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Scientist entrepreneurship across scientific fields

T. Taylor Aldridge · David Audretsch · Sameeksha Desai · Venkata Nadella

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Abstract Knowledge generated in universities can serve as an important base for the commercialization of innovation. One mechanism for commercialization is the creation of a new company by a scientist. We shed light on this process by examining the role of scientist characteristics, access to resources and key university conditions in driving the likelihood of a scientist to start a company. Our sample comprises 1,899 university scientists across six different scientific fields. We make a methodological contribution by using self-reported data from the scientists themselves, whereas most previous research relied on university or public data. Our consideration of six scientific fields is a substantive contribution and reveals that scientist startups are heterogeneous in nature. Our findings are largely consistent with extant research on the role of individual and university variables in scientist entrepreneurship; in addition, we uncover the novel finding that the type of research field is also a key driver of scientist startup activity.

Keywords Scientist entrepreneurship · Commercialization · Startup · University · Research

JEL Classification L26 · M13 · O30

T. T. Aldridge
Leibniz Institute for Regional Development & Structural Planning, Flaksenstraße 28-31, 15537 Erkner, Germany
e-mail: aldridge@irs-net.de

D. Audretsch · S. Desai (✉) · V. Nadella
School of Public & Environmental Affairs, Indiana University, 1315 E. 10th Street, Bloomington, IN 47405, USA
e-mail: desai@indiana.edu

D. Audretsch
e-mail: daudrets@indiana.edu

V. Nadella
e-mail: vnadella@indiana.edu

1 Introduction

University contributions to economic growth have long been acknowledged, such as by playing a role in supporting research which could later lead to innovation (Dosi 1988; Nelson 1959). Scholars and policymakers tend to agree that universities are an important hub for knowledge creation, and can serve as a base for commercialization of innovations.

A key question in understanding this process is scientist entrepreneurship—specifically, why some scientists, and not others, start companies. We shed light on this question by examining self-reported data on commercialization from scientists across six fields of research. Using survey data from 1,899 scientists in six research fields which received National Science Foundation (NSF) funding between 2005–2012(Q1), we examine the role of scientist characteristics, access to resources, and university conditions in explaining the likelihood of starting a company. In doing so, we leverage the methodological advantage of directly surveying scientists and we improve upon previous research on the drivers of scientist entrepreneurship by examining multiple scientific fields. Our findings indicate that scientist startup activity is heterogeneous in nature, and varies according to scientist and university characteristics, as established by previous research, and also by the research field.

The remainder of the paper is as follows. We discuss the relevant literature next. We describe our sample and method in the third section, and present our empirical findings in the fourth section. We employ a two-part empirical strategy, first testing six hypotheses on our full sample of 1,899 scientists and second, providing a disaggregated picture of trends in scientist startups across six fields of science. We discuss our findings in the fifth section, followed by a brief conclusion.

2 Scientist entrepreneurship

Entrepreneurial activities undertaken by university scientists have important implications for the scientists themselves, their universities, funding agencies, regional economic development, and innovation processes and discovery more broadly (Dosi 1988). Assessing entrepreneurial activity by university scientists is difficult and can produce inconsistent results depending on the type, source and quality of data used (Aldridge and Audretsch 2011). The use of some measures are potentially problematic (see Pakes and Griliches 1980; Griliches 1990), such as patents (see Henderson et al. 1998) which reflect the extent to which innovative activities are taking place but do not necessarily capture commercialization activities more comprehensively. Patents could be problematic because they capture one mechanism for protecting innovations, rather than measuring innovation more broadly or the market value of innovations. For example, some patented innovations simply do not make it to the market. In this way, studying only patents does not always capture the scale, scope and breadth of scientist entrepreneurship. Further, scientists could have multiple modes of commercialization, such as by providing consulting services, other innovative products and the like. We therefore focus on a broad measure of scientist entrepreneurship, the *scientist startup*, defined as the founding of a new legal company, which could in fact be providing many types of economic activity.

Previous research examining scientist entrepreneurship has provided insights specifically on the founding of a new company by scientists. Aldridge and Audretsch (2011) study scientist startups among 400 National Cancer Institute (NCI) grant recipients and 1,200 matched patents in the period 1998–2004. They find that roughly one in four scientists started new businesses. However, they examined scientists in only one field, they examined scientists in only one field of research (cancer research) and second, their sample was limited to high-performing scientists (all of whom had patents in cancer research and received on average $3.5 million in grant money from the National Cancer Institute between 1998 and 2002). In order to examine entrepreneurial activity among a more representative scientist population, we examine all NSF-funded scientists in six research fields (civil, mechanical and manufacturing innovation; environmental biology; computer and network systems; physical oceanography; particle and nuclear astrophysics; biological infrastructure). We now turn to our hypotheses about scientist characteristics (human capital and social capital), resources, and university conditions.

2.1 Scientist characteristics

2.1.1 Scientist human capital

Greater human capital could mean scientists also gain greater access and ability to exploit opportunities, as well as more chances to recognize opportunities to begin with. Scientists represent a well-educated and highly accomplished subsection of the general population and are exceptional in many ways, but there is no apparent indication to consider human capital would impact scientists differently than the general population (Aldridge and Audretsch 2010). Human capital has been found to improve entrepreneurial activity in the general population (Davidsson and Honig 2003; Bates 1995; Evans and Leighton 1989).

Most research scientists are highly specialized and hold multiple advanced degrees and educational qualifications. In some fields, scientists follow a traditional academic path, completing doctorates and becoming professors. Their professional academic status (i.e. assistant, associate, full professor) could be an important reflection of educational qualifications and experience. In other fields, a scientist's career trajectory could include several years of working in a lab before becoming faculty or finding employment outside the university; in this case, a scientist may have accumulated significant experience before leading substantial NSF-funded projects and overseeing large research teams. It could be then that the overall amount of experience, regardless of tenure status, could reflect the amount of time the scientist has been able to establish a reputation by publishing and being cited (Audretsch and Stephan 2002; Aldridge and Audretsch 2011). We thus hypothesize on both the role of academic rank and the role of experience:

H1 Scientist academic rank is positively associated with scientist startup.

H2 Scientist experience is positively associated with scientist startup.

2.1.2 Scientist social capital

Scientist social capital refers to the scientist's potential to derive tangible and intangible benefits from interactions and cooperative activities with other individuals and groups. Social capital could be an important determinant of scientist entrepreneurship because it enhances existing resources (like human capital) through social ties and networks. Social capital could affect a scientist's likelihood of starting a new company in several ways. First, interactions and linkages among scientists working across different institutional contexts, such as industry in private labs, could function as conduits of knowledge spillovers and allow for information about entrepreneurship to transfer. Second, interactions and linkages with industry, such as participation on scientific boards of companies in industry, could facilitate flow of knowledge and information about the demand, potential and likelihood for successful entrepreneurship. Agarwal and Henderson (2002) posit that industry interaction can encourage university scientists to commercialize, and Lawson (2012) finds evidence for the importance of collaboration with industry in academic patenting. Social capital has in fact been found to enhance entrepreneurial activity in the general population (Mosey and Wright 2007; Aldrich and Martinez 2010; Shane and Stuart 2002; and Davidsson and Honig 2003) and among scientists specifically (see Karlsson and Wigren 2012; Thursby and Thursby 2002; Aldridge and Audretsch 2011). Thus, we expect scientists with more networks and industry ties to have greater propensity to start a new company:

H3 Scientist social capital is positively associated with scientist startup.

2.2 Resources

In his model of knowledge production function, Griliches (1979) proposed that investments in knowledge-generating inputs have the greatest effect on innovative outputs. A central role for resources has been identified in productive capacity and in aggregate innovative output. Though much of the existing research focuses on the role of resources in driving the innovative capacity of firms, it could also be that individual scientists harness resources in a similar manner as firms. Scientists are agents who use resources, ranging from their own human and social capital to external financial resources, for knowledge creation and to transform scientific knowledge into innovative outputs (Aldridge and Audretsch 2010, 2011).

We consider two types of resources relevant in this context. First, *human resources* refer to a set of knowledge and intellectual resources available to the scientist, such as students working in the lab, pre- and post-doctoral researchers and other scientists. A larger number and higher quality of human resources could support scientist entrepreneurship by helping speed up the innovative process and improve the efficiency of the scientific research activity. In addition, human resources available to the scientist could also improve opportunity recognition by expanding the scope and applications of the ongoing research. The amount and availability of financial resources are expected to positively influence scientist startup propensity in several ways. Second, *financial resources* support research activity by providing funds for technological, infrastructure and labor inputs. Second, financial resources support research activity by providing funds for technological, infrastructure and labor inputs and increase the scope of research by increasing knowledge creation. Further, greater financial resources could lead to greater experimentation and expand opportunities to transform scientific knowledge into innovative outputs. This leads us to posit the following about the role of human resources and the role of financial resources:

H4 Human resources are positively associated with scientist startup.

H5 Financial resources are positively associated with scientist startup.

2.3 University conditions

The scientist could be affected by her immediate work (departmental) environment as well as broader work (university) conditions. Support from within the department could encourage scientific entrepreneurship in several ways. First, interactions with scientists in the same department could provide knowledge about starting a new company. This could lead to awareness and interest in entrepreneurship among scientists who might have otherwise not known or considered the possibility. In addition, the exchange of knowledge about the entrepreneurial process could take place within the department. Second, departmental support, particularly from leadership such as deans or department chairs, could demonstrate that becoming an entrepreneur is also rewarded or at least not discouraged. This could be especially applicable for younger or untenured scientists.

The broader university context could also be important. For example, a university could implicitly or explicitly place a positive emphasis on innovations with market value and on bringing the fruits of research to the market. Such an emphasis could be communicated by a strong university TTO office, whose successes are known across the institution. The support of the university TTO could mean better resources for scientist commercialization (Mowery 2005) and provision of knowledge about the opportunities and process of commercialization for the scientist. For example, university TTO offices have been found to influence the scientist's mode of commercialization depending on their organizational priorities (O'Shea et al. 2005; Lockett and Wright 2005). An effective TTO could help lower risk for scientists with technical and scientific training but not the kind of legal, financial or managerial training useful to start and grow a new company. The importance of institutional conditions which shape the scientist's work environment (Henrekson and Stenkula 2010; Karlsson and Karlsson 2002) leads us to posit:

H6 A supportive immediate working environment (department) is positively associated with scientist startup.

H7 A supportive broader working environment (university) is positively associated with scientist startup.

3 Sample and method

Our method in this paper consists of two sets of empirical analyses. First, we test our seven hypotheses using a large sample of 1,899 university scientists. Second, we explore the determinants of field-specific variation and analyze the drivers of scientist startups in six scientific fields.

3.1 Sample

In order to analyze scientist entrepreneurship at the scientist level and across different fields of research, we used primary survey data from scientists to create a database[1] which measures entrepreneurial activity in terms of scientist commercialization through startups. Most empirical investigations of scientist entrepreneurship used information from university TTOs, other university units or data from the Association of University Technology Managers (AUTM). However, in their study of scientists funded by the National Cancer Institutes (NCI), Aldridge and Audretsch (2011) bypassed university and official sources of data and surveyed scientists directly. They concluded that the rate of scientist entrepreneurship, as reported by the scientists themselves, is higher than previously thought when using TTO or AUTM data.

[1] The database used in this study comes from Small Business Administration (SBA) Report No. 409, and the project is funded under the contract SBAHQ-11-M-0212. The full report and research summary can be accessed at http://www.sba.gov/advocacy/7540/586391.

For this reason, we use data based on surveying scientists directly. We identified 9,361 scientists that received NSF funding between 2005 and 2012(Q1) and worked in six different fields of research: (1) CMMI: Civil, mechanical and manufacturing innovation (2) DEB: Environment biology (3) CNS: Computer and network systems (4) OCE: Physical oceanography (5) PHY: Particle and nuclear astrophysics (6) DBI: Biological infrastructure.

An online survey questionnaire was directed to the entire population of 9,361 scientists in the first round of survey administration. We detected that 30 scientists were on sabbatical, 9 scientists were inactive, and email addresses of 172 scientists were returned since they were incorrect/incomplete. Thus, we administered the survey questionnaire to a sample of 9,150 scientists (97.75 % of the population). We achieved a response rate of 20.75 % for a total of 1,899 individual scientists in the database.

The survey questionnaire was designed to capture scientist entrepreneurship through startups (key dependent variable, with a response rate of 99.5 %), as well as scientist characteristics, access to resources, university characteristics, and other institutional context.

3.2 Dependent variable

To test the hypotheses presented in the previous section, we use a dependent variable defined as the likelihood of startup of a new legal company by a scientist. This is based on the survey question “Have you started a legally recognized company?” and is a binary variable, with a value of 1 identifying a “yes” response and a value of 0 identifying a “no” response.

Considerable variation is apparent in the propensity for a scientist to start a firm in different scientific fields, as depicted in Fig. 1. This ranges from 4.6 % in environmental biology to 23.8 % in computer and network systems. Scientists in the fields of physical oceanography, biological infrastructure, particle and nuclear astrophysics and environmental biology are less likely to commercialize their research through startups. This variation could have several explanations. First, it is possible that scientists in the fields of biological, physical and environmental sciences need greater human capital (access to a large number of prior patents, collaboration from a large number of field experts) to commercialize their research. Second, due to the basic nature of their research, it is possible that scientists in these fields need greater access to financial and infrastructure resources to commercialize their research. Third, it could be that the technology transfer offices in their universities are not competent in understanding their area of research, and hence less successful in surpassing the knowledge filer to commercialize research through startups. Finally, it could be possible that scientists in these fields select other modes of commercializing their research without founding a new company. Description of variables used in the study are shown in Table 1; descriptive statistics are shown in Table 2.

3.3 Explanatory variables

Our key explanatory variables relate to scientist characteristics (demographic, human capital, social capital), access to human and financial resources, and the scientist’s institutional context. We use measures from Audretsch et al. (2013) scientist entrepreneurship database, reflecting self-reported responses from each individual scientist who participated in the adaptive online survey.

For human capital, we use two measures. First, we use *academic rank* of the scientist, based on the scientist’s self-identification as: Non-tenured, assistant professor, associate professor, endowed professor and emeritus professor. We measure academic rank as full

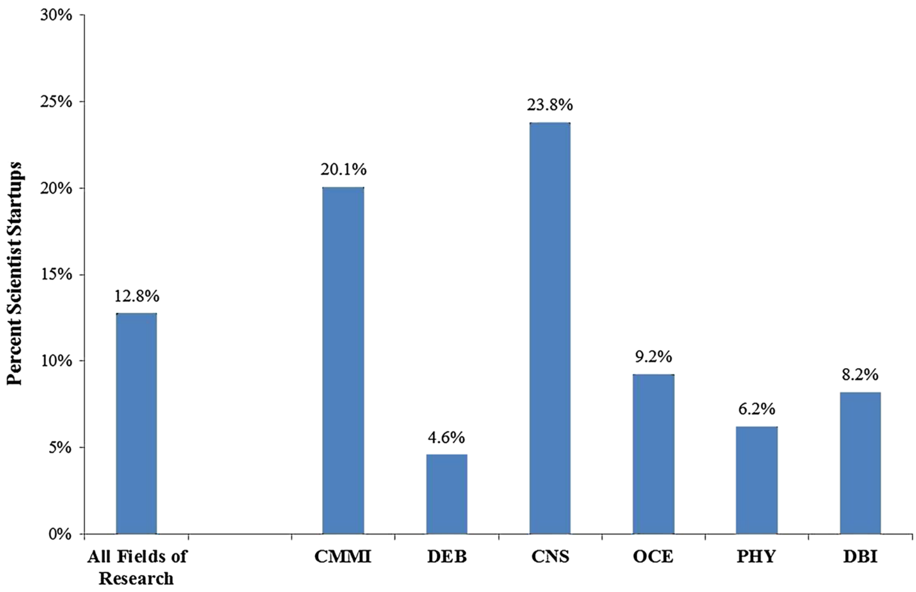

Fig. 1 Scientist startups by field of research. *CMMI* Civil, mechanical and manufacturing innovation, *DEB* Environmental biology, *CNS* Computer and network systems, *OCE* Physical oceanography, *PHY* Particle and nuclear astrophysics, *DBI* Biological infrastructure

professorship, defined as 1 if the scientist indicated that their tenure status is a full professor and 0 otherwise. Second, we use *scientist experience*, measured as the number of years since the scientist made tenure. We measure scientist social capital as board membership (Aldridge and Audretsch 2011), defined as 1 if the scientist indicated that they sat on a scientific advisory board and 0 otherwise.

We consider two types of resources important—human resources and financial resources. We measure human resources as the number of student collaborators that worked closely with the scientist during the duration of research. We measure financial resources using two measures: the amount of NSF research grant funding received by the scientist (continuous variable), and whether the scientist reported receiving substantial amount of funding (greater than $750,000) from other sources such as nonprofits, university, government organizations, industry and others (binary variable).

We use two measures to capture the immediate institutional context in which the scientist works. First, we measure the entrepreneurial orientation of the department head as 1 if the department head of the scientist's institution is an entrepreneur (started a firm). Second, we measure the extent to which the department encourages commercialization on a 7-point likert scale. In order to measure the broader university context in which the scientist works, we measure the scientist's perception of the TTO's success in commercializing research in her field. This variable is created on a 7-point likert scale based on the scientist's answer to the question: "My Technology Transfer Office is successful at commercializing my field of research". We consider scientist perception of the TTO appropriate to understand the broader university context as this also reflects relevance to the scientist.

Table 1 Variable definitions and description

Variable	Description
Startup	Binary dependent variable, for scientists indicating that they started a firm = 1 and 0 otherwise
Board membership	Binary variable, for scientists indicating that they sat on a scientific advisory board = 1 and 0 otherwise
Award amount	Continuous variable indicating the scientist's NSF funding amount received between 2005 and 2012-Q1
Other funding (>750 K)	Binary variable, for scientists indicating that they received other sources of funding greater than 750,000 USD = 1 and 0 otherwise
# Student collaborators	Count variable indicating the number of students that worked on the scientist's project funded by the NSF
Tenure experience	Count variable indicating the number of years in tenure status
Full professor	Binary variable, for scientists indicating if the scientist's tenure status is a full professor = 1 and 0 otherwise
Dept. Commercialize	7-point likert scale, for scientists whose department's encourage commercialization of research
Dept Head E.O.	7-point likert scale, for scientists whose department head is an entrepreneur
Univ TTO Success	7-point likert scale, for scientists who consider their university technology transfer office to be successful
Male	Binary variable, for male scientists = 1 and 0 for female scientists
Midwest	Binary variable, for scientists affiliated to institutions located in the midwest region = 1 and 0 otherwise
South	Binary variable, for scientists affiliated to institutions located in the south region = 1 and 0 otherwise
West	Binary variable, for scientists affiliated to institutions located in the west region = 1 and 0 otherwise

3.4 Control variables

We control for gender because of previous findings on its importance (Elston and Audretsch 2010, 2011). Previous research on scientist entrepreneurship points to a lower propensity for females to start new companies (Link and Scott 2009), and Aldridge and Audretsch (2010, 2011) argue that gender could also play a role through other mechanisms, such as propensity to patent an innovation and access to financial resources. We include gender to account for demographic characteristics of the scientist. This is a dummy variable where a value of 1 represents a "male" scientist and a value of 0 represents a "female" scientist.

Additionally, we control for region of the United States to account the spillover of knowledge within geographically bounded regions (Jaffe 1989; Audretsch and Feldman 1996; Jaffe et al. 1993; Glaeser et al. 1992): Location could play a role in driving investment in new knowledge, access to technological infrastructure, and even in shaping scientist behavioral norms and attitudes towards entrepreneurship (Louis et al. 1989). We use dummy variables to control for Midwest, South and West regions with Northeast as the reference group. Correlations for our variables are reported in Table 3.

4 Empirical results

The purpose of this analysis is to identify factors that are predictive of scientist entrepreneurship. Our main dependent variable of interest takes on a value of 1 if the scientist

Table 2 variable descriptive statistics

	Mean	SD	Min	Max
Scientist startups	0.13	0.33	0	1
Award amount (in Millions USD)	0.95	5.58	0	166.27
Other sources of funding (>750 K)	0.41	0.49	0	1
Number of student collaborators	15.54	16.13	0	250
Non-Tenured	0.10	0.29	0	1
Assistant professor	0.09	0.29	0	1
Associate professor	0.27	0.45	0	1
Full professor	0.44	0.50	0	1
Endowed professor	0.09	0.29	0	1
Emeritus professor	0.02	0.14	0	1
Years of tenure	16.08	9.00	0	52
Board of directors	0.34	0.47	0	1
Dept. Head Entrepreneurial Orientation	0.40	0.49	0	1
Dept. Encourages Research Commercialization	4.47	1.77	1	7
Univ. TTO Competent in Understanding Research	4.71	1.74	1	7
Univ. TTO Successful in Commercialization	5.13	1.64	1	7
Male scientist	0.79	0.41	0	1
North east region	0.24	0.43	0	1
Midwest region	0.20	0.40	0	1
South region	0.28	0.45	0	1
West region	0.26	0.44	0	1

started a firm and 0 if she did not. We use probit regression estimation as appropriate for our binary dependent variable, to analyze the role of scientist characteristics, access to resources, and university conditions in explaining scientist startup propensity. We first present probit estimation results for our full sample (all six research fields together) and then for each research field separately.

4.1 Hypothesis testing and probit models for the full sample

The probit regression results for our full sample are reported in Table 4. Model 1 is the base model and Model 2 includes scientist experience and TTO success. The negative and statistically insignificant coefficients on scientist years in tenure and academic rank (dummy for full professor) do not provide support for H1 and H2. These results indicate that human capital does not play an important role in determining the likelihood of scientist startup.

However, the results for social capital provide support for H3. Social capital, measured as the scientist's membership on a scientific advisory board, is positively related to the likelihood of that scientist starting a firm. These results are consistent with previous findings for scientists (Aldridge and Audretsch 2011) and with the importance of social capital for the general population (Davidsson and Honig 2003).

With respect to access to human resources, the negative and statistically significant coefficient for the number of student collaborators is surprising. However, the practically insignificant magnitude of the coefficient is insufficient in providing substantial support for

Table 3 Correlation Matrix of Variables

	Startup	Board membership	Award amount	Other funding (>750 K)	# Student collaborators	Tenure experience	Full Professor	Dept. Commercialize	Dept Head E.O.	Univ TTO Success	Male
Startup	1										
Board membership	0.2291	1									
Award amount	0.0714	−0.0215	1								
Other funding (>750 K)	0.158	0.134	0.0599	1							
# Student collaborators	−0.0411	0.0101	0.0213	0.0335	1						
Tenure experience	−0.0233	0.0566	0.013	−0.0695	−0.0087	1					
Full Professor	−0.0574	−0.1069	0.0205	−0.0589	−0.0194	−0.282	1				
Dept. Commercialize	−0.225	−0.0547	−0.0278	−0.1514	0.05	−0.0382	−0.0414	1			
Dept Head E.O.	0.1824	0.0497	−0.0424	0.1091	−0.0316	−0.0025	−0.0289	−0.2022	1		
Univ TTO success	−0.0965	−0.0289	−0.0256	−0.1431	0.0488	−0.0782	−0.0455	0.5144	−0.1886	1	
Male	0.0729	−0.0208	0.0305	−0.0126	−0.0074	0.1377	−0.0105	−0.0887	−0.0431	−0.0788	1

Table 4 Probit regression results estimating likelihood of scientist starting a firm

Independent variables	(1)	(2)	(3)	(4)
Grant amount (in millions)–*Fin Res.*	0.011	0.013	0.011	0.011
	(2.07)**	(2.58)***	(2.07)**	(2.16)**
Other funding (> 750 K)–*Fin Res.*	0.296	0.173	0.282	0.304
	(2.42)**	(1.84)*	(2.27)**	(2.39)**
# of Students–*Human Res.*	−0.001	0	−0.001	−0.001
	(−2.08)**	(−1.57)	(−1.88)*	(−2.03)**
Years in tenure–*Human Capital*	−0.006		−0.011	−0.01
	(−0.88)		(−1.45)	(−1.39)
Full Professor–*Human Capital*			−0.209	−0.212
			(−1.33)	(−1.34)
Board membership–*Social Capital*	0.668	0.706	0.66	0.687
	(5.31)***	(7.44)***	(5.26)***	(5.40)***
Dept. Encourages Commercialization	−0.163	−0.152	−0.161	−0.183
	(−4.18)***	(−5.23)***	(−4.07)***	(−4.32)***
Dept. Head Entrepreneurial Orientation	0.514	0.37	0.512	0.513
	(4.11)***	(3.82)***	(4.04)***	(3.98)***
Univ. TTO success				0.051
				−1.22
Male	0.412	0.561	0.469	0.478
	(2.23)**	(3.93)***	(2.51)**	(2.55)**
Midwest *region*	−0.056	0.072	−0.034	−0.026
	(−0.31)	−0.52	(−0.19)	(−0.14)
South *region*	0.041	−0.037	0.054	0.056
	−0.25	(−0.29)	−0.32	−0.33
West *region*	−0.014	−0.021	−0.019	−0.006
	(−0.09)	(−0.16)	(−0.11)	(−0.04)
Constant	−1.311	−1.587	−1.125	−1.322
	(−4.12)***	(−6.92)***	(−2.95)***	(−3.12)***
Number of observations	793	1517	786	766
Wald Chi–sq.	75.97	124.22	76.1	80.25

Absolute z values in parentheses

* Denotes significant at the 10 % level; ** significant at the 5 % level; *** significant at the 1 % level

H4. This result could be interpreted to indicate that projects which require a large number of student collaborators, in the sciences, tend to be applied and hence indicate the incremental nature of scientific contributions geared at academic contributions. With respect to financial resources, the results provide strong support for H5. The positive and statistically significant coefficient for other significant sources of funding, and magnitude of the grant amount, indicates that scientists with more financial resources for research have a greater propensity to start a firm.

When it comes to the role of the department head's entrepreneurial orientation, we find a positive and statistically significant coefficient. However, we find a negative and statistically significant coefficient for department encouragement to commercialize scientific research. This surprising finding could be interpreted as a substitution effect between department encouragement and the department head's entrepreneurial orientation in providing a more conducive environment for the scientist in starting a firm. Since the net effect between these two measures is positive, our results overall support H6.

We find that a broader supportive university technology transfer office does not improve the likelihood of scientist's starting a firm, which does not support H7. We find that male scientists have greater propensity to start a company.

4.2 Probit models by research field

We tested our hypotheses on the full sample of 1,899 scientists without considering specialization of research fields. Now, we turn to our findings in six different research fields. When our sample is disaggregated in this manner, we find that the overall trend changes according to the specialization of the scientist and our results are heterogeneous.

We run the same probit regression model individually for each of our six research fields: Civil, mechanical and manufacturing innovation (CMMI), Environment biology (DEB), Computer and network systems (CNS), Physical oceanography (OCE), Particle and nuclear astrophysics (PHY), Biological infrastructure (DBI). For all fields, we report our results from the model which includes scientist experience and TTO success. Findings are reported in Table 5.

The results for Civil, Mechanical, and Manufacturing Innovation (CMMI) are consistent with the overall sample of scientists in providing evidence for H3 indicating that greater social capital increases the scientist's likelihood in starting a firm. The positive and statistically significant coefficient on department head's entrepreneurial orientation also indicates evidence supporting H6. Interestingly, the co-efficient on scientist tenure experience is negative and statistically significant, indicating that older CMMI scientists are less likely to start firms than younger untenured-scientists. The magnitude of the coefficient is small compared to the effect from social capital and departmental-environment. The positive and statistically significant co-efficient for the Midwest variable indicates that CMMI scientists with university affiliations in the Midwest have a greater likelihood in starting new firms compared to scientists affiliated to universities in the northeast region.

The results for Environmental Biology (DEB) do not provide support to any of the seven hypotheses. The general directionality of the results is consistent with the overall sample; however none of the measures are statistically significant at the 5 % level. We find a positive and statistically significant coefficient for scientists with other sources of funding at the 10 % level, providing support for H5.

The results for Computer and Network Systems (CNS) are consistent with the overall sample of scientist in providing evidence for H3 on the positive role of social capital in propensity for a scientist to start a firm. The positive and statistically significant coefficient on department head's entrepreneurial orientation and the negative and statistically significant coefficient for department encouragement to commercialize scientific research indicate support for H6. Consistent with the results for the overall scientist population, the positive and statistically significant coefficient for male scientists indicates that male CNS scientists are more likely to start new firms as compared to female CNS scientists.

The results for Physical oceanography (OCE) are consistent with the overall sample of scientists in providing evidence for H5, indicating that other sources of funding increases the scientist's likelihood in starting a firm. The positive and statistically significant coefficient on years in tenure indicates evidence supporting H2. Unlike any other field of research, the positive and statistically significant coefficient of technology transfer office

Table 5 Probit regression results estimating likelihood of scientist starting a firm, by field of research

Independent variables	CMMI	DEB	CNS	OCE	PHY	DBI
Grant amount (in millions)–*Fin Res.*	0.111	−0.499	0.204	0.009	−1.103	0.139
	(0.69)	(−1.33)	(1.25)	(1.64)	(−2.57)**	(1.59)
Other funding (> 750 K)–*Fin Res.*	0.043	0.54	−0.2	0.857	0.767	0.839
	(0.16)	(1.5)	(−0.70)	(2.06)**	(1.48)	(2.11)**
# of students–*Human Res.*	−0.001	−0.001	−0.001	−0.002	0.006	−0.004
	(−0.53)	(−0.87)	(−1.13)	(−1.11)	(1.1)	(−2.03)**
Years in Tenure–*Human Capital*	−0.036	0.016	0.012	0.041	−0.101	−0.007
	(−2.10)**	(0.83)	(0.77)	(1.78)*	(−2.52)**	(−0.39)
Full professor–*Human Capital*	−0.075	0.518	−0.205	0.222	−1.98	0.282
	(−0.23)	(0.88)	(−0.45)	(0.34)	(−3.31)***	(0.67)
Board membership–*Social Capital*	1.078	0.113	1.058	−0.593	3.165	0.994
	(4.07)***	(0.33)	(3.75)***	(−1.22)	(3.52)***	(3.00)***
Dept. Encourages commercialization	−0.081	0.012	−0.255	−0.493	−0.072	−0.146
	(0.89)	(0.11)	(−2.55)**	(−2.55)**	(−0.53)	(−1.30)
Dept. Head Entrepreneurial Orientation	0.447	−0.436	0.446	−0.251	0.171	0.591
	(1.69)*	(−0.85)	(1.67)*	(−0.43)	(0.25)	(1.36)
Univ. TTO Success	−0.073	0.039	0.041	0.558	−0.142	0.151
	(−0.71)	(0.25)	(0.48)	(3.02)***	(−0.82)	(1.19)
Male	0.503		0.792		0.974	−0.089
	(1.43)		(1.74)*		(1.24)	(−0.21)
Midwest region	0.797		−0.164		1.956	−0.573
	(1.79)*		(−0.38)		(2.28)**	(−1.02)
South region	0.694	0.122	−0.189	−0.797	−0.125	−0.169
	(1.51)	(0.27)	(−0.51)	(−1.22)	(−0.22)	(−0.37)
West region	−0.038	0.669	0.012	−1.177	−0.744	0.11
	(−0.07)	(1.49)	(0.04)	(−2.31)**	(−0.73)	(0.27)
Constant	−1.297	−2.641	−1.349	−2.798	−0.939	−2.306
	(−1.40)	(−2.06)**	(−1.24)	(−1.88)*	(−0.72)	(−2.06)**
Number of observations	157	113	138	89	100	104
Wald Chi–sq.	35.27	16.11	40.44	31.31	23.71	24.64

Absolute z values in parenthesis

* Denotes significant at the 10 % level; ** significant at the 5 % level; *** significant at the 1 % level

(TTO) success indicates that OCE scientists in universities with successful TTO offices are more likely to commercialize research than OCE scientists in other offices.

The results for Particle and Nuclear Physics (PHY) are consistent with the overall sample of scientists in providing evidence for H3, indicating that greater social capital increases the likelihood to start a firm. Unlike any other field of research, the coefficient on grant amount is negative and statistically significant, providing preliminary evidence against H5. This result in particle and nuclear physics could be related to basic (and theoretical) research requiring more initial funding, but the results could be subject to a larger knowledge filter before they can be commercialized through startups. Similar to

CMMI scientists, the coefficients for full-professor and years in tenure variables are negative and statistically significant, indicating preliminary evidence against H4. Also, the positive and statistically significant coefficient for the Midwest variable indicates that PHY scientists with university affiliations in the Midwest have a greater likelihood in starting new firms compared to scientists affiliated to universities in the northeast region.

The results for Biological Infrastructure (DBI) are consistent with the overall sample of scientists in supporting H3, indicating the positive role of social capital in scientist propensity to start a firm. Consistent with the results for the overall scientist population, the positive and statistically significant coefficient of other sources of funding provide support for H5, and negative and statistically significant co-efficient for number of student collaborators provides preliminary evidence against H4 (however, the magnitude of the effect is insignificant).

5 Discussion

When we consider the heterogeneity of scientific research by disaggregating our sample into six research fields, the results provide a much richer picture than could be obtained from the simple hypotheses testing conducted using the full sample. Table 6 provides a summary of statistically significant effects for the full sample and for each of the six research fields.

The empirical results demonstrate key differences in scientist propensity to start a firm across fields. First, we observe that scientist human capital and human resources are not strong consistent predictors of scientist entrepreneurship for the overall sample and for scientists in each of the six fields of research. We find that scientist social capital, measured as membership in scientific advisory board, is a strong predictor for the likelihood to start a new firm. Second, with the exception of Physical Oceanography, financial resources measured primarily as an indicator of other sources of funding is a factor conducive to scientist entrepreneurship. Third, we find that university conditions, measured at the departmental level (department encouraging commercialization and department head's entrepreneurial orientation) and university level (success of the university technology transfer office), are strong predictors of a scientist's propensity to start a new firm.

Future research can also build upon this paper by expanding and enhancing data sources, and examining the differences between data reported by university TTOs and self-reported data from scientists. This could help university administrators and policymakers better understand how to assess the contribution of universities to innovative activity and commercialization.

Another agenda is to broaden the spectrum of scientific and academic contexts being analyzed. Thus far, most studies have examined one field but our findings point to the need to understand the drivers of important differences across fields. We uncover a strongly nuanced picture of scientist entrepreneurship for which heterogeneity of scientific field is important. The propensity for a university scientist to commercialize knowledge varies considerably across scientific fields. In some fields, such as Computer and Network Systems, the rate of entrepreneurship is remarkably high at almost 24 %; similarly, more than 20 % of scientists in Civil, Mechanical, and Manufacturing Innovation start a firm. In contrast, scientist startups are lower in other fields: Less than 5 % in Environmental Biology and just over 6 and 8 % in Particle and Nuclear Astrophysics and Biological Infrastructure, respectively. Further, we find that many of our variables do not have consistent effects across six fields of research. For example, scientist experience, measured as

Table 6 Summary of key determinants of scientist entrepreneurship by field of research

	All fields	CMMI	DEB	CNS	OCE	PHY	DBI
Financial resources	**+**				**+**	**−**	**+**
Grant amount	+					−	+
Other funding (>750 K)	+				+		+
Human resources	**−**						**−**
# of students	−						−
Human capital		**−**			**+**	**−**	
Years in tenure		−			+	−	
Full professor						−	
Social capital	**+**	**+**		**+**		**+**	**+**
Board membership	+	+		+		+	+
Institutional factors	**+**	**+**		**+**	**+**		
Dept. Encourages Commercialization	−			−	−		
Dept. Head Entrepreneurial Orientation	+	+		+	−		
Univ. TTO Success					+		
Scientist demographics							
Male	**+**			**+**			
Midwest region		+				+	
South region							
West region					−		

The signs indicate directionality of the coefficients that are statistically significant in the models

CMMI civil, mechanical, and manufacturing innovation, *DEB* environmental biology, *CNS* computer and network systems, *OCE* physical oceanography, *PHY* particle and nuclear astrophysics, *DBI* biological infrastructure

years in tenure, is positively associated with startups for Physical Oceanography scientists but negatively for Particle and Nuclear Astrophysics scientists. Our findings caution against generalizations across fields of science, as both the prevalence and determinants of startup vary. An important question for future research is not only to understand how, but also why, scientific fields are different. This could help advance understanding of how best to help scientists in some fields commercialize their research, if for example, they work in fields which are systematically characterized by less commercialization.

6 Conclusion

We analyzed scientist entrepreneurship by examining the drivers of scientist startup propensity among 1,899 scientists across six research fields. Our approach is novel because we collected primary survey data from scientists rather than use data collected by sources such as university TTOs or AUTM. We use a two-part empirical approach, first testing six hypotheses on our full sample. Second, we examined differences in the drivers of scientist startups in each field individually. Our findings suggest that approximately 13 % of scientists have started a new company, indicating spillovers of knowledge from universities for commercialization, innovation and ultimately economic growth, employment creation and global competitiveness.

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