicated process and can take years of certifications, operations verification, and security checks. Government spin-offs gain knowledge of how to conduct business with the government from interactions between the parent organization and government agencies and the successful awarding of government funding.

Government spin-offs can enjoy other benefits from their lineage. A continued relationship with research center parents can provide access to additional funding and R&D resources (Audretsch, Link, & Scott, 2002; Toole & Czarnitzki, 2007). Being affiliated with a government research center or lab also provides legitimacy for government spin-offs (Scott, 2003). While, government research centers and labs are less market driven than firms and universities, they are also less sensitive to economic fluctuations (Link, Siegel, & Van Fleet, 2011). Thus, when a government spin-off starts, it benefits uniquely from its parent.

People. The founding teams of government spin-offs are unusual in that they tend to be composed of federal employees that leave relatively secure positions at facilities that have considerable resources (Carayannis *et al.*, 1998). These founders innovated in supportive environments with a range of resources, including those at other government research centers. Therefore, inexperience with harsh start-up conditions, such as limited resources, can prove difficult. The founding teams of government spin-offs also have less business experience than those of corporate spin-offs (Audretsch *et al.*, 2002) and less business knowledge (Ensley & Hmieleski, 2005; Zahra *et al.*, 2007). In terms of networks, government spin-off founders have networks concentrated on government relationships due to having less interaction with corporate partners compared to academic and corporate spin-offs. A government-focused network will have fewer ties in industry and less business experience, which limits the market opportunities for the firm. However, a well-established network with the government market is useful for firms in industries that target government customers (e.g. defense-related industries). Thus, government spin-offs are both helped and hindered by their lineage.

METHODS

Data and Research Setting

To compare the outcomes of start-up firms, this study analyzes nanotechnology firms started in the United States between 1980 and 2002. Nanotechnology is the R&D of materials and products between one and 100 nanometers (National Science and Technology Council, 2000). Nanotechnology R&D has found applications in nearly every industry, ranging from semiconductors to optics to biotechnology (National Nanotechnology Coordination Office, 2007). Nanotechnology entrepreneurship provides insight into spin-offs from universities, government labs, and firms as well as independent start-ups.

To study these firms, information about all U.S. nanotechnology firms started between 1980 and 2002 was compiled into a comprehensive database. The database is especially appropriate for this study since all nanotechnology firms were established after the 1980 Bayh-Dole Act, which allowed universities and government laboratories to own the IP created therein that was supported by government funding. Additionally, the year 1981 marks a fundamental milestone in nanotechnology. That year, two IBM researchers invented the scanning tunneling microscope (STM), the first instrument that enabled scientists to see and manipulate material at the nanoscale (National Nanotechnology Initiative, 2006; Smalley, 1999). The STM is considered the foundation of nanotechnology (Woolley, 2010). Likewise, no nanotechnology-specific firm was founded before 1981, thus providing a starting date for this study. This ensures that the data are not left-censored, whereby the origins of an event occur before the opening of the observation window (Yamaguchi, 1991; Blossfeld & Rohwer, 2002).

In 2000, the National Nanotechnology Initiative (NNI) was passed and implemented in the U.S. The NNI provided researchers in the field with almost a half billion dollars the first year and contributed five billion cumulatively over the next five years into nanotechnology R&D (National Nanotechnology Coordination Office, 2007). Prior to the NNI, the cumulative government funding of nanotechnology R&D (including commercialization) totaled less than what was invested in 2001 alone. To avoid the influence of the environmental change sparked by the NNI, only firms founded through the year 2001 were included in this study.

A master list of nanotechnology firms was compiled from industry lists, directories, press releases, publications, and web sites related to nanotechnology. For example, lists and directories were obtained from (1) Nano Science and Technology Institute (NSTI); (2) NanoInvestorNews (market research); (3) NanoMarkets (market research); (4) NanoTechWire; (5) Small Times Media; and (6) the Foresight Institute. These resources obtain data directly from nanotechnology-related organizations. Data from these sources were aggregated and augmented with information about firms discovered in a search for nanotechnology in PR Newswire and PriceWaterhouseCoopers' venture capital site.

Before being added to the database, each firm was analyzed to determine if it fit the criteria for being a nanotechnology firm: single-business ventures founded to develop, produce, and sell nanotechnology products on the merchant market. Specifically, included firms must have more than 50 percent of their activities, such as products, R&D, or sales, derived from or related to nanotechnology. Thus, captive producers, divisions, and subsidiaries of existing firms, distributors, designers, custom engineering, software, investing, and consulting firms were excluded. Nanotechnology-related activities were identified by firms' product, patent, and technology data. The final list of nanotechnology firms was compared to that of a colleague who had undertaken a similar process to identify such firms. The databases overlapped by almost 90 percent and any firms not included in the original database were examined using the previously identified criteria for nanotechnology firms. No additional firms met the criteria, as they were: (1) firms proposing to use nanotechnology, but unsuccessful; (2) software modeling firms; or (3) firms using micro-level technology, but not nanoscale. Thus, the database was not augmented. Given the extensive search, it is probable that nearly all new nanotechnology firms have been captured in this database. However, if the founders of a nanotechnology company were not involved in the nanotechnology community, elected not to expose their existence, and were not known to others in the community, this firm would not be discernible and not be included. However, as the nanotechnology is science-based and there are very few people with the substantial knowledge of the technology needed for a commercial endeavor, it is unlikely that a firm would remain undetected by the community.

Independent variables. The independent variables of interest focus on firm origins. In-depth data were collected on each firm, the technology or IP on which it was founded, and its founding team. Data were collected from firm, university, and government documents, websites, and patent files, as well as articles from FACTIVA and sources listed above. Data sources also included Dun and Bradstreet, Hoover's, and NAICS listings. Separate dichotomous variables identified if the firm's foundational IP was from 1) a university research center, 2) an existing firm, 3) a government research center, or 4) internally derived. Spin-off firm origins are also distinguished by background of their founding team members. Thus, the employment of each founder was gathered through university records, company documentation, resumes, and profiles. Three proportion measures were calculated for each firm: the proportions of professors, business executives, and others (such as student or research scientist) on the founding team.

Dependent variables. Scholars studying survival and death of firms often take a dichotomous view: either the firm succeeds and is alive or fails and is dead (Wennberg *et al.*, 2010). For the most part, firm exits have been treated in the literature as a failure. However, research has started to distinguish between firms that end in distress (low performance) and those that are closed while performing well (Bates, 2005; Wennberg, Wiklund, & Wright, 2010). For instance, Rothaermel and Thursby (2005) distinguished between a negative outcome, cessation, and two positive outcomes survival and graduation from a technology incubator.

To provide a more nuanced analysis of firm outcomes, this study uses five dependent variables of interest: firm closure, acquisition, liquidation/bankruptcy, venture capital, and Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) funding. Firm closure was measured as the cessation of business activity as an individual entity (0=alive, 1=the firm had ceased operations). For firms that had ceased to exist, the year of cessation was recorded and the number of years from founding to death was calculated. Since firm closure cannot provide insight into the performance of the firm, two additional variables were constructed: closure by acquisition and closure due to liquidation or bankruptcy. Firm acquisitions are a type of firm exit in which all of a firm's assets are purchased by and incorporated into another firm. In contrast to other forms of business cessation such as distress liquidation, bankruptcy, or dissolution, an acquired firm may be performing well. In fact, firms with knowledge and IP valued by the industry and other firms are likely to be the target of an acquisition. Acquisitions also provide investors with a mechanism to exit and potentially profit. Although acquisitions can be hostile or friendly (i.e. with or without cooperation from the firm's stakeholders), the purchase of a firm indicates value. This suggests that we should not hold acquisitions in the same light as other firm exits (Greve, 2011; Fortune & Mitchell, 2012). In cases such as this study when financial metrics are not available, information about a firm's acquisition can indicate whether the firm closed in distress or in success. Here, firm acquisition was measured as a dummy variable (0=not acquired, 1=acquired), along with the time from founding until firm acquisition was recorded. Similar variables were constructed to identify firms that closed due to liquidation or bankruptcy, which indicate ceasing operations in duress.

Just as firm closure does not always indicate positive performance, firm survival does not always indicate success. Thus, two additional variables were constructed to indicate two positive, yet contrasting outcomes: venture capital funding (VC) and government funding though SBIR and STTR grants. VC refers to an investment by a company in exchange for partial equity ownership of the focal firm. Venture capitalists not only provide funding for operations, but also often mentor the management of the firm through their own team of investors who have years of business knowledge. Thus, VC funding is a positive signal to the market and helps firms build legitimacy for emerging fields (Aldrich & Ruef, 2006), which is critical for nascent technologies. A binary variable measured if a firm had obtained VC funding and the time to first funding was calculated.

SBIR and STTR are government grant programs funded by 11 of the largest government agencies in the U.S. and administered through the U.S. Small Business Administration.[1] One of

[1] The 11 agencies are the Department of Agriculture (USDA), Department of Commerce - National Institute of Standards and Technology (DOC-NIST), Department of Commerce - National Oceanic and Atmospheric Administration (DOC-NOAA), Department of Defense (DOD), Department of Education (ED), Department of Energy (DOE), Department of Health and Human Services (HHS), Department of Homeland Security (DHS),

the main goals of the SBIR and STTR programs is to help organizations cross the "valley of death" between invention and commercialization: the point at which an innovation is promising, but too expensive for private investors to pursue (Bonvillian, 2011). Awardees are chosen through a competitive process that focuses on firms believed to be viable and to have the potential to successfully bring their technology to market.[2] These programs provide financing that increases a firm's ability to improve staff skills and conduct long-term research (Cooper, 2003). Obtaining a SBIR or STTR grant also enables recipient firms to better compete with larger firms with more resources. The vetting process also helps establish legitimacy and credibility for SBIR and STTR recipients. Again, in the present study a binary variable measured if a firm had obtained an SBIR or STTR grant and the time to first grant was calculated.

Control variables. Since the year a firm was started can influence a firm's mortality (Singh *et al.*, 1986), the year of first founding was included in the models. The number of nanotechnology firms alive each year was included to control for density dependence (Hannan & Freeman, 1988; Carroll & Hannan, 1989). To ensure that the death or acquisition of firms is not simply a reflection of the overall firm activity, trends in the economy and the number of all firm closures each year in the U.S. were included (Hannan & Freeman, 1988). All such environmental control variables were taken at a two-year lag to provide time for the macro-level

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Department of Transportation (DOT), Environmental Protection Agency (EPA), National Aeronautics and Space Administration (NASA), and National Science Foundation (NSF).

[2] The first phase of SBIR and STTR funding is limited to about $150,000 (originally $50,000 in 1982, which increased to $100,000 in 1992 and to its current level in 2013) over six months and focuses on projects that evaluate the feasibility and commercial potential of an R&D effort. Additional information regarding the SBIR and STTR programs is available at www.sbir.gov.

condition to have an effect.[3] All models included industry controls and the total number of patents obtained by the firm. Closure, acquisition and negative closure models included binary firm-level measures indicating VC funding and SBIR or STTR grants as well.

Analysis

Event history analyses were conducted on the data using STATA with maximum likelihood estimation and robust standard errors. Data with consistently decreasing survival prospects are best modeled with Weibull and Gompertz models. Models can be compared by considering the difference in the log-likelihood ratios using the chi-square distribution (Blossfeld & Rohwer, 2002). Comparing the models showed that the best fitting survival model for the data was the Weibull failure (event) time model. Hazard ratios were estimated such that values over one indicate an increase in the likelihood that the covariate influenced the dependent variable, and values under one indicate lower likelihood of covariate influence.

Insert Figure 1 about here

Insert Table 2 about here

FINDINGS

By the end of 2001, 187 nanotechnology firms had been started, of which 43 percent were academic spin-offs, 11 percent were corporate spin-offs and seven percent government spin-offs.

[3] Geographic controls and annual government funding for nanotechnology R&D were tested, but did not show significance and were not included in the models. As a robustness check, the data were modeled controlling for the total number of founders, but this was also not significant.

The remaining 39 percent were de novo start-ups. Figure 1 shows the number of nanotechnology firms surviving each year between 1981 and 2001 by origin. Academic spin-offs and non-spin-off start-ups enjoyed the largest growth, especially after 1995 as indicated in Figure 1. The firms included several different industries: 32% were in the materials industry, 21% were instrumentation, 12% biotechnology, 11% pharmaceuticals, 5% optics, 5% electronics, and 4% semiconductors. The remaining firms were active in other industries such as energy and various consumer products. Table 2 shows the correlation matrix for the variables, their means and standard deviations.

The models for the event history analysis for each of the dependent variables are presented in Tables 3 through 7. The first model in each table shows the results for the control variables. IP origins (academic, corporate, or government) are added stepwise in the next three models in each table. The fifth model shows the results for all IP types together. The last model includes the background of the founding team with the proportions of professor founders and executive founders.

Table 3 shows the results for all types of firm cessation of business, both positive and negative. Of the control variables, neither the number of patents nor the attainment of VC influenced the closure of the firm. However, government spin-offs were significantly more likely to close than other firms and corporate spin-offs were less likely to close. Having a higher proportion of business executives on the founding team increased a firm's likelihood to close.

Providing details into firm closures, Table 4 displays the results for firm acquisitions. While patents did not influence closure by acquisition, obtaining VC did increase the likelihood of being acquired. Models 9 and 10 show that while government spin-offs were more likely to close than other start-ups (Models 4 and 5), they were more likely to do so by being acquired, a positive outcome. The composition of the founding team was not significantly tied to acquisitions.

Looking at the negative side of firm closures, Table 5 shows the results for cessation by liquidation and bankruptcy. Only the proportion of business founders influenced the likelihood of a negative closure, and showed a significant increase in liquidations and bankruptcies. The positive outcomes of obtaining VC or government grants are shown in Tables 6 and 7, respectively. Origins and government funding were both positively associated with obtaining VC funding and government grants. Firms with university IP or a higher proportion of professor founders were also more likely to obtain VC. Obtaining government grants was also associated with university spin-offs.

Insert Table 3-7 about here

DISCUSSION AND CONCLUSIONS

Currently literature suffers four weaknesses: 1) a lack of work that distinguishes between the different types of spin-offs, 2) few in-depth comparisons of the outcomes for these spin-offs, 3) little understanding of government spinoffs, and 4) a lack work using different types of outcomes. This study empirically examines the fates of nanotechnology firms with different origins in terms of IP source and founding team composition. The results are provocative, showing that the origins of a high-technology firm does influence its likelihood of closing, being acquired, going bankrupt or liquidating, obtaining venture capital, and receiving government funding. Table 8 summarizes the results by type of spin-off and outcomes.

Including three types of spin-offs along with de novo start-ups in the analysis here provides insight into the role of resources gained at founding. Rare studies have compared academic and corporate spin-off outcomes. The work here builds on the comparative studies of Wennberg and colleagues (2011) and Clarysse and colleagues (2011b) who include both types in their analyses of growth. This study shows that academic and corporate spin-offs differ greatly in their long-term prospects. For example, firms with academic origins, either started with university IP or with a high proportion of professors on the founding team, are more likely to obtain VC or government funding than other firms. This may be due to academic spin-offs tending to be cutting edge and farther from commercialization than other firms, and subsequently having a higher need for additional funding to reach market. Alternatively, academic spin-offs rarely obtain financial support from their parent. Thus, these firms may need more funding, faster than other start-ups, and the executives of academic spin-offs may seek additional funding quickly.

The outcomes of corporate spin-offs vary depending on the type of corporate resources that define the firm. Spin-offs based on IP from parent firms are not significantly different than other firms, with the exception of being less likely to close (at the 0.1 level of significance). However, corporate spin-offs defined by having a high proportion of founders from a parental firm are three times more likely to close through bankruptcy or liquidation. These spin-offs are also more likely to obtain VC (at the 0.1 level of significance). These results suggest that in terms of corporate spin-offs, it is not the IP that defines a spin-off's success, but the people. The previous experience of this team in the corporate world may not be as beneficial an asset as originally thought. The increased likelihood of bankruptcy or liquidation may be indicative of the business founders' familiarity with and the lack of a negative perception for these outcomes.

If the possibility of closing a firm by bankruptcy or liquidation is not perceived as potentially harmful to one's career, the founder may be more likely to follow this course of action. Similarly, founders who lack industry experience may fear these types of business cessation as potentially career ending or have a more difficult reentering their previous profession. Thus, these founders may avoid closure, even if this means survival with low performance.

Government spin-offs have been neglected in entrepreneurship literature (Rogers *et al.*, 2001; Smith & Ho, 2006). This study not only includes government spin-offs as a distinct form of venture, but also compares their long-term outcomes with those of other types of start-ups in the same market. The findings show that government spin-offs are more likely to close than other firms, but these closures are mainly from being acquired. In fact, government spin-offs are five times more likely to be acquired than other firms in the market. A driving factor in the acquisitions may be the stage of development of government IP since it tends to bridge basic science and commercial application (Bozeman, 2000). As such, government IP may also be at the stage at which other firms can integrate it into complementary product development. Additionally, government spin-offs are attractive acquisition targets when they target and have been adopted by the government market. Development of government contracts is a valuable asset since the market is considerably large. Surprisingly, firms with government origins were not more likely to obtain government funding. Over seven percent of the sample in this study were based on government IP and over half of these were founded by former government employees. Thus, the experience of these firms with the government provides knowledge about the requirements of such funding programs. However, instead of obtaining developmental funding these firms were acquired.

Another unique contribution of this study is the use of five types of outcomes, one of which is considered negative. The inclusion of acquisitions, VC and government funding as indicators of success provides insight about outcomes from multiple angles. This is particularly useful since success means different things to different stakeholders. For some founders, being acquired after achieving breakeven and a considerable market share is exactly what they wanted for themselves and the company. An acquisition may be one of the few ways for the firm to grow. Other founders find that they have investors who push to be acquired since they want to obtain a return on their investment or "cash out." Both situations can be considered successful. However, founders and investors may have different and sometimes conflicting objectives, such as the case in which founders want to continue organic growth. The power of the investors is also a factor that has not been greatly explored in previous research. If investors outside of the founding team gain control of company, they may make decisions that conflict with how the founders originally conceived of success.

The difference in outcomes found here also may be due to differences in the founders' time horizon —a factor largely unexplored in current research. For example, founders who previously worked at firms may be more concerned with the fast pace of the investment community who typically want to cash out within five to ten years. These founders may make decisions to optimize short-term returns and attractiveness to potential acquirers. Alternatively, researchers who work on projects that require years for results may see no urgency to cash out. For example, it took 32 years for NASA to launch the Space Infrared Telescope Facility in 2003 (Rottner, 2010). These founders may make decisions with long-term success in mind. Thus, it is important for start-up founders and early investors to identify the outcomes they are seeking. Furthermore, aligning these goals may influence the success of their venture, by any measure.

The results of this study highlight many interesting opportunities for research. For example, further research is warranted to unpack the resource stocks of spin-off firms (Agarwal, *et al.*, 2004; Wiklund & Shephard, 2003; Clarysse et al., 2011b). In addition to patents and professor-founders, which remain topics of interest in spin-off literature (e.g. Ensley & Hmieleski, 2005; Ding & Choi, 2011; Clarysse et al., 2011a), other distinctive resources may prove interesting such as the continued monetary support by parent firms, the ownership of IP, or type of technology. For instance, the type of spin-off technology may limit a firm's scalability and thus IPO prospects. Additional categorization of spin-offs may also provide insight into the role of resource stocks for start-ups (e.g. Druilhe & Garnsey, 2004). Research in this area is promising.

This study focuses on nanotechnology firms across all industries. Such a specialized field requires specific knowledge related to the technology. The sample here represents what are considered the "hard sciences" such as engineering, physics, chemistry, and biology. Thus, this study is limited to only a portion of potential spin-offs, excluding those from the "soft sciences" such as psychology, humanities, and business. An interesting line of research could compare the types of academic spin-offs. The findings here suggest that further research should attend to the different types of spin-offs as well as the different types of outcomes, good and bad, to provide a richer understanding of the dynamics at play.

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TABLE 1A
Summary of advantages and disadvantages of academic spin-offs

	Benefits	Examples of related work	Disadvantages	Examples of related work
IP	*Main type: Basic research*			
	- Cutting edge technology and IP	Wennberg et al., 2011	- Ahead of market readiness	
			- Not invented with market in mind	Wennberg et al., 2011
			- Not close to market ready	Jensen & Thursby, 2001; Shane, 2000; Rothaermel & Thursby, 2005; Thursby et al., 2007; Clarysse et al., 2011b; Wennberg et al., 2011
			- Originate in a non-commercial environment	Bathelt et al., 2010
			- Considered high risk	Rothaermel & Thursby, 2005
Parent	- Access to resources (e.g. research assistants, labs, libraries, etc)	Quintas et al., 1992; Colombo & Delmastro 2002; Lockett & Wright, 2005; Powers & McDougall, 2005; Grandi & Grimaldi, 2003; DeGroof, 2004; Mian, 1996	- Lack of support for profit generation activities	Vohora et al., 2004; Lockett & Wright, 2005; Siegel et al., 2003
	- Post founding support	Mian, 1996	- Multiple stakeholders, bureaucracy, resource control	Vohora et al., 2004
	- Technology transfer mechanisms	Rothaermel et al., 2007; Clarysse et al., 2007; Clarysse et al., 2011a	- Stakeholders with conflicting objectives	Clarysse et al., 2007; Jensen & Thursby, 2001; Vohora et al., 2004; Visintin et al., 2014
	- University network	Colombo & Delmastro, 2002; Lindelof & Lofsten, 2004; Murray, 2004	- Limited experience and expertise of technology transfer offices	Lockett & Wright, 2005; Siegel et al., 2003; Vohora et al., 2004
	- Signals legitimacy	Stuart & Ding, 2006; Ding & Choi, 2011; Mian, 1996; Rothaermel & Thursby, 2005	- Limited and diffused resources and attention allocation	Lockett & Wright, 2005; Siegel et al., 2003; Vohora et al., 2004
	- Access to subsidies and research programs	Colombo & Delmastro, 2002	- Contentious IP protection	Thursby et al., 2001
	- Knowledge resources	Clarysse et al., 2011b; Zahra et al., 2007	- VC bias against	Munari & Toschi, 2011; Wright et al., 2006; Watson et al., 2003
	Scientists and other academic founders			
People	- Education	Burton, et al., 2002; Wennberg, et al., 2011; Watson et al., 2003; Sapienza & Grimm, 1997	- Tacit knowledge required continuation of academic founders	
	- In-depth technical knowledge	Ding & Choi, 2011; Clarysse et al., 2011b	- Lack industry knowledge and experience	Wennberg et al., 2011; Zahra et al., 2007; Ensley & Hmieleski, 2005
	- R&D network	Lofsten & Lindelof, 2005; Murray, 2004	- Lack entrepreneurship experience, opportunity recognition or exploitation skills	Duchesneau & Gartner, 1990; Stuart & Abetti, 1990; Franklin et al., 2001
			- Lack commercial goals / incentives	Ensley & Hmieleski, 2005; Clarysse & Moray, 2004; Roure & Keeley, 1990
			- Homogeneity leads to reduced decision making efficacy	Ensley & Hmieleski, 2005; Ruef et al., 2003; Beckman et al. 2007; Fesser & Willard, 1990; Visintin & Pittino, 2014
			- Lack industry network	Zahra et al., 2007; Shane & Stuart, 2007; Walter, Auer, & Ritter, 2006; Mosey & Wright, 2007
			- Difficulty developing social capital	Mustar et al., 2006; Nicolaou & Birley, 2003; Corrolleur et al., 2004; Mosey & Wright, 2007

TABLE 1B
Summary of advantages and disadvantages of corporate spin-offs

	Benefits	Examples of related work	Disadvantages	Examples of related work
IP	*Main type: Applied R&D*	Singh et al., 1986		
	- Created with market in mind		- Lack of outsider perspective	
	- Closer to commercialization	Chatterji, 2009; Wennberg et al., 2011	-IP from small markets deemed unappropriable	Bruneel et al., 2013
	- Investors perceived as less risky	Schipper & Smith, 1983; Seward & Walsh,		
Parent	- Imprints routines	Nelson & Winter, 1982; Romanelli, 1989; Phillips, 2002	- Imprinted routines	Amburgey et al., 1993; Romanelli, 1989; Klepper & Sleeper, 2005
	- Existing supply chain relationships	Semadeni & Cannella, 2011	- Power dynamics	Semadeni & Cannella, 2011
	- Resources and infrastructure	Scott, 2003; Teece, 1988		
	- Legitimacy via reputation of parent firm.	Stuart et al., 1999	- If maintains ownership, continues	Semadeni & Cannella, 2011
	- If maintains ownership, continues oversight	Semadeni & Cannella, 2011		
	Former employees of incumbent firm			
People	- Heterogeneous	Ensley & Hmieleski, 2005; Ruef et al., 2003; Beckman et al., 2007	- Lack technical proficiency	
	- Industry experience	Colombo & Grilli, 2005; Colombo & Piva, 2012; Siegel et al., 2003; Fesser & Willard, 1990	- Myopic industry knowledge and experience	
	- Industry and market knowledge	Klepper & Sleeper, 2005; Agarwal, et al. 2004; Wennberg et al., 2011		
	- Network and social capital with industry and former co-workers	Sapienza et al., 2004; Higgins & Gulati, 2003; Yli-Renko et al., 2001; Shane & Stuart, 2002		
	- Ties with venture capital	Shane & Stuart, 2002		

TABLE 1C
Summary of advantages and disadvantages of government spin-offs

	Benefits	Examples of related work	Disadvantages	Examples of related work
IP	*Main type: Basic and Applied R&D*			
	- Progressed beyond basic science toward application	Bozeman, 2000	- Focused, application specific	Rogers et al., 2001
	- Focused, application specific	Rogers et al., 2001	- Not adaptable to other markets	Rogers et al., 2001
	- Created for government market (specialized)	Rogers et al., 2001	- Created for government market - specialized	Rogers et al., 2001
	- Complex and large-scale	Hruby et al., 2011		
	- Patent quality has improved slightly over time	Jaffe & Lerner, 2001	- Unclear market potential	
Parent	- Transfer knowledge of target market protocol		- Provides little guidance or market support	
	- Government parent relationship with existing government market		- Difficult transition from government to market	
	- Continued relationship and support	Audretsch et al., 2002	- Bureaucracy	
	- Support for R&D	Toole & Czarnitzki, 2007		
	- Legitimacy signal	Scott, 2003		
	Former governent employees			
People	- Team supported by centers with considerable resources	Carayannis, 1998	- Lack of business knowledge and commercialization experience	Audretsch et al., 2002; Ensley & Hmieleski, 2005; Zahra et al., 2007
	- Concentrated government network		- Concentrated government network	
	- Relationship with government customers		- Limited network scope	

TABLE 2
Descriptive Statistics and Correlation Matrix

Variable	Mean	Std. Dev.	Min	Max	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1 Closure	0.45	0.50	0	1	1.00																
2 Acquisition	0.27	0.44	0	1	0.67	1.00															
3 Negative Failure	0.14	0.35	0	1	0.35	0.11	1.00														
4 Venture Capital	0.31	0.46	0	1	0.07	0.17	0.03	1.00													
5 SBIR or STTR Funding	0.60	0.49	0	1	-0.15	-0.10	-0.05	0.16	1.00												
6 Year Founded	1998	3.23	1981	2001	0.06	0.01	-0.03	0.25	-0.11	1.00											
7 Nanotech Firms	492.0	108.3	84.0	621.0	-0.72	-0.51	-0.22	0.05	0.15	0.11	1.00										
8 US Firm Closures ('000)	443.6	22.3	378.0	508.7	-0.17	-0.08	-0.08	0.14	-0.02	0.06	0.61	1.00									
9 VC	0.31	0.46	0	1	0.07	0.17	0.03	1.00	0.16	0.25	0.05	0.14	1.00								
10 SBIR or STTR Funding	0.60	0.49	0	1	-0.15	-0.10	-0.05	0.16	1.00	-0.11	0.15	-0.02	0.16	1.00							
11 University IP	0.43	0.50	0	1	0.04	-0.03	0.06	0.28	0.19	0.13	-0.03	0.04	0.28	0.19	1.00						
12 Firm IP	0.11	0.31	0	1	0.07	0.10	0.01	-0.01	-0.07	-0.04	-0.09	0.06	-0.01	-0.07	-0.26	1.00					
13 Govt IP	0.07	0.26	0	1	0.07	0.10	-0.06	-0.06	0.02	-0.01	-0.05	-0.10	-0.06	0.02	-0.16	-0.10	1.00				
14 Proportion Prof Founders	0.28	0.40	0	1	0.02	0.06	0.00	0.31	0.19	0.09	-0.04	-0.01	0.31	0.19	0.54	-0.11	-0.20	1.00			
15 Proportion Busi Founders	0.43	0.45	0	1	0.11	0.03	0.13	0.04	-0.17	0.06	-0.04	0.13	0.04	-0.17	-0.23	0.07	0.01	-0.32	1.00		
16 Balanced Founding Team	0.13	0.34	0	1	-0.01	0.05	-0.02	0.08	0.03	0.01	0.06	0.06	0.08	0.03	0.20	-0.03	-0.05	0.10	-0.05	1.00	
17 Heterogeneous Founding Team	0.08	0.27	0	1	-0.03	0.00	0.11	0.23	0.04	0.14	0.08	0.02	0.23	0.04	0.14	-0.04	-0.01	0.19	-0.07	-0.06	1.00

TABLE 3
Event History Analysis – Firm Closure

	Model 1		Model 2		Model 3		Model 4		Model 5		Model 6	
	Haz. Ratio (Std. Err.)		Haz. Ratio (Std. Err.)		Haz. Ratio (Std. Err.)		Haz. Ratio (Std. Err.)		Haz. Ratio (Std. Err.)		Haz. Ratio (Std. Err.)	
Year Founded	3.33	***	3.34	***	3.39	***	3.39	***	3.48	***	3.62	***
	(0.51)		(0.53)		(0.54)		(0.54)		(0.58)		(0.67)	
Nanotech firms	0.02	***	0.02	***	0.02	***	0.02	***	0.02	***	0.02	***
	(0.01)		(0.01)		(0.01)		(0.01)		(0.01)		(0.01)	
US Firm Closures	0.78	*	0.78	^	0.80	^	0.79	^	0.81	^	0.75	*
	(0.10)		(0.10)		(0.10)		(0.10)		(0.10)		(0.11)	
VC	1.15		1.16		1.18		1.15		1.22		1.16	
	(0.33)		(0.33)		(0.33)		(0.33)		(0.34)		(0.32)	
Govt Funding	0.63	^	0.64	^	0.64	^	0.67		0.71		0.76	
	(0.15)		(0.16)		(0.16)		(0.17)		(0.19)		(0.21)	
University IP			0.91						0.79		0.79	
			(0.20)						(0.17)		(0.18)	
Firm IP					0.57	^			0.52	^	0.54	^
					(0.19)				(0.19)		(0.18)	
Govt IP							2.29	*	2.05	*	2.03	^
							(0.81)		(0.74)		(0.75)	
Prof Founder Proportion											1.25	
											(0.39)	
Business Founder Proportion											1.77	*
											(0.50)	
Time at risk	2259		2259		2259		2259		2259		2259	
Log pseudolikelihood	19.04		19.12		20.36		20.81		22.32		24.28	
Wald chi2(12)	136.8	***	136.8	***	130.5	***	136.6	***	132.0	***	128.3	***

n= 187, failures = 84 *** p<0.001; ** p<0.01, * p<0.05, ^p<0.1

TABLE 4
Event History Analysis – Acquired

	Model 7		Model 8		Model 9		Model 10		Model 11		Model 12	
	Haz. Ratio (Std. Err.)		Haz. Ratio (Std. Err.)		Haz. Ratio (Std. Err.)		Haz. Ratio (Std. Err.)		Haz. Ratio (Std. Err.)		Haz. Ratio (Std. Err.)	
Year Founded	1.40	***	1.40	***	1.39	***	1.42	***	1.40	***	1.40	***
	(0.10)		(0.10)		(0.10)		(0.11)		(0.10)		(0.10)	
Nanotech firms	0.19	***	0.19	***	0.19	***	0.17	***	0.16	***	0.16	***
	(0.04)		(0.04)		(0.04)		(0.04)		(0.04)		(0.04)	
US Firm Closures	1.52	***	1.52	***	1.52	***	1.59	***	1.61	***	1.64	***
	(0.18)		(0.17)		(0.18)		(0.20)		(0.19)		(0.21)	
VC	2.42	*	2.93	**	2.39	*	2.48	*	2.98	^	2.95	**
	(0.88)		(1.05)		(0.88)		(0.97)		(1.15)		(1.13)	
Govt Funding	0.92		0.94		0.92		0.86		0.86		0.84	
	(0.37)		(0.36)		(0.37)		(0.35)		(0.35)		(0.35)	
University IP			0.56	^					0.56		0.55	
			(0.17)						(0.20)		(0.22)	
Firm IP					0.90				0.71		0.71	
					(0.37)				(0.35)		(0.35)	
Govt IP							5.11	***	4.42	***	4.45	***
							(2.02)		(1.88)		(2.03)	
Prof Founder Proportion											1.04	
											(0.57)	
Business Founder Proportion											0.78	
											(0.30)	
Time at risk	2413		2413		2413		2413		2413		2413	
Log pseudolikelihood	-71.10		-69.49		-71.07		-66.87		-65.55		-65.25	
Wald chi2(12)	105.04	***	108.77	***	106.07	***	109.39	***	104.21	***	114.99	***

n= 187, failures = 50 *** p<0.001; ** p<0.01, * p<0.05, ^p<0.1

TABLE 5
Event History Analysis – Negative Closure

	Model 13		**Model 14**		**Model 15**		**Model 16**		**Model 17**		**Model 18**	
	Haz. Ratio (Std. Err.)		Haz. Ratio (Std. Err.)		Haz. Ratio (Std. Err.)		Haz. Ratio (Std. Err.)		Haz. Ratio (Std. Err.)		Haz. Ratio (Std. Err.)	
Year Founded	4.89	***	4.72	***	4.90	***	4.85	***	4.70	***	5.36	***
	(1.09)		(1.05)		(1.11)		(1.04)		(1.03)		(1.50)	
Nanotech firms	0.01	***	0.01	***	0.01	***	0.01	***	0.01	***	0.01	***
	(0.01)		(0.01)		(0.01)		(0.01)		(0.01)		(0.01)	
US Firm Closures	0.40	*	0.38	*	0.41	^	0.39	^	0.39	^	0.36	*
	(0.19)		(0.19)		(0.19)		(0.19)		(0.21)		(0.18)	
VC	1.06		1.06		1.10		1.06		1.08		1.02	
	(0.54)		(0.52)		(0.56)		(0.55)		(0.53)		(0.50)	
Govt Funding	0.53	^	0.46	^	0.52	^	0.53	^	0.47	^	0.59	
	(0.21)		(0.20)		(0.21)		(0.21)		(0.21)		(0.29)	
University IP			1.62						1.51		1.56	
			(0.77)						(0.74)		(0.85)	
Firm IP					0.60				0.73		0.76	
					(0.52)				(0.66)		(0.71)	
Govt IP							0.71		0.71		0.84	
							(0.85)		(0.86)		(1.00)	
Prof Founder Proportion											1.10	
											(0.68)	
Business Founder Proportion											3.16	*
											(1.80)	
Time at risk	2259		2259		2259		2259		2259		2259	
Log pseudolikelihood	-6.90		-6.35		-6.61		-6.84		-5.84		-3.61	
Wald chi2(12)	101.11	***	107.00	***	98.21	***	125.18	***	111.20	***	105.84	***

n= 187, failures = 26 *** p<0.001; ** p<0.01, * p<0.05, ^p<0.1

TABLE 6
Event History Analysis – Venture Capital

	Model 19		**Model 20**		**Model 21**		**Model 22**		**Model 23**		**Model 24**	
	Haz. Ratio (Std. Err.)		Haz. Ratio (Std. Err.)		Haz. Ratio (Std. Err.)		Haz. Ratio (Std. Err.)		Haz. Ratio (Std. Err.)		Haz. Ratio (Std. Err.)	
Year Founded	1.30	***	1.28	***	1.30	***	1.30	***	1.28	***	1.32	***
	(0.09)		(0.09)		(0.09)		(0.09)		(0.09)		(0.11)	
Nanotech firms	0.67	*	0.70	^	0.64	*	0.67	*	0.70	^	0.71	
	(0.13)		(0.15)		(0.13)		(0.13)		(0.15)		(0.16)	
US Firm Closures	1.47	*	1.47	*	1.55	**	1.46	*	1.48	*	1.45	*
	(0.25)		(0.23)		(0.25)		(0.25)		(0.24)		(0.23)	
Govt Funding	3.06	**	2.60	**	3.08	***	3.04	**	2.603	**	2.49	*
	(1.08)		(0.96)		(1.08)		(1.08)		(0.97)		(1.00)	
University IP			2.39	**					2.46	*	1.65	*
			(0.76)						(0.91)		(0.68)	
Firm IP					0.58				0.96		0.91	
					(0.38)				(0.67)		(0.64)	
Govt IP							0.81		1.34		1.74	
							(0.55)		(0.93)		(1.33)	
Prof Founder Proportion											3.58	***
											(1.37)	
Business Founder Proportion											1.92	^
											(0.74)	
Time at risk	2111		2111		2111		2111		2111		2111	
Log pseudolikelihood	-167.5		-162.8		-166.8		-167.4		-162.7		-156.8	
Wald chi2(12)	61.88	***	83.87	***	82.21	***	63.04	***	86.40	***	97.96	***

n= 187, failures = 58 *** p<0.001; ** p<0.01, * p<0.05, ^p<0.1

TABLE 7
Event History Analysis – SBIR/STTR

	Model 25		Model 26		Model 27		Model 28		Model 29		Model 30	
	Haz. Ratio (Std. Err.)		Haz. Ratio (Std. Err.)		Haz. Ratio (Std. Err.)		Haz. Ratio (Std. Err.)		Haz. Ratio (Std. Err.)		Haz. Ratio (Std. Err.)	
Year Founded	0.98		0.98		0.98		0.98		0.98		0.98	
	(0.03)		(0.03)		(0.03)		(0.03)		(0.03)		(0.03)	
Nanotech firms	1.47	*	1.49	*	1.45	*	1.47	*	1.49	*	1.50	*
	(0.24)		(0.25)		(0.24)		(0.24)		(0.25)		(0.26)	
US Firm Closures	0.72	*	0.72	*	0.74	*	0.72	*	0.72	*	0.73	*
	(0.11)		(0.11)		(0.11)		(0.11)		(0.11)		(0.12)	
VC	2.23	***	1.91	*	2.22	***	2.26	***	1.93	**	1.87	*
	(0.55)		(0.50)		(0.55)		(0.56)		(0.50)		(0.50)	
University IP			1.78	**					1.83	*	1.64	^
			(0.43)						(0.46)		(0.48)	
Firm IP					0.76				1.00		1.00	
					(0.29)				(0.40)		(0.41)	
Govt IP							1.17		1.38		1.44	
							(0.38)		(0.45)		(0.48)	
Prof Founder Proportion											1.32	
											(0.50)	
Business Founder Proportion											0.99	
											(0.27)	
Time at risk	1354		1354		1354		1354		1354		1354	
Log pseudolikelihood	-271.5		-267.5		-271.2		-271.5		-267.2		-266.7	
Wald chi2(12)	94.70	***	102.15	***	95.55	***	94.63	***	101.08	***	103.42	***

n= 187, failures = 113 *** p<0.001; ** p<0.01, * p<0.05, ^p<0.1

TABLE 8
Summary of results

Type of Spin-out		Closed	Liquidated / Bankrupt	Acquired	VC	SBIR/ STTR
		Negative Outcome		*Positive Outcomes*		
Academic	University IP	0	0	-^	+	+
	Professor Founder	0	0	0	+	0
Corporate	Firm IP	-^	0	0	0	0
	Business Founder	+	+	0	+^	0
Government	Government IP	+	0	+	0	0

^p<0.1, no superscript indicates p<0.05, 0 indicates no significance

FIGURE 1
Number of US Nanotechnology Firms by Origin from 1981 through 2001