Czarnitzki, Dirk; Toole, Andrew A.

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Andrew A. Toole and Dirk Czarnitzki

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Non-technical Summary

This paper argues that academic scientists bring a specialized form of human capital to the companies they found or join. The particular skills that make up their human capital are developed during their research careers in the academic research environment and depend on how scientists chose to respond to the evolution of scientific and commercial opportunities. Looking at a particular group of academic entrepreneurs who commercialize their knowledge through the NIH SBIR program, we find that differences in the scientists' prior research orientation toward scientific and commercial opportunities correlate with differences in their firms' performance. Our empirical results suggest that biomedical academic entrepreneurs whose human capital is oriented toward exploring scientific opportunities significantly improve their firms' performance of research oriented tasks whereas those biomedical academic entrepreneurs whose human capital is oriented toward exploring commercial opportunities significantly improve their firms' performance of invention oriented tasks. Consistent with prior evidence, there also appears to be a form of diminishing returns to scientifically oriented human capital in a commercialization environment. Holding the commercial orientation of the scientists' human capital constant, we find that increasing their human capital for identifying and exploring scientific opportunities significantly detracts from their firms' patenting performance.

Our findings suggest that academic entrepreneurs bring valuable but heterogeneous human capital to the firms they found or join. Their human capital appears to be source of organizational capabilities or competence leading to superior performance. However, we also find that the contribution of these biomedical academic entrepreneurs depends on the "match" between their specialized human capital and specific tasks within the firm. In science-based industries where competitive advantage is closely tied to developments in the Republic of Science, such as the pharmaceutical and biotechnology sectors, academic entrepreneurs may augment their firms' absorptive capacity, act as technological gatekeepers, or build on other aspects of their firms' architectural competence. To the extent that academic entrepreneurs found new firms, the orientation of their human capital toward scientific or commercial opportunities could influence the firms' growth strategies and have implications for the distribution of firm types within science-based sectors. For instance, academic entrepreneurs who have a strong orientation toward scientific opportunities may be

more likely to start “research shop” firms whose strategies do not focus on maximizing standard market performance indicators such as market value, but focus on contract research or technology licensing strategies. While these possibilities remain unexplored, our analysis does highlight the need for additional research on the roles academic scientists play in the firms they found or join and on how these scientists add value to the commercialization process for scientific knowledge as well as to organizational performance more broadly.

Exploring the relationship between scientist human capital and firm performance: The case of biomedical academic entrepreneurs in the SBIR Program*

Andrew A. Toole** and Dirk Czarnitzki***

** Rutgers University, NJ, United States
*** Katholieke Universiteit Leuven, Belgium, and ZEW Mannheim, Germany

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Abstract

Do academic scientists bring valuable human capital to the companies they found or join? If so, what are the particular skills that compose their human capital and how are these skills related to firm performance? This paper examines these questions using a particular group of academic entrepreneurs – biomedical research scientists who choose to commercialize their knowledge through the U.S. Small Business Innovation Research Program. Our conceptual framework assumes the nature of an academic entrepreneurs' prior research reflects the development of their human capital. We highlight differences in firm performance that correlate with differences in the scientists' research orientations developed during their academic careers. We find that biomedical academic entrepreneurs with human capital oriented toward exploring scientific opportunities significantly improve their firms' performance of research tasks such as "proof of concept" studies. Biomedical academic entrepreneurs with human capital oriented toward exploring commercial opportunities significantly improve their firms' performance of invention oriented tasks such as patenting. Consistent with prior evidence, there also appears to be a form of diminishing returns to scientifically oriented human capital in a commercialization environment. Holding the commercial orientation of the scientists' human capital constant, we find that increasing their human capital for identifying and exploring scientific opportunities significantly detracts from their firms' patenting performance.

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Address: Andrew A. Toole
Rutgers University
Dept. of Ag, Food and Resource Economics
55 Dudley Road
New Brunswick, NJ 08901, United States
E-Mail: toole@Aesop.rutgers.edu

Dirk Czarnitzki
K.U. Leuven
Steunpunt O&O Indicatoren
Dekenstraat 2
3000 Leuven, Belgium
dirk.czarnitzki@econ.kuleuven.be

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1 Introduction

Do academic scientists bring valuable human capital to the companies they found or join? If so, what are the particular skills that compose their human capital and how are these skills related to firm performance? These questions are of significant interest to scholars studying entrepreneurship, university technology transfer, and organizational performance. In the entrepreneurship literature, only a handful of studies focus on academic entrepreneurs even though a large literature has emerged examining the influence of founder human capital on the creation and survival of non-academic ventures (Bates 1990; Shane and Khurana 2003; Colombo and Grilli 2005; Mueller 2006; Hsu et al. 2006). In the university technology transfer literature, scholars emphasize the importance of faculty human capital for successful commercialization of university-based discoveries (Jensen and Thursby 2001; Thursby and Thursby 2003; Lowe 2001; Shane 2004). A developing organizational literature emphasizes the role of individuals and their specialized human capital as determinants of firm capabilities and competitive advantage (Grant 1996; Zucker et al. 2002; Song et al. 2003, Gittelman and Kogut 2003; Lacetera et al. 2004; Felin and Hesterly 2007).

In this paper, we examine the role of scientist human capital in firm performance using a particular group of academic entrepreneurs – biomedical research scientists who choose to commercialize their knowledge through the U.S. Small Business Innovation Research (SBIR) program. The SBIR program provides a unique opportunity to identify and characterize academic entrepreneurs and examine how their human capital influences firm performance. As individual scientists venture from research to commercialization they can be tracked since many of the principal investigators (PIs) on SBIR projects were researchers at universities and other non-profit research institutions. The firms they found or join are mostly small startups without long histories of asset accumulation. Our focus on small start-ups should provide a clean "laboratory" for examining how scientist human capital affects firm performance.

To date only a few scholars have written about the role of the SBIR program in academic entrepreneurship (Lerner 1999; Audretsch et al. 2002; Toole and Czarnitzki 2007). Toole and Czarnitzki (2007) provide the first broad-based evidence that biomedical scientists use the SBIR program to transfer knowledge and technology to the private sector. Using data from 1983 to 1996, they consider SBIR principal investigators with awards from the Department of Health and Human Services, the umbrella agency housing the National Institutes of Health (NIH), that were previously NIH supported academic scientists. They examine several

performance measures for the SBIR firms associated with these biomedical academic entrepreneurs and find they perform better than other SBIR firms.

This analysis addresses one of the gaps in the current literature by examining the relationship between the human capital of the academic entrepreneurs and the performance of the firms they found or join. Several scholars argue that new knowledge, research skills, management experience, and social networks are developed by running an academic laboratory and that this human capital is valuable and transferable to for-profit firms.[1] We collect information on two important components of a scientist's human capital which are identified in the literature. First, we measure the biomedical scientist's prior research productivity in terms of his or her annualized success at obtaining research funding from the NIH. The NIH has a long tradition of selecting projects addressing scientific opportunities that are likely to make a significant contribution to scientific knowledge (IOM 1998). Second, we measure the patent productivity of the scientist's prior research. The patent productivity of the scientist's research portfolio indicates the commercial orientation of that individual's human capital. Our empirical analysis examines how both the scientific and commercial components of a scientist's human capital influence the successful performance of research and invention at the firm. Our indicator for research performance is the successful completion of Phase I of the SBIR program and our indicator of invention performance is successful patenting.

For biomedical academic scientists commercializing through the SBIR program, our regression results indicate that the scientific and commercial components of scientists' human capital have differential effects on the performance of research and invention tasks at their firms. Those biomedical academic entrepreneurs with greater NIH research productivity – those individuals who have honed their scientific research capabilities – significantly increase the likelihood that their firms will complete the SBIR program by winning a Phase II award. This suggests that academic research skills are valuable for successfully completing Phase I of the SBIR program which entails "proof of concept" style research, a result that is consistent with the literature on the nature of university-based discoveries and the importance of faculty involvement in successful technology transfer. We find that the patent productivity of the academic entrepreneurs' prior research, a measure of their commercially oriented human

[1] In this paper, we use "human capital" as shorthand for the broader concept of "scientific and technical human capital" which is defined as "the sum of the researchers' professional network ties and their technical skills and resources" (Bozeman et al. 2001, p. 636).

capital, significantly increases both the likelihood their firms will patent as well as the number of firm patents. This suggests that scientists who undertake patentable research and gain experience with the patent system develop human capital that further stimulates invention at their firms. However, holding the commercial orientation of their research constant, increasing the scientists' academic research productivity reduces both the likelihood of patenting at their firms as well as the number of firm patents. It appears that academic entrepreneurs whose human capital is more strongly oriented towards identifying and exploring scientific opportunities actually hinder inventive performance at their firms.

Without more detailed information, it is difficult to know why academic human capital with a stronger orientation toward scientific opportunities does not improve invention at the firm. It may be a form of diminishing returns to academic research skills in a commercialization environment (Zucker et al. 1998). This would be the case, for instance, if the number of patentable ideas from a scientist's human capital falls as his or her human capital is extended along scientific knowledge trajectories, holding other dimensions constant. Gittelman and Kogut (2003) find a negative relationship between the quality of a firm's stock of scientific knowledge and the firm's patent citations and suggest that scientific knowledge creation and patenting follow different and opposing "selection logics" because the value calculations in science and industry are different. It could also be the case that the most accomplished academic scientists devote less time to "bench-level" invention at the firm (Corolleur et al. 2004). While we make no claims about causality at this stage of the research, we believe our results indicate that the nature of an academic entrepreneur's prior research shapes and reflects the development of his or her human capital. The contribution of this "specialized" knowledge worker to firm performance depends on the types of tasks needed to obtain competitive advantage and to execute the firm's growth strategy.

The rest of the paper proceeds as follows. The next section presents our conceptual framework for understanding the relationship between a firm's performance and the capabilities of its research personnel, particularly those individuals who are former academic scientists. Because we focus on academic entrepreneurs in the biomedical sector, our conceptual framework emphasizes the important influences which shape the development of human capital among biomedical academic scientists within the non-profit research environment. Section 3 discusses the SBIR empirical setting for our analysis. This section highlights the advantages and disadvantages of our empirical context. Section 4 begins with a description of our data sources and human capital measures and ends with an overview of our

empirical approach. The regression results appear in section 5 and concluding remarks follow in section 6.

2 Conceptual Framework and Hypotheses

Most observers would agree that specialized knowledge can be a source of value. When this knowledge is held by the employees of a firm, it is theoretically possible for the firm to gain an advantage over its competitors in the performance of certain tasks. A firm that is able to harness the specialized knowledge of its employees for superior performance has developed firm-specific competencies or capabilities (Kogut and Zander 1992; Grant 1996, and many others). Among science-based firms, particularly small startups, the specialized human capital of the firms' scientists can be a source of firm-specific capabilities and superior performance.

Three empirical studies looking at pharmaceutical and biotechnology firms have explored the relationship between firm-specific capabilities and performance. Henderson and Cockburn (1994) examine how patenting performance among pharmaceutical firms depends on two broad classes of organizational capabilities which they call component and architectural competence. They find evidence supporting the importance of these competencies for patenting performance; however, they note that their measure of a firm's architectural competence, which captures the firm's capability for accessing and integrating external knowledge, could reflect the quality of the scientists recruited by the firm.[2] Zucker et al. (2002) examine several performance measures for biotechnology firms and find those firms linked to "star" academic scientists, as measured through co-authorships, perform better. They suggest that a scientist's tacit knowledge, which confers an advantage to the firm because it has an element of "natural excludability," is particularly important for increasing the number and citation rate to firm patents. Interestingly, the marginal impact of star scientists who are "affiliated" with the firm is negative and significant. Gittelman and Kogut (2003) also use citations to a biotechnology firm's patents as an indicator of performance. They find that the "closeness" of a firm's knowledge to open science, as measured by backward patent citations to nonpatented literature, increases performance. However, they

[2] Cockburn and Henderson (1998) extend this line of research using data on co-authorships between private firms and public institutions. They find the degree of "connectedness" with publicly funded researchers significantly increases private research productivity and is correlated with the firm's internal organization. Using the same underlying data, Lacetera et al. (2004) examine how a firm's decision to adoption of science-based drug discovery relates to the hiring of star scientists.

also find that the quality of the firm's scientific knowledge stock, as measured by the average patent cites to the firm's publications, reduces the firm's performance. Overall, these studies suggest that a firm's scientific capabilities are important as a source of advantage in patenting but there also appears to be a form of diminishing returns to scientific capabilities. Firms that are too science-oriented, measured by their affiliation with star scientists or the quality of their publications, have fewer patents and patent citations.[3]

Incentives, Opportunities and the Development of Scientist Human Capital

The nature of the human capital scientists develop over the course of their careers is shaped by the institutional incentive systems characterizing their work environments as well as the evolution of opportunities. In this regard, there are important differences between the non-profit "academic" and for-profit "industrial" research environments. Dasgupta and David (1994), drawing on a rich sociological literature, describe the differences as (also see Stephan 1996):

> It is the nature of the goals accepted as legitimate within the two communities of researchers, the norms of behavior especially in regard to the disclosure of knowledge, and the features of the reward systems that constitute the fundamental structural differences between the pursuit of knowledge undertaken in the realm of Technology and the conduct of essentially the same inquires under the auspices of the Republic of Science.
>
> Dasgupta and David 1994, p. 495

The nature of the goals and reward systems that characterize a scientist's primary community of research peers fundamentally shapes the development of his or her human capital. It does this by acting as a filter or lens that informs his or her perspective on opportunities.[4] Differences in how opportunities are identified, evaluated, and exploited between the communities of researchers influence the extent to which human capital is valuable and transferable across the boundary between the academic and industrial research environments. Academic scientists who are particularly adept at pursing "academic goals," who we think of as individuals with a specialized form of human capital that is honed for

[3] Taking a somewhat different approach, Corolleur et al. (2004) examine how the human capital of scientist founders relates to their position titles within the firm such as Chief Executive Officer. Looking at recently formed biotechnology companies in France, they find that prior scientific experience in academia is negatively related to membership on the Board of Trustees and not significantly related to the other positions analyzed.

[4] Our view of opportunities is consistent with the discussion and evidence presented by Shane (2000).

identifying and exploring scientific opportunities, may *not* be well suited for advancing invention in an industrial research environment. Similarly, industrial scientists who are particularly adept at pursuing "industrial goals," who we think of as individuals with a specialized form of human capital that is honed for identifying and exploring commercial opportunities, may *not* be well suited for advancing scientific knowledge in an academic research environment.

When scientific and commercial opportunities converge, as Powell and Owen-Smith (1998) argue for the biomedical sciences, scientists in both research environments learn new ways to identify, evaluate, and exploit opportunities. Instead of their human capital being "fully specialized" in either scientific or commercial opportunities, scientists occupy "locations" in human capital "space" that lie somewhere along a continuum between full specialization in scientific opportunities and full specialization in commercial opportunities. The overlap between scientific and commercial opportunities is a fertile middle ground that has already been identified and discussed by a variety of scholars. The R&D management literature highlights the important role of boundary spanning individuals for organizational performance (Allan 1977; Tushman 1977; Nochur and Allen 1992). In their analysis of biotechnology firms, Gittelman and Kogut (2003, p. 380) note that "…bridging the disconnect between scientific knowledge and innovation appears to depend on access to individuals who perform both activities…" Murray (2002) uses the paper-patent pair as an analytical device to explore the co-evolution of scientific and technological knowledge and networks.[5] If, as Dasgupta and David (1994) argue, scientists in both research environments share the same cognitive skills and expertise, the key difference in their human capital will be their location on the continuum between scientific and commercial opportunities. Their location or "orientation" will mediate the extent to which their human capital is valuable and transferable across the boundary between the academic and industrial research environments.

In biomedical academic research, the emergence of grant supported "large-scale" laboratory science is a particularly important force shaping the development of human capital. Louis et al. (1989) highlight this as a traditional form of faculty behavior that has increasingly become an indicator of the scientist's disciplinary competence. Etzkowitz (2002, 2003) suggests that academic research groups are "quasi-firms" led by a principal investigator who

[5] There has been a flurry of research examining the relationship between faculty patenting and publishing aimed primarily at determining if these two outcomes are complements or substitutes and sorting out the implications for the rate and direction of knowledge creation within the academic research enterprise. (Agrawal and Henderson 2002; Azoulay et al. 2005, 2006; Markiewicz and DiMinin 2004; Stephan et al. 2005)

manages a team. These individuals hone their skills at a number of management tasks including proposal writing, recruitment, managing post-docs, writing and reviewing articles, serving on review panels, and so forth. Zucker et al. (1998, 2002) emphasize the development and communication of tacit knowledge through "bench-level" experience and interaction. Using interview and quantitative data from twelve biotechnology firms, Murray (2004) suggests that biomedical scientists build their social capital by expanding their "local laboratory" network, which includes their graduate students, as well as their "cosmopolitan" network, which captures their reputation and broader network of contacts.

To support laboratory-based biomedical academic research, scientists raise most of their money through grantsmanship which requires them to become skilled at identifying, evaluating, and exploiting scientific opportunities within the academic community. In the United States, the NIH is the dominant funding source and the NIH grant selection criteria strongly influence the nature and character of the biomedical research performed in academic environments. The NIH is one of the best institutional examples of what Dasgupta and David (1994) call the Republic of Science. The overarching criterion in the proposal evaluation process is "scientific opportunity." The Institute of Medicine notes that the NIH has a "…long-standing reliance on peer review of specific research proposals by relevant scientific experts to ensure that it supports the best projects in terms of scientific impact or significance…" (IOM 1998, p. 34) Scientific opportunity determines the nature of the goals in the biomedical academic research community and is a critical part of what sociologists of science call the cycle of credibility (Etzkowitz 2002; Latour and Woolgar 1979). Scientists who are successful in the NIH grant system will have research oriented toward scientific opportunities, develop research competencies, build their professional prestige/network, and gain quasi-firm managerial experience.

Another important force shaping the development of human capital in biomedical academic research is the emergence and growth of patenting. Unlike successful grant getting from scientific institutions like the NIH, patenting is a legal mechanism to obtain property rights over research results for the purpose of commercial gain. Dasgupta and David (1994) place patenting squarely in the realm of Technology, the historical domain of industrial and military R&D activities. Louis et al. (1989) describe patenting as one of the new entrepreneurial behaviors among life science faculty. Packer and Webster (1996) discuss the emergence of a patenting culture in university science and show how the social environments producing research and patents are distinct. Using interview data, Owen-Smith and Powell

(2001) find that the decision to patent for life scientists is closely tied to the potential commercial value of their research and not as strongly motivated by the desire to build collaborative relationships as it is among physical scientists. Patenting is an observable manifestation of the influence of commercial opportunities within the academic research environment.

The human capital biomedical academic scientists develop over their research careers will reflect the influence of scientific and commercial opportunities and, at least to some degree, this influence should be detectable in the scientists' research portfolio. Some academic scientists will essentially ignore the influence of commercial opportunities and focus the development of their human capital on identifying, evaluating, and exploiting scientific opportunities. Their emphasis on academic research skills should lead to greater academic research productivity. When these scientists move out of the academic research environment to found or join firms, they will bring with them specialized human capital. We expect these academic entrepreneurs will be particularly effective at research oriented tasks within the firm. This leads to our first hypothesis:

Hypothesis #1: Firms with academic entrepreneurs whose human capital is oriented toward scientific opportunities are better at performing research-oriented tasks.

Other biomedical academic scientists will embrace commercial opportunities to a greater degree and will develop human capital that puts more emphasis on identifying, evaluating, and exploring commercial opportunities. Their emphasis on commercial opportunities should lead to patenting as part of their research portfolios. Since this type of human capital development places more emphasis on invention skills, we expect these academic entrepreneurs will be particularly effective at inventive tasks within the firm. Our second hypothesis states:

Hypothesis #2: Firms with academic entrepreneurs whose human capital is oriented toward commercial opportunities are better at performing invention-oriented tasks.

Based on our reading of Zucker et al. (2002) and Gittelman and Kogut (2003), we also expect firms that are too science-oriented are less successful at inventive activities. For our SBIR academic entrepreneurs, this leads to the following hypothesis:

Hypothesis #3: Holding the commercial orientation of an academic scientist's human capital constant, increasing his or her orientation toward scientific opportunities

detracts from invention-oriented tasks at the firm – a form of diminishing returns to academic research skills in a commercialization environment.

3 Empirical Setting: The SBIR Program

In this analysis, we examine the research and invention performance of small U.S. firms in the biomedical sector that have participated in the SBIR program. A subset of these firms employ a "full-time" academic entrepreneur who was previously an NIH supported biomedical researcher at a university, medical school, or other non-profit research institution.[6] These individuals may be part of the founding team of the firm or join an existing firm. We expect the employment of an academic entrepreneur will provide these organizations with a valuable resource whose heterogeneity will stem from the scientist's unique human capital developed during his or her research career in the non-profit environment.

The Small Business Innovation Development Act of 1982 established the SBIR program. Since then, it has become the largest U.S. commercialization program focused on small firms in U.S. history. According to the Small Business Administration, the program awarded $8.6 billion in direct subsidies between 1983 and 1996. Funds awarded under SBIR have generally grown each year because the SBIR budget is a fixed proportion of each agency's extramural R&D budget. This has been especially true for the two largest SBIR agencies, the Department of Defense and the Department of Health and Human Services (DHHS). Beginning in 1997, annual awards across all agencies exceeded $1 billion and a recent figure from the National Research Council (NRC) estimates the total value of awards made in 2003 to be over $1.6 billion (NRC 2004).

The legislation established three phases to the SBIR program. All applicants must start with a Phase I proposal. The Phase I project entails "proof of concept" research intended to show the feasibility of a new idea. It is essentially an "academic style" research project.[7] The Phase I study lasts from six to twelve months and can be up to $100,000 in value. If the results of the Phase I research are favorable, firms may apply for a Phase II grant to move

[6] "Full-time" employment at the for-profit firm is an eligibility requirement for the principal investigator in the SBIR program. Scientists must certify that they are employed at least 51% at the firm at the moment of award and throughout the duration of the project(s). It is possible that these individuals return to the non-profit research environment after their SBIR experience.

[7] Academic style research relies heavily on the scientific method as a form of inquiry. The outcomes from this style of research, as the university technology transfer literature makes clear, are typically embryonic and appropriately characterized as "proofs and prototypes" (Jensen and Thursby 2001; Lowe 2001; Colyvas et al. 2002; Shane 2004).

their ideas into product development. The Phase II award is up to $750,000 and typically lasts for a two-year period.[8] Finally, there is a Phase III in the SBIR program. This is an unfunded phase in which companies are expected to commercialize their product or process. Sometimes agencies award non-SBIR funds to firms in Phase III.

Information from SBIR participation plays an important role in this analysis since it allows us to systematically identify those academic scientists who chose to commercialize their knowledge at for-profit firms. Observing these individuals permits us to overcome one of the serious data constraints that limit scholarly research in this area. However, it is important to note that we observe these scientists after they decide to pursue commercialization. Since our analysis focuses on firm performance measures, we do not examine the factors underlying the scientist's initial decision to commercialize. For life scientists, Stuart and Ding (2006) look at the factors associated with when scientists choose to become entrepreneurs. Using a hazard model, they find that both cumulative publication counts and patent counts are positively related to when a life scientist founds a new biotechnology firm or joins a scientific advisory board (SAB). In our conceptual framework, their paper suggests that life scientists who are skilled at pursuing both scientific and commercial opportunities, that fertile middle ground, are the individuals most likely to engage in for-profit science. In a somewhat related analysis, Colloreur et al. (2004) look at the factors associated with having a specific position within recently founded French biotechnology firms. They find that an individual's cumulative publication count is negatively related to being the firm's Chief Executive Officer but positively related to having a position on the firm's SAB. Our paper does not attempt to contribute to this vein of research, which would require us to analyze the factors associated with an academic scientist's decision to become a "principal investigator" on SBIR projects. Instead, we take this decision as given and examine how the academic entrepreneurs' human capital influences the subsequent performance of research and invention tasks at their firms.

Identifying biomedical academic entrepreneurs using the SBIR program does limit our sample in two ways. First, we only observe an academic scientist as an entrepreneur if he or she was both a principal investigator on an NIH research grant and a principal investigator on an SBIR project. Restricting our analysis to the population of NIH research PIs is not very

[8] There is also an SBIR "fast track" application process in which both Phase I and Phase II proposals are approved at the same time. There are still relatively few of these proposals and we do not treat these separately in our analysis.

limiting. We identified about 80,000 unique NIH PIs in our sample period, 1972-1996. It may be restrictive, however, to require a scientist to be a principal investigator on an SBIR commercialization grant since we suspect many NIH PIs interact frequently with SBIR and non-SBIR firms without becoming full-time employees. Unfortunately, we simply cannot observe an academic scientist who has a non-PI role at the SBIR firm. Second, and perhaps more importantly, the SBIR program represents only one mode of financing commercialization. To the extent that academic scientists rely completely on other modes of financing, such as venture capital, personal assets, or friends and family, they are not part of our sample. This means our sample of academic entrepreneurs may not be representative of the population of all NIH scientists pursuing commercialization.

The SBIR program also provides some important information at the firm level. First, it allows us to identify the for-profit firms our biomedical academic entrepreneurs found or join, which is a critical link for investigating how the scientists' human capital influences firm performance. Second, using the NIH SBIR program provides an "industry" focus to reduce variations in commercialization opportunities at the firm level. Third, all the firms have access to financial capital. Within the entrepreneurship literature, human capital is positively related to wealth and may be confounding variable if there are binding financial constraints (Astebro and Bernhardt 2005). Participation in the SBIR program guarantees that all firms have a minimum baseline of funding.

Along with these advantages, there are two drawbacks due to the design of the SBIR program. The first one is basically a data problem. The vast majority of participating firms are small and private which makes it nearly impossible to get comprehensive data on firm level characteristics and outcomes. The next section describes our efforts to supplement the NIH SBIR data with other public sources. The second drawback stems from the fact that firms participating in the SBIR program are selected based on a proposal review process. If the NIH is "picking winners," our group of firms will be the "best" among the population of applicants. While there is no obvious reason to believe this will introduce bias into our empirical analysis of how the scientists' human capital influences firm performance among the selected firms, it does limit the extent to which we can generalize our findings beyond our sample.

4 Data and Empirical Approach

To examine the human capital that biomedical researchers bring to the firms they found or join, we need to observe individual academic scientists undertaking commercialization at for-profit firms, aspects of those scientists' human capital developed during their research careers in the non-profit research environment, and characteristics and outcomes of the firms they found or join. As described in the last section, the SBIR program provides a unique way to identify individual scientists as they venture from research to commercialization. Because we focus on biomedical researchers, we start with the NIH Computer Retrieval of Information on Scientific Projects (CRISP) database to identify the population of biomedical researchers who received at least one research award between 1972 and 1996.[9] In this population, we track those researchers who commercialize through the NIH SBIR program by observing them as a PI on both NIH research grants and one or more SBIR commercialization grants.[10] We identified 213 academic entrepreneurs in the NIH SBIR program between 1983 and 1996. This is about 5% of the total number of all NIH SBIR PIs (4,196) during this period.

For each of the SBIR academic entrepreneurs, we construct a measure of their research productivity prior to their first SBIR award. Using the CRISP database, we construct the scientists' annualized success at obtaining research funding from the NIH by calculating the cumulative value of their NIH awards and dividing this by the number of years they were active in the NIH grant system. This measure captures the degree to which the scientist is successful at engaging in "large scale" laboratory science. Importantly, it also captures the success of individual scientists at identifying and exploring scientific opportunities since the NIH grant approval system acts as a peer review filter for scientific significance. Two additional points are worth mentioning. First, success at NIH grant getting should be highly correlated with other measures of research productivity such as publications. Leibert (1977) finds that past research publications are strongly related to successful grant getting. Using

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[9] After 1996, the NIH stopped publicly reporting the award amounts for individual grants and contracts. Through 1996, the database includes the grant number, research activity code, grant title and abstract, the PI name, the NIH awarding institution, the fiscal year, the award amount, the institutional affiliation of the PI at the time of award, the institution's street address, city, state, and an NIH award type code. These data include all DHHS SBIR awards as well.

[10] Matching PIs by name is notoriously difficult and requires cross-referencing information in order to eliminate false matches. This process was facilitated by using specialized software developed by Thorsten Doherr at the Center for European Economic Research (ZEW), Mannheim, Germany, and by exploiting the internal consistency of the NIH CRISP database, which includes information on all NIH research project grants and NIH SBIR grants. We manually checked each individual in our final group to verify that they were former researchers in the non-profit research environment prior to their first SBIR award and that they were not participating in the Small Business Technology Transfer (STTR) program.

detailed data and a structural model for research teams in biotechnology, Arora et al. (1998) find a strong relationship between quality-adjusted publications and the research budget. Azoulay and Zivin (2005) use cumulative NIH awards to identify the "superstars" in biomedical research. Second, it is important to account for the seniority of the biomedical scientists when measuring success. Newcomers have not had the time to accumulate NIH grants and will not have the professional "local laboratory" or "cosmopolitan" networks that older and more senior scientists enjoy. We account for this by annualizing their cumulative NIH awards by the number of years the scientists are active in the NIH grant system, their "NIH tenure," and also including their NIH tenure as a separate explanatory variable. Consistent with Murray (2004), scientists with greater NIH tenure will have more social capital since they have had more professional opportunities to build their prestige and network. Figure 1 shows the distribution of NIH research productivity for our sample of NIH SBIR academic entrepreneurs.

For each of the SBIR academic entrepreneurs, we construct a measure of the patent productivity of their academic research portfolio prior to their first SBIR award. Patent productivity is measured by the total number of U.S. patents, assigned to non-profit institutions, on which the scientists are listed as inventors divided by their NIH tenure.[11] Those scientists with human capital oriented toward commercial opportunities will patent a greater proportion of their research. Importantly, this measure captures the success of individual scientists at identifying and exploring commercial opportunities since the U.S. patent approval system acts as a filter for expected commercial potential. To be sure, obtaining a patent is not a guarantee of commercial value since there is significant heterogeneity in the value of individual patents. However, patenting does involve effort and represents an expectation that the scientist's research may have valuable commercial application. From the inventor-assignee patent matching, we found that 31% of the SBIR academic entrepreneurs have at least one patent assigned to a non-profit research institution. Figure 2 illustrates the distribution of patent productivity for our sample of NIH SBIR academic entrepreneurs.

[11] To identify the scientist's patents, a name match was performed based on the inventor name and assignee name contained in the NBER patent database using the text field search engine developed by Thorsten Doherr (Hall et al. 2001). Including both the scientist's name and affiliation improves the matching results. We limited the assignees to universities and non-profit research institutions. So, our patent variable does *not* include patents invented by these scientists but assigned to firms. This was done to guarantee the validity of the matches obtained. Serious measurement error would be introduced by including for-profit assignees since we do not have access to the complete career histories for each of our scientists.

In sum, we include four human capital measures for those firms with an NIH academic entrepreneur. First, we use a dummy variable that indicates the presence of an academic entrepreneur at the firm. This should capture the effect of unmeasured tacit knowledge capital that is transferred through bench-level interaction (and other unmeasured effects as well). Second, we include the academic entrepreneur's NIH tenure. This variable is intended to capture the influence of the scientist's social capital as described by Murray (2004). Our third and fourth measures are the academic scientists' prior research and patent productivity during their research careers in the non-profit environment.[12]

The final part of our data collection effort gathers information on the characteristics and outcomes of the firms that participated in the NIH SBIR program between 1983 and 1996. Since most of these firms are small private companies, the amount of publicly available information is very limited. The NIH CRISP database provides the firm name, address, and number of SBIR awards from the NIH. We supplement this with three other databases: the Small Business Administration (SBA) SBIR database, the NBER patent database, and the SDC VentureXpert database.[13] The SBA is the coordinating agency for the whole U.S. SBIR program and collects SBIR award data from each of the eleven participating agencies. From this database we extracted the firm's total number, total value, and type of SBIR awards as well as indicators for whether the company is woman or minority owned. Using the NBER patent database, we identified all of the U.S. patents granted (by application date) to our sample of SBIR firms. The SDC VentureXpert database allowed us to identify those firms which were venture capital backed before the time of their first SBIR award.

We construct a database of firms that participated in the NIH SBIR program between 1983 and 1996. The dataset has 2,727 unique firms that participated in the program over this period. Our biomedical academic entrepreneurs are associated with 169 firms. Some of the 213 individuals identified previously could not be matched to the firm level data due to inconsistencies between the firm names in the NIH CRISP records and the firm names in the SBA database. Also, there were a few cases where multiple academic entrepreneurs join the

[12] Dietz and Bozeman (2005) examine the determinants of publication and patent productivity for a sample of 1200 research scientists and engineers.

[13] We also attempted to locate the founding date for all of the firms employing our academic entrepreneurial scientists by using the Dun & Bradstreet database. Unfortunately, we found only about 50% of the firms. Of these, 71% were less than six years old at the time of their first SBIR award. Based on this information and the results of a broader SBIR report (NIH 2003), we believe the bulk of our academic entrepreneurs started or joined young firms.

same firm. For these cases we use the year in which the first academic entrepreneur joined the firm and an average of their human capital measures after the other people join.

Tables 1 presents the variable definitions and Table 2 provides descriptive statistics for the firm-year observations separately for the group of SBIR firms employing an NIH academic entrepreneur (AE-linked) and the group of SBIR firms without an NIH academic entrepreneur (non-AE-linked). The firm-year statistics show that AE-linked SBIR firms are more likely to patent and have larger stocks of patents, on average. Also, more AE-linked firms have venture capital backing prior to participating in the SBIR program. The other variables, including SBIR program information and regional controls, are similar between the AE-linked and non-AE-linked firms.

Empirical Approach

Our conceptual framework suggests that the nature of an academic entrepreneur's human capital has differential effects on the performance of research and invention tasks at the firm. Biomedical academic scientists who have focused the development of their human capital on identifying, evaluating, and exploiting scientific opportunities are expected to significantly improve their firms performance of research oriented tasks (hypothesis one). In the firm level regression model, our indicator of a firm's competence at completing research oriented tasks is successfully winning a Phase II SBIR award from the NIH. Successfully winning a Phase II award shows that the firm is good at completing academic style proof of concept studies, at least in the judgment of NIH SBIR review committees.

We use a Probit method to estimate the probability that the firm wins a Phase II award where the dichotomous indicator takes the value of one for those firms that successfully win a Phase II award and zero otherwise. Our firm dataset includes all companies that participated in the NIH SBIR program from 1983 through 1996, however, since 1983 was the first year of the program, no Phase II awards were granted and we must use the 1984-1996 time period in our regressions. Within this group, a subset of these firms employ a "full-time" academic entrepreneur who was an NIH supported biomedical researcher at a university, medical school, or other non-profit research institution. This subset of firms is identified using a dummy variable to indicate the presence of an academic entrepreneur as in Toole and Czarnitzki (2007). To test hypothesis one, we interact the AE dummy variable with our measure of the academic's prior NIH research productivity. This specification allows the effect of having an academic entrepreneur at the SBIR firm to depend on the level of the

scientist's prior research productivity. According to our conceptual framework, the interaction variable should be positive and significant.

We include a number of other independent variables as controls in the Probit specification. With respect to other dimensions of an academic entrepreneur's human capital, we also include interaction terms between the AE dummy and both the scientist's prior patent productivity and his or her NIH tenure. Holding these other dimensions of the academic entrepreneur's human capital constant provides a ceteris paribus interpretation. Regarding firm characteristics, we include an independent variable for the R&D capacity of the firm measured by the stock of the firm's patents cumulated by application date. A venture capital dummy variable controls for any financial or advisory benefits from receiving venture capital backing. Prior SBIR Phase I success and funding is controlled for using the total value of SBIR Phase I awards to the firm from all government agencies. We include indicators for whether the firm is minority or woman owned and for whether the firm is located in California or Massachusetts, which are the U.S. states with the dominant share of NIH SBIR participating firms. We also include seventeen dummy variables for the firms' technology fields. These capture differences across biomedical research areas (cancer, central nervous system, cardiovascular, and so on) as indicated by the awarding component of the NIH. Finally, yearly time dummies capture exogenous trends common across all firms.

Our second and third hypotheses regarding an academic entrepreneur's human capital relate to the performance of invention oriented tasks at the firm. The second hypothesis suggests that biomedical academic scientists who develop human capital for identifying, evaluating, and exploiting commercial opportunities will significantly improve their firms' performance of invention oriented tasks. Our third hypothesis, which stems from our reading of the prior literature, suggests that there may be diminishing returns to academic research skills in a commercialization environment. In our firm level regression models, our indicator of a firm's competence at completing invention oriented tasks is successful patenting. We analyze two variations of this indicator. First, since there are many firms that never patent, we use a Probit specification to look at the probability of applying for a patent (that is eventually granted) in a given year. Second, we use a Negative Binomial (NegBin) count data model to analyze the number of firm patents.

The model specifications for patenting performance are very similar to the specification used for analyzing the firm's research performance. The academic scientist's human capital dimensions are interacted with the AE dummy variable. In line with hypothesis two, we

expect the commercial orientation of the scientists' human capital to significantly improve their firms' probability of patenting as well as the number of firm patents. Evidence consistent with hypothesis three would show that increasing the academic entrepreneurs' academic research productivity, holding constant the commercial orientation of their human capital, will significantly decrease the probability their firms will patent in a given year as well as the number of firm patents. The firm level control variables are the same except we now control for the total SBIR financial awards received by the firm and whether or not the firm ever won a Phase II award.

Finally, it is important to note that we treat the explanatory variables in our regression models as exogenous. There are a variety of ways this assumption might be violated. For instance, Kortum and Lerner (2000) argue that venture capital is endogenous when looking at a firm's patent performance because of reverse causality – venture capital spurs patenting and patenting is a common precondition for venture capital investment. Our empirical analysis uses an indicator of venture capital investment prior to patenting to help address this possibility. More important for our analysis is the possibility that an academic entrepreneur's human capital is endogenous. Reverse causality is unlikely since the human capital dimensions we measure are predetermined – developed during the individual's prior academic research career. Lacetera (2006) argues that academic entrepreneurs will be associated with better performing firms since they face a higher opportunity cost of pursuing commercialization than their industrial research counterparts. The argument posits that academic entrepreneurs require a higher expected return than industrial research teams and this will confound any comparative analysis of firm performance. While we cannot observe the underlying quality of the SBIR projects our firms are pursuing, there are two reasons to believe unobserved quality is not driving our results. First, the SBIR review committees provide an intervening selection mechanism which should harmonize, at least to some degree, the quality of the projects accepted into the program. Second, our empirical results show that the academic entrepreneur's human capital has differential effects on our firm performance indicators. If omitted quality introduced a positive bias into our analysis, we would expect our human capital measures, particularly a scientist's patent productivity, to be positive and significant across both performance indicators. As we report in the next section, this is not the case.

5 Empirical Findings

Table 3 presents the Probit results on the firm's likelihood of winning a Phase II SBIR award, our indicator of successfully completing research oriented tasks at the firm. Model A replicates the results reported in Toole and Czarnitzki (2007) but also includes dummy variables for minority and women owned firms. The AE dummy is positive and significant which indicates that firms employing a full-time NIH academic entrepreneur are more likely to successfully complete the Phase I proof of concept research. With regard to the minority owned and woman owned firm dummy variables, one of the original SBIR legislative objectives mandates agencies to foster and encourage minority and disadvantages populations to participate in technological innovation. Our finding that minority and women owned firms have a better chance at a Phase II award, other things constant, indicates the NIH program administrators are following the legislative guidelines. The other control variables have the expected signs and are consistent with earlier work. One of the technology field dummies is significant, but as a group, they are jointly insignificant. The time dummies are always jointly significant.

Model B introduces the interaction terms between the AE dummy and the scientist's human capital which allow the effect of having an academic entrepreneur to depend on the scientist's prior research productivity, prior patent productivity, and his or her NIH tenure. The AE dummy is no longer individually significant and indicates that any generic scientist effect is explained by the human capital dimensions in the model. The interaction term between the presence of an academic entrepreneur and the scientist's prior research productivity is positive and significant. Biomedical academic scientists with greater prior research productivity contribute more to their firms' capacity to successfully complete Phase I of the SBIR program. Since prior research productivity is an indicator of scientifically oriented human capital, this result suggests that academic research skills are valuable for completing research oriented tasks at the firm (support for hypothesis one). Table 3 also displays marginal effects. The average probability of winning a Phase II grant is equal to 0.095 in the subsample of scientist-linked firms. The estimated marginal effect at the sample mean of research productivity amounts to 0.034. This says an increase in the scientist's prior NIH research productivity of $1 million dollars would increase the firm's chance of winning a Phase II award by almost 36%. The interaction term between the presence of an academic entrepreneur and the scientist's prior patent productivity, indicating his or her human capital orientation toward commercial opportunities, is not significant. This suggests that human

capital skills related to patentable research do not make any marginal contribution to successful completion of research oriented tasks at the firm, holding the other dimensions of the scientist's human capital constant. Our results also indicate that the biomedical academic entrepreneurs' social capital, measured by their tenure in the NIH grant system, does not make any marginal contribution to successful completion of research oriented tasks at the firm. All of the other results in Model B are essentially the same as in Model A.

Table 4 contains the regression results for the likelihood of patenting in a given year and the number of firm patents, both indicators of invention oriented tasks at the firm. Although not reported in this table, the regression results with only the AE dummy are similar to those reported in Toole and Czarnitzki (2007). Also, because the results are very consistent across the Probit and NegBin models, we combine the discussion. In both models, the interaction term between the presence of an academic entrepreneur and the scientist's prior research productivity is negative and significant. Holding the scientists' patent productivity and social capital constant, increasing their academic research productivity lowers the probability their firms will patent in a given year as well as the number of firm patents. This suggests that academic entrepreneurs whose human capital is relatively better suited for identifying and exploring scientific opportunities actually hinder their firms' inventive performance. While the mechanisms through which this occurs are not clear, there appear to be "knowledge trajectories" that produce valuable insights for scientific goals but produce fewer and fewer patentable ideas useful in a commercialization environment – an observation that is reminiscent of the arguments regarding why firms generally focus on "applied" research and leave the bulk of "basic" or "fundamental" research to the non-profit research sector. In any case, our empirical results indicate a form of diminishing returns to academic research skills in a commercialization environment and this is consistent with hypothesis three.

In the literature, there are at least three other papers that report a form of diminishing returns to academic research skills. Zucker et al. (1998) find the quadratic term for their star scientists is negative and significant. They suggest, based on comments from Jeff Armstrong, the possibility of diminishing returns. Zucker et al. (2002) find a negative coefficient on the stars who are affiliated – meaning the scientist has a contractual relationship or is employed at the firm – after controlling for links to star scientists and other university researchers. In that paper, however, they view this as the consequence of "special circumstances" (Zucker et al. 2002, p. 149). In contrast, Gittelman and Kogut (2003) explicitly recognize the possibility that good science may not lead to good innovation performance in the business sector.

Consistent with hypothesis two, academic entrepreneurs whose human capital is oriented toward commercial opportunities, as indicated by the patent productivity of their research portfolio, significantly increase both the likelihood their firms will patent in a given year and the number of firm patents. The marginal effect of increasing patent productivity, holding their prior research productivity and social capital (NIH tenure) constant, is positive and significant. This suggests that scientists who undertake patentable research and gain experience with the patent system develop human capital that further stimulates invention at their firms. The empirical results for academic entrepreneurs' social capital, measured as the total number of years they are active in the NIH grant system (NIH tenure), are not as robust. For the Probit model on the likelihood of any patenting in a given year, NIH tenure is positive and marginally significant. Biomedical scientists with longer NIH tenure, those who have time to build their prestige and network, increase the chances the firm will patent. In the NegBin model, however, NIH tenure is insignificant for the number of patents. While NIH tenure is logically connected to the type of social capital that Murray (2004) discusses, this measure may not be specific enough to adequately capture the effects of social capital on firm patenting.

The findings in this paper do not support the argument that academic entrepreneurial firms perform better as a consequence of academic scientists choosing to commercialize opportunities with higher expected returns than their industrial research counterparts. If that argument were true, one would expect our measure of academic patent productivity to be positive and significant in all regressions in Tables 3 and 4. This would occur because academic patenting, which is related to commercial opportunities, would proxy for higher expected returns among AE-linked firms. We find that an academic scientist's patent productivity has no significant impact on their firms' probability of winning a Phase II SBIR award and we interpret this as evidence against the higher expected returns argument. Since the possibility exists that winning a Phase II SBIR award is independent of expected returns, our evidence is not conclusive. However, given the SBIR program's emphasis on commercialization, we believe expected returns play a role in the Phase II SBIR selection process (see Archibald and Finifter 2003 for evidence supporting the importance of commercialization in the National Aeronautics and Space Administration (NASA) SBIR program). Among the regressors in our models, it seems more likely that venture capital backing would capture the influence of expected returns.

6 Conclusions

This paper argues that academic scientists bring a specialized form of human capital to the companies they found or join. The particular skills that make up their human capital are developed during their research careers in the academic research environment and depend on how scientists chose to respond to the evolution of scientific and commercial opportunities. Looking at a particular group of academic entrepreneurs who commercialize their knowledge through the NIH SBIR program, we find that differences in the scientists' prior research orientation toward scientific and commercial opportunities correlate with differences in their firms' performance. Our empirical results suggest that biomedical academic entrepreneurs whose human capital is oriented toward exploring scientific opportunities significantly improve their firms' performance of research oriented tasks whereas those biomedical academic entrepreneurs whose human capital is oriented toward exploring commercial opportunities significantly improve their firms' performance of invention oriented tasks. Consistent with prior evidence, there also appears to be a form of diminishing returns to scientifically oriented human capital in a commercialization environment. Holding the commercial orientation of the scientists' human capital constant, we find that increasing their human capital for identifying and exploring scientific opportunities significantly detracts from their firms' patenting performance.

Our findings suggest that academic entrepreneurs bring valuable but heterogeneous human capital to the firms they found or join. Their human capital appears to be source of organizational capabilities or competence leading to superior performance. However, we also find that the contribution of these biomedical academic entrepreneurs depends on the "match" between their specialized human capital and specific tasks within the firm. In science-based industries where competitive advantage is closely tied to developments in the Republic of Science, such as the pharmaceutical and biotechnology sectors, academic entrepreneurs may augment their firms' absorptive capacity, act as technological gatekeepers, or build on other aspects of their firms' architectural competence. To the extent that academic entrepreneurs found new firms, the orientation of their human capital toward scientific or commercial opportunities could influence the firms' growth strategies and have implications for the distribution of firm types within science-based sectors. For instance, academic entrepreneurs who have a strong orientation toward scientific opportunities may be more likely to start "research shop" firms whose strategies do not focus on maximizing standard market performance indicators such as market value, but focus on contract research or technology

licensing strategies. While these possibilities remain unexplored, our analysis does highlight the need for additional research on the roles academic scientists play in the firms they found or join and on how these scientists add value to the commercialization process for scientific knowledge as well as to organizational performance more broadly.

Our analysis is not without limitations. Given the current state of understanding in this area of research, particularly dealing with the complexities of sorting out the endogenous versus exogenous aspects of the co-evolution of scientific and commercial opportunities, we are hesitant to make any strong claims about causality. As discussed in section 3, our use of the SBIR program does not allow us to generalize our findings (in a statistically legitimate way) to the population of biomedical academic entrepreneurs or to the population of academic entrepreneurial firms. Additional research on the development of human capital for other sub-populations of academic entrepreneurs, such as those individuals in non-biomedical areas of scientific study, would complement the research we present in this paper. There are also opportunities for theoretical modelling of the dynamic process of human capital development in which scientists endogenously choose their human capital based on their individual preferences and various institutional and environmental conditions. At the firm level, a dearth of detailed and reliable information continues to limit our ability to estimate more complete models with additional controls for firm characteristics. This is certainly true for small private firms in the United States such as those that participate in the SBIR program. These caveats notwithstanding, we believe our analysis offers new insights into the relationship between the human capital of entrepreneurial scientists and the performance of the firms they found or join.

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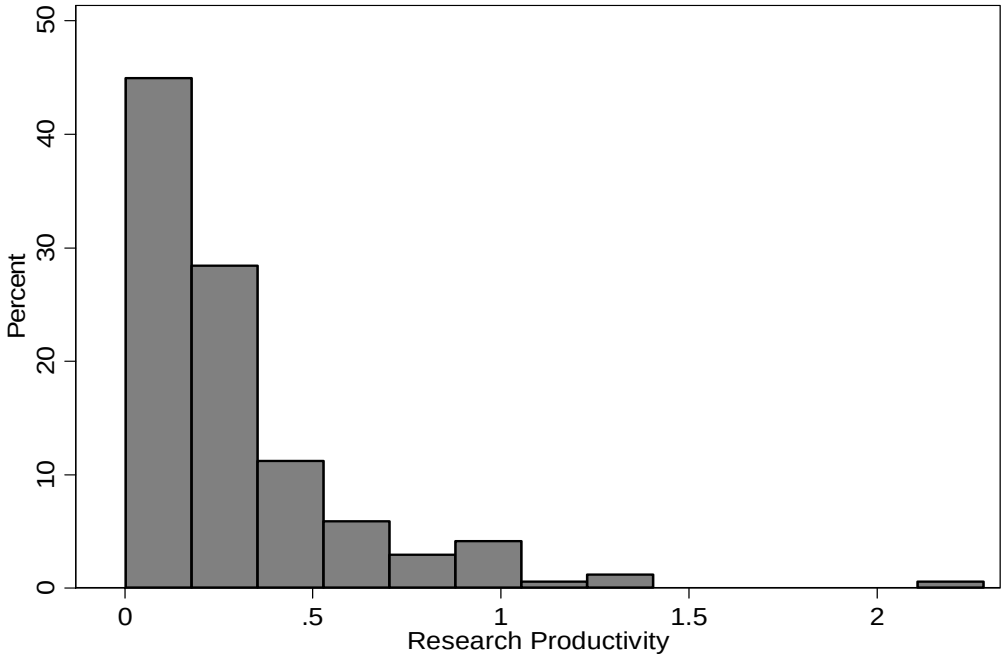

Figure 1: The distribution of NIH research productivity for SBIR academic entrepreneurs.

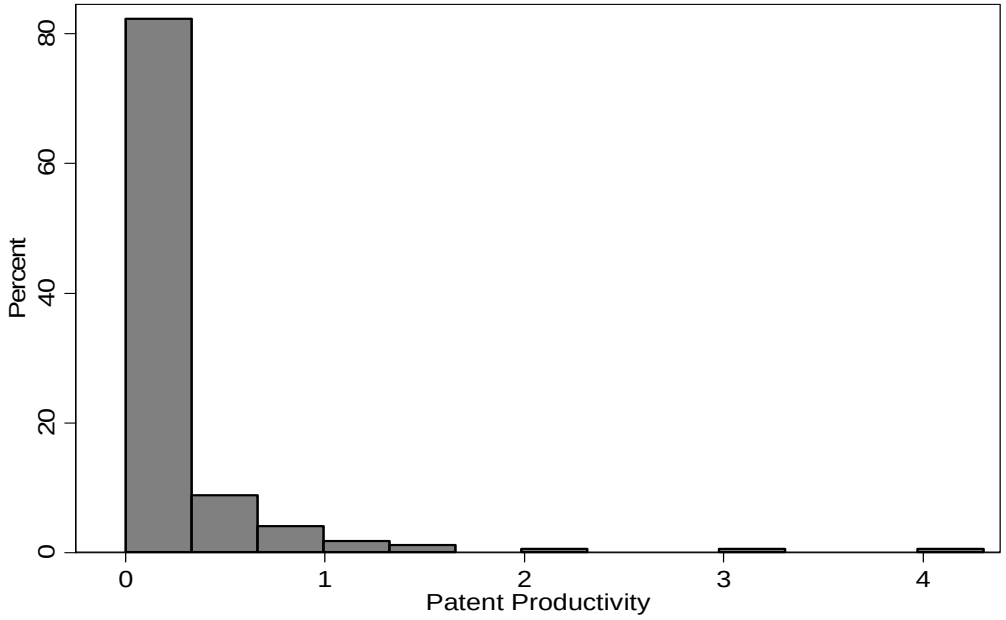

Figure 2: The distribution of patent productivity for SBIR academic entrepreneurs.

Table 1: Variable Definitions and Measurement	
Patents $_{i\,t}$	Number of patent applications of firm *i* in year *t*
Patent dummy $_{i\,t}$	Dummy indicating that firm *i* filed at least one patent in period *t* [D(Patents $_{i\,t} > 0$)]
Patent stock $_{i,\,t-1}$	Patent stock (PSTOCK) of firm i in period *t*-1; calculated as PSTOCK $_{i\,t}$ = (1-d)*PSTOCK $_{i\,t}$ + Patents $_{i\,t}$, where d is set to 15% as common in the literature. The initial value of PSTOCK is equal to zero in 1975. Due to the included depreciation rate of knowledge (d = 15%), the bias arising from the initial condition, PSTOCK $_{i,\,1975} = 0$, should be negligible for our sample period starting in 1983.
AE Dummy $_{i\,t}$	The academic entrepreneur dummy variable is zero in all cases where firm *i* in period *t* is not linked to an NIH scientist. As soon as a scientist joins firm *i* in period *t*, the dummy variable takes the value 1 for the rest of the observed time periods in our sample.
VC-backed $_{i,\,t-1}$	Dummy variable indicating that firm *i* received venture capital investment in the past.
SBIR$ $_{i,\,t-1}$	Total SBIR grants in millions of US$ (phases I and II) of firm *i* in *t*-1. If a firm got more than one grant per year, SBIR corresponds to the sum of all awards in this time period. The US$ are measured in constant 1996 prices. We used the NIH biomedical research and development price index for the adjustment.
Phase I $ $_{i,\,t-1}$	Analogous to SBIR, but only phase I awards.
Phase II dummy $_{i,\,t-1}$	Dummy indicating that firm *i* got a phase II award in period t-1 [D(PhaseII$ $_{i,\,t-1} > 0$)]. When the Phase II dummy is considered as dependent variable indicating SBIR program completion, we use the value in period *t* instead of its lagged value.
California $_{i}$	Dummy indicating that firm *i* is located in California
Massachusetts $_{i}$	Dummy indicating that firm *i* is located in Massachusetts
AE Research Productivity $_{i\,t}$	Cumulative value (in millions of 1996 dollars) of the scientist's NIH research awards (1973-1996) divided by their NIH tenure
AE Patent Productivity $_{i\,t}$	Cumulative count of patents on which the scientist is an inventor (1975-1996) divided by their NIH tenure
AE NIH Tenure $_{i\,t}$	A count of the number of years the NIH scientist was active in the NIH research grant system which equals the number of years elapsed between first and last NIH grant with an academic institution.

Table 2: Descriptive Statistics – NIH SBIR firms								
	AE-linked firms (N = 2,366)				Non-AE-linked firms (N = 35,812)			
Variable	Mean	Std. Dev.	Min.	Max.	Mean	Std. Dev.	Min.	Max.
Firm-level variables								
Patent dummy	0.104	0.306	0	1	0.063	0.243	0	1
Patent Stock (t-1)	0.827	3.846	0	58.56	0.414	2.306	0	97.54
Academic Entrepreneur	0.543	0.498	0	1				
VC-backed (t-1)	0.162	0.368	0	1	0.062	0.240	0	1
SBIR$ (t-1)	0.061	0.203	0	2.32	0.057	0.287	0	10.64
Phase I $ (t-1)	0.018	0.050	0	0.50	0.017	0.077	0	3.30
Phase II dummy	0.069	0.254	0	1	0.062	0.242	0	1
California dummy	0.183	0.387	0	1	0.196	0.397	0	1
Massachusetts dummy	0.142	0.349	0	1	0.111	0.314	0	1
Minority-owned dummy	0.089	0.284	0	1	0.103	0.304	0	1
Woman-owned dummy	0.112	0.316	0	1	0.118	0.322	0	1
Scientist-level variables								
AE*Patent Productivity	0.105	.405	0	4.3				
AE*Research Productivity	0.167	0.279	0	2.3				
AE*NIH Tenure	5.570	6.610	0	32				

Sample covers the years 1983 to 1996; 17 technology field dummies and time dummies are omitted from the table.

Notes on scientist level variables: All are interacted with the academic entrepreneur dummy. Thus the scientist-level variables are zero before the academic entrepreneur enters the firm, and take the value of the scientist-level variable afterwards (= AE * scientist level variable).

As some firms are linked to more than one academic entrepreneur, these measures are calculated as follows for the firm-level regressions:

- Patent productivity: sum of academic patents of the scientists divided by the sum of NIH tenure;
- Research productivity: sum of NIH grants of the scientists divided by sum of NIH tenure;
- NIH tenure: average experience of scientists measured as years elapsed between first and last NIH grant with an academic institution..

Table 3: Probit regressions on SBIR Phase II award dummy				
	Dependent variable: Phase II award dummy[a]			
	Model A		Model B	
Variable	Coeff.	dy/dx[b]	Coeff.	dy/dx[b]
AE Dummy	0.278***	0.023***	0.234	0.020
	(0.086)	(0.007)	(0.170)	(0.015)
AE*Research Productivity			0.469**	0.034**
			(0.226)	(0.016)
AE*Patent Productivity			-0.125	-0.009
			(0.108)	(0.008)
AE*NIH Tenure			-0.008	-0.001
			(0.013)	(0.001)
Patent Stock (t-1)	0.027***	0.002***	0.031***	0.002***
	(0.007)	(0.0005)	(0.007)	(0.0005)
VC-backed (t-1)	0.146**	0.012**	0.160**	0.013**
	(0.060)	(0.005)	(0.064)	(0.005)
Phase I$ (t-1)	10.531***	0.809***	10.919***	0.794***
	(1.145)	(0.028)	(1.191)	(0.029)
California dummy	0.008	0.0006	0.009	0.0006
	(0.042)	(0.003)	(0.044)	(0.003)
Massachusetts dummy	0.180***	0.015***	0.181***	0.014***
	(0.052)	(0.004)	(0.054)	(0.004)
Minority-owned dummy	0.310***	0.027***	0.306***	0.025***
	(0.057)	(0.005)	(0.059)	(0.005)
Woman-owned dummy	0.213***	0.018***	0.227***	0.018***
	(0.052)	(0.004)	(0.055)	(0.004)
Intercept	-2.182***		-2.182***	
	(0.067)		(0.068)	
Test on joint significance of technology fields $\chi^2(17)$	19.22		21.21	
Test on joint significance of time dummies: $\chi^2(11)$	47.47***		43.50***	
# of obs.	32,724		32,724	
McFadden R-squared	0.1734		0.1741	
Log-Likelihood	-7,095.25		-7,092.53	
LR-Test on hetero-scedasticity: $\chi^2(28)$	169.78***		171.64***	

Notes: Standard errors in parentheses. *** (**,*) indicate a significance level of 1% (5 ,10%).
a) Heteroscedastic probit model; heteroscedasticity is modeled groupwise multiplicatively; heteroscedasticity term includes 11 time dummies and 17 field dummies.
b) Marginal effects describe changes in the expected probability; calculated at sample means for continuous variables, and for a discrete change from 0 to 1 for dummy variables. The average predicted probability conditional on X is 0.054 for both models.

Table 4: Probit and Negative Binomial regressions on patenting activity				
	Dependent variable:			
	Patent dummy		Number of patents	
	Coeff.[a]	dy/dx[c]	Coeff.[b]	dy/dx[c]
AE Dummy	-0.012	-0.001	0.145	0.009
	(0.186)	(0.011)	(0.223)	(0.016)
AE*Research Productivity	-0.854***	-0.050***	-1.117***	-0.682***
	(0.331)	(0.019)	(0.444)	(0.027)
AE*Patent Productivity	0.600***	0.035***	0.308***	0.019***
	(0.179)	(0.010)	(0.123)	(0.008)
AE*NIH Tenure	0.279*	0.002*	0.026	0.002
	(0.015)	(0.001)	(0.016)	(0.001)
Patent Stock (t-1)	0.492***	0.028***	0.377***	0.023***
	(0.035)	(0.001)	(0.016)	(0.001)
VC-backed (t-1)	1.102***	0.109***	1.470***	0.185***
	(0.096)	(0.008)	(0.068)	(0.015)
SBIR$ (t-1)	0.460***	0.027***	0.301***	0.018***
	(0.091)	(0.005)	(0.106)	(0.006)
Phase II dummy (t-1)	0.277***	0.018***	0.487***	0.037***
	(0.088)	(0.005)	(0.107)	(0.010)
California dummy	0.139***	0.008***	0.286***	0.019***
	(0.045)	(0.003)	(0.064)	(0.005)
Massachusetts dummy	0.201***	0.011***	0.337***	0.024***
	(0.054)	(0.004)	(0.076)	(0.006)
Minority-owned dummy	0.001	-0.001	-0.042	-0.003
	(0.064)	(0.004)	(0.086)	(0.005)
Woman-owned dummy	-0.092	-0.006*	-0.111	-0.006
	(0.064)	(0.003)	(0.091)	(0.005)
Intercept	-2.514***		-3.933***	
	(0.065)		(0.112)	
Test on joint significance of technology fields: $\chi^2(17)$	88.89***		165.00***	
Test on joint significance of time dummies: $\chi^2(12)$	56.36***		91.17***	
# of obs.	38,178		38,178	
McFadden R-squared	0.2892		0.166	
Log-Likelihood	-6,576.55		-11,162.60	
LR-Test on hetero-scedasticity: $\chi^2(29)$	305.78***			

Notes: Standard errors in parentheses. *** (**,*) indicate a significance level of 1% (5 ,10%).
a) Heteroscedastic probit model; heteroscedasticity is modeled groupwise multiplicatively; heteroscedasticity term includes 11 time dummies.
b) Negative binomial regressions. Standard errors are calculated heteroscedastic-consistently. Equidispersion is clearly rejected: $LR(\chi^2(1)) = 9{,}552.17$.
c) Marginal effects describe changes in the expected probability (number of events) for the probit (NegBin) model; calculated at sample means for continuous variables, and for a discrete change from 0 to 1 for dummy variables. The average predicted probability (number of events) conditional on *X* is 0.040 for the Probit and 0.061 for the NegBin model.