Knowledge begets knowledge: university knowledge spillovers and the output of scientific papers from U.S. Small Business Innovation Research (SBIR) projects

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Abstract:

Scientific papers submitted for publication from U.S. Small Business Innovation Research (SBIR)-funded research projects are an innovative output that has yet to be studied systematically. Using a knowledge production framework, we identify empirically covariates with the number of scientific papers resulting from SBIR projects over the period 1992 through 2001. We find empirically that when the firm involves a university in its funded project, more scientific papers result. When the form of university involvement is taken into account, we find the greatest impact on the output of scientific papers comes from the inclusion of an individual from the university who originally developed the technology being pursued by the firm in its SBIR project. In other words, the project-specific technical human capital knowledge from the university that spills over to the firm's project begets (i.e., brings about) additional knowledge in the form of scientific papers submitted for publication.

Keywords: Innovation | Technology | Scientifc publications | R&D | University knowledge spillovers | Small Business Innovation Research (SBIR) program | Patents

Article:

Introduction

The U.S. Small Business Innovation Research (SBIR) program is a set-aside program created through the U.S. Small Business Innovation Development Act of 1982 (Public Law 97-219). This legislation identified small firms as an engine for innovation and economic growth.[1] Thus, government agencies were legislated to set aside a portion of their extramural research budgets to fund agency-relevant extramural research projects in small (less than 500 employees) firms.[2]

The specific purposes of the SBIR program, as stated in the 1982 Act were to: (1) stimulate technological innovation; (2) use small business to meet Federal research and development needs; (3) foster and encourage participation by minority and disadvantaged persons in technological innovation; and (4) increase private sector commercialization innovations derived from Federal research and development.[3]

Section I of the 1982 Act presents Congress' view about the social benefits from technology developed through SBIR-funded research (i.e., through purpose (4) above): "The Congress finds that (1) technological innovation creates jobs, increases productivity, competition, and economic growth, and is a valuable counterforce to inflation and the United States balance-of-payments deficit. …." In addition to a commercialized technology, there are other means through which SBIR-funded research can create social value that are not mentioned, or even suggested, in the 1982 Act. One means is through knowledge spillovers that result from the funded research. In this paper, we focus on one particular form of knowledge spillovers, namely the output of scientific papers submitted for publication by the SBIR-funded firm based on its SBIR-funded research project. Scientific papers that emanate from SBIR-funded research projects clearly have public good characteristics and thus have the potential to contribute social value for the commonweal. We also focus on one antecedent to the firm's knowledge spillovers, namely knowledge that spills over to the firm through the research participation of universities in their SBIR-funded projects.[4]

The remainder of this paper is outlined as follows. In "A knowledge production framework for scientific papers" Section, we posit a knowledge production framework for scientific papers. In "SBIR-funded research project data" Section, we describe the data on SBIR-funded research projects used to implement empirically our framework. Our empirical findings are presented in "Empirical findings and discussion" Section. Finally, in "Concluding observations and future research" Section, we offer concluding observations about our findings, we discuss their robustness, we suggest possible implications of our findings for university administrators, and we posit a direction for future research related to knowledge spillovers especially from publicly-funded research.

A knowledge production framework for scientific papers

In the economics literature, discussion about the production of knowledge traces directly to Griliches (1979) about the transformation of innovative inputs into innovative outputs.Footnote5 The empirical research that developed from Griliches is discussed in the recent literature review by Hall and Harhoff (2012). Most authors, including Griliches, have focused on R&D investments, within the context of a knowledge production function, as the relevant innovative input and on patents from the funded research as the relevant innovative output. Here, we focus on scientific papers submitted for publication by the SBIR-funded firm based on its SBIR-funded research project as the relevant innovative output.[6]

Following Griliches, knowledge can be endogenously created by a firm through both its investments in R&D and its endowments of human capital (HC). Thus,

$$Kn = F\left(R\&D, HC\right) \tag{1}$$

In our analyses that follow, we approximate Kn by the number of scientific papers submitted for publication by the firm that resulted from its SBIR-funded research project, and we represent that relationship as:

$$Scientific\ Papers = f\left(R\&D,\ Employees, \mathbf{X}\right) \tag{2}$$

where X is a vector of other project characteristics that control for cross-project and cross-firm differences in the number of scientific papers from the SBIR-funded research project, and where the structural form of $F(\cdot)$ in Eq. (1) is not assumed to be the same as the structural form of $f(\cdot)$.Footnote7 Regarding the vector X, Audretsch and Link (2018) make the case that knowledge that spills over from the public sector is also a relevant input into a firm's knowledge base. Our SBIR data set, as discussed in "SBIR-funded research project data" Section, does not include a direct measure of knowledge spillovers from the public sector to the funded firm; but, it does include an indirect measure, namely the involvement of university-based resources in the firm's SBIR-funded research project.[8]

With our emphasis on university involvement in the production of knowledge through scientific papers, the empirical analysis that follows also contributes to the literature on the role of universities in firm production and firm outputs as well reviewed by Perkmann et al. (2013), Link (2015) and Colombo et al. (2019). This body of literature, as well as our categorical empirical analysis of different forms of university involvement in knowledge creation below, emphasizes the heterogeneity of university research partnerships.

SBIR-funded research project data

In the year 2000, as part of the periodic SBIR program's reauthorization (Public Law 106-554), the U.S. Congress mandated that the National Research Council (NRC) of the National Academies of Science, Engineering, and Medicine conduct an evaluation of the economic benefits associated with the program.Footnote9 One method used by the NRC to meet its charge was to conduct in 2005 a random sample survey of projects funded between the years 1992 and 2001 (inclusive). The projects in the data set were funded by the five largest agency SBIR programs: the Department of Defense (DoD), the National Institutes of Health (NIH), the National Aeronautics and Space Administration (NASA), the Department of Energy (DOE), and the National Science Foundation (NSF).[10]

SBIR research awards fall within two categories: Phase I and Phase II awards. Generally, Phase I awards are for proof of concept; those projects are currently funded at not more than \$150,000 for a 6-month period. Successful Phase I awarded firms may be invited to apply for Phase II funding. Those firms that receive funding for a 2-year Phase II project are expected to develop and commercialize an innovative technology. Currently, funding for Phase II awards is generally not more than \$1,000,000.[11]

In 2005, the NRC collected data from a random sample of Phase II projects on, among other things, the intellectual contributions or knowledge produced by the firm from its SBIR-funded research project.Footnote12,Footnote13 In particular, project data were collected from funded firms on the number of scientific papers submitted for publication as of 2005 that were directly related to the technology developed during the funded Phase II projects and on the amount of the SBIR award. As part of the 2012 reauthorization of the SBIR program (Public Law 112-81), Congress again requested that the NRC conduct a follow-up study of SBIR award projects.[14] The focal years for this second wave of surveys were 2001 through 2010.[15,16]

While the names and locations of the funded firms are masked in the data from both surveys, for additional confidentiality the NRC also did not release the amount of the project's award to each firm in the 2012 follow-up study. Because the amount of the project award measures the amount of R&D available to the project, and because R&D is a focal variable in a knowledge production function as shown in Eqs. (1) and (2) above, only the data from the 2005 survey are used in this study. Thus, the data used in this paper represent the most complete and most recent set of information available on publicly supported research projects in small U.S. firms. And, while a number of other countries have programs that support technology development and innovation in small firms, to the best of our knowledge none of these countries have conducted surveys and made project-related data available for study.[17]

The U.S. SBIR program, and similar programs in other countries, as pointed out above, are only one source of financing for science-based entrepreneurial firms as Civera et al. (2017) correctly note. However, in the United States the SBIR program is the most visible such program and one that garners the continued attention of the U.S. Congress.

Table 1 defines the variables in the 2005 NRC SBIR data set that we used to estimate Eq. (2). Descriptive statistics for these variables are in Table 2.

Table 1 Variables used in the estimation of Eq. (2)

Variable	Definition
Scientific Papers	Number of scientific papers submitted for publication by the firm related to the technology developed in the current Phase II project
R&D	Phase II award amount (thousands $2005)
Employees	Number of employees in the firm at the time the Phase II proposal was submitted
Project Age	Age, in years, of the Phase II research project (as of the 2005 survey)
Previous Awards	= 1 if the firm previously received one or more Phase II awards that are related to the current Phase II project/technology supported by the current Phase II award, 0 otherwise
University	= 1 if the firm conducting the current Phase II project involved university resources in the current Phase II project, 0 otherwise
University Faculty	= 1 if the principal investigator in the current Phase II project was a faculty or adjunct faculty member at a university, 0 otherwise
University License	= 1 if the technology researched in the current Phase II project was licensed from a university, 0 otherwise
University Developed Technology	= 1 if the technology researched in the current Phase II project was originally developed at a university by one of the participants in the funded Phase II project, 0 otherwise
University Equipment	= 1 if facilities or equipment at a university were used in the funded Phase II project, 0 otherwise
University Graduate Students	= 1 if graduate students were used in the funded Phase II project, 0 otherwise
Patents	Number of patent applications by the firm related to the technology developed in the current Phase II project
DOD	= 1 if the Phase II project was funded by DOD, 0 otherwise
NIH	= 1 if the Phase II project was funded by NIH, 0 otherwise
NASA	= 1 if the Phase II project was funded by NASA, 0 otherwise
DOE	= 1 if the Phase II project was funded by DOE, 0 otherwise
NSF	= 1 if the Phase II project was funded by NSF, 0 otherwise

Table 2. Descriptive statistics on the variables (n = 1554)

Variable	Mean	SD	Range
Scientific Papers	1.761	5.818	0–165
R&D	763.328	349.317	19.26–8039.64
Employees	31.508	57.344	1–451
*R&D per Employee**	138.247	263.277	1.377–8039.64
Project Age	7.456	2.751	4–13
Previous Awards	0.400	0.490	0/1
University	0.362	0.481	0/1
University Faculty	0.051	0.220	0/1
University License	0.034	0.182	0/1
University Developed Technology	0.057	0.231	0/1
University Equipment	0.133	0.340	0/1
University Graduate Students	0.049	0.216	0/1
Patents	0.818	3.000	0–100
DOD	0.480	0.500	0/1
NIH	0.248	0.432	0/1
NASA	0.098	0.298	0/1
DOE	0.087	0.282	0/1
NSF	0.087	0.282	0/1

Only projects that were not discontinued prior to completing their Phase II research are included in the sample
*The project shown at just over $8 million ($2005) was funded in 1992, and at that time the firm had 1 employee

Empirical findings and discussion

Our empirical specification of Eq. (2) considers the number of scientific papers submitted for publication, Scientific Papers, as the dependent variable. Scientific Papers is a count variable, so we use a negative binomial regression model to estimate Eq. (2).[18]

Regarding the independent variables in Eq. (2), R&D per Employee is hypothesized to be positively related to the number of scientific papers. Our argument is that the greater the SBIR project's R&D budget the greater is the complexity of the project; and the greater the complexity of the project, the greater is the number of potentially publishable scientific papers from the project's research. For estimation purposes, R&D per Employee is measured as a natural logarithm because its values are highly skewed and have a large range; see Table 2.

The variable Project Age controls for the time between the year of the initial funding of the project and the NRC survey in 2005. To increase the flexibility of our regression specification, we included Project Age and (Project Age)2 as independent variables. Projects funded in 2001 had 4 years not only to complete their Phase II research project, which generally took 2 years, but also to prepare related scientific papers; in contrast, projects funded in 1992 had 13 such years. We therefore hypothesize Project Age to be positively related to the number of scientific papers submitted for publication.

Some firms in the NRC SBIR data set had previously received Phase II awards related to the current Phase II project/technology, Previous Awards, and those firms with such prior research-related experience and technology-related expertise are hypothesized to be more successful in their current Phase II project. We hypothesize that the more successful the current Phase II project, the greater the number of scientific papers submitted for publication.

The variable University is an indicator for university involvement in the research project. As discussed above, SBIR awards are set aside for small (fewer than 500 employees) firms. The average number of employees in our sample is about 31 (see Table 2). Small firms have resource constraints, especially research-related constraints because of the scale requirements often associated with R&D activity. Universities represent a source of technical knowledge that can potentially leverage the successfulness of the funded Phase II project. Thus, we hypothesize that those firms that included a university in a research project, in one form or another, will be more successful in their research and thus, following our previous argument, will have more potentially publishable scientific papers.[19]

Our final control variable, Patents, is the number of patent applications based on the Phase II project. We include both Patents and (Patents)2 in our regression specification. The empirical relationship between the number of patent applications and the number of scientific papers submitted for publication is a priori ambiguous. On the one hand, firms may prefer to seek patent protection, rather than publish, if they believe that scientific publications could undermine their competitive advantage or preclude subsequent patenting.[20] We would then expect to see a negative relationship between patent applications and the number of scientific papers submitted for publication. Alternatively, patenting and publishing could be complements, if pursuing one lowers the cost, in terms of investments in human and scientific capital, of pursuing the other. In this case, the relationship between patents and publications would be positive.

The regression results in column (1) of Table 3 confirm statistically our arguments from above. The coefficient of ln (R&D per employee) is positive, as hypothesized and highly significant. It suggests that a 10% increase in an SBIR project's budget corresponds to an 11% increase in the number of scientific papers submitted for publication.[21]

The coefficients of Project Age and (Project Age)2 show that for values of about 5 years and higher, which cover most of the sample range (see Table 2), the relationship between project age and the number of scientific papers submitted for publication is positive but it is not statistically significant.[22]

As hypothesized, firms that had received previous Phase II awards related to the current Phase II project or technology, and firms that involved a university as a research partner in its Phase II research project also submitted more scientific papers for publication. The estimated coefficients of Previous Awards and University are both positive and highly significantly.

Finally, the coefficients of Patents and $(\text{Patents})^2$ are positive and negative, respectively, and both are highly significant. The estimates imply that up to about 75 patent applications, the relationship between the number of patent applications and the number of scientific papers submitted for publication is positive.[23] Thus, we find no evidence that patents "crowd out" scientific publications. Instead, patent applications and scientific papers submitted for publication appear to be complements.

Table 3. Negative binominal regression results from Eq. (2) (n = 1554)

Variable	(1) *Scientific Papers*	(2) *Scientific Papers*
ln (R&D per Employee)	0.115***	0.121***
	(0.038)	(0.036)
	[0.002]	[0.001]
Project Age	−0.097	−0.120
	(0.128)	(0.118)
	[0.447]	[0.309]
(Project Age)^2	0.010	0.011
	(0.008)	(0.007)
	[0.229]	[0.160]
Previous Awards	0.440***	0.488***
	(0.120)	(0.098)
	[0.000]	[0.000]
University	0.803***	–
	(0.131)	
	[0.000]	
University Faculty	–	0.779***
		(0.232)
		[0.001]
University Licenses	–	−0.062
		(0.366)
		[0.866]
University Developed Technology	–	1.174***
		(0.414)
		[0.005]
University Equipment	–	0.481**
		(0.207)
		[0.020]
University Graduate Students	–	0.477***
		(0.158)
		[0.002]
Patents	0.151***	0.170***
	(0.034)	(0.032)
	[0.000]	[0.000]
(Patents)^2	−0.001***	−0.002***
	(0.000)	(0.000)
	[0.000]	[0.000]
Intercept	−0.589	−0.592
	(0.497)	(0.447)
	[0.236]	[0.185]
Agency fixed effects	Yes	Yes
ln (α)	0.847***	0.804***
	(0.087)	(0.078)
	[0.000]	[0.000]
LR statistic	314.734	324.881
p value	0.000	0.000
log-likelihood	−2513.375	−2497.804

Robust standard errors in parentheses; p-values in brackets; α is the overdispersion parameter of the negative binomial model

**p <0.05; ***p <0.01

The NRC SBIR data set also contains information on the form of the university's involvement in the firm's Phase II research project. We interpret each form of university involvement as embodying differential knowledge or resources that can potentially spill over to, or be used in, a firm's Phase II project. As shown in Table 1, university involvement can range from being the licensor of a technology to the firm (University License), to providing access to research equipment for the firm to use in its research project (University Equipment), to including a university faculty member as the principal investigator (University Faculty), to including as a research participant the individual from the university who originally developed the technology being pursued by the firm in its Phase II project (University Developed Technology), or to including university graduate students in its Phase II project (University Graduate Students). These five categories of university involvement are not mutually independent of each other. A respondent to the NRC survey was asked to identify all categories of university involvement. If at least one category was selected, then the variable University = 1.

Referring to the definition of these forms of university involvement from Table 1, one might think of University License as representing a dimension of technical knowledge that is owned by the university but that has restrictions on its appropriability as defined by the terms of the license; one might also think of University Equipment as representing a dimension of technical knowledge that is also owned by the university but that is appropriable by the firm only during the time that it is being used; one might think of University Faculty and University Graduate Students as representing a dimension of human capital experiential knowledge that is related to project management; and one might think of University Developed Technology as representing a dimension of project-specific human capital technical knowledge that is embodied in an individual and transferable to and fully appropriable by the funded firm.

To explore in more detail specific aspects of university involvement in the firm's SBIR-funded research project that may be particularly salient for understanding the output of scientific papers submitted for publication, we also estimate a model in which the University variable is replaced by the five indicators discussed above. These results are given in column (2) of Table 3.

We hypothesize that all forms of university involvement will be positively related to Scientific Papers. However, the estimated coefficient of University License is negative but it is not statistically significant at conventional levels. It may be the case that a firm that licenses a technology from a university to use in its own research is either not permitted to publish findings related to the licensed technology or that the results from Phase II research that simply build on a licensed technology are not appropriate for publication because they do not significantly advance the state of knowledge. The estimated coefficients of the other areas of university involvement are all positive and statistically significant.

What is interesting is the ranking of the estimated coefficients on the forms of university involvement in column (2) because the size of the coefficients reveals information about the relative importance of each form of university involvement as it relates to the submission of scientific papers for publication. It appears that the most important form of university involvement is the inclusion of an individual from the university who originally developed the technology being pursued by the firm in its Phase II project. In other words, one might conclude that the project-specific human capital technical knowledge that spills over to the firm's project brings about additional knowledge in the form of submitted scientific papers for publication. Less important in terms of the magnitude of the estimated coefficient, is the per se inclusion of a university faculty member as the principal investigator in the Phase II project. His/her human capital experiential knowledge also brings about scientific papers but not as many as project-specific human capital technical knowledge. And even less important, but still important in a statistical sense, is the use of university facilities or equipment and the involvement of university graduate students in the Phase II project. In other words, university knowledge, which has public goods characteristics does bring about scientific knowledge in the form of potential publications, which also have public good characteristics.

To further quantify the association between university involvement in the research project and scientific papers submitted for publication, we present in Table 4 estimated marginal effects and incidence rate ratios (IRRs) from the negative binomial model results.

Table 4 Marginal effects and incidence rate ratios

Variable	(1) Marginal effect	(2) IRR	(3) Marginal effect	(4) IRR
University	1.483***	2.233***	–	–
	(0.313)	(0.292)		
	[0.000]	[0.000]		
University Faculty	–	–	2.054**	2.178***
			(0.863)	(0.506)
			[0.017]	[0.001]
University Licenses	–	–	−0.115	0.940
			(0.667)	(0.344)
			[0.863]	[0.866]
University Developed Technology	–	–	3.594*	3.236***
			(2.085)	(1.340)
			[0.085]	[0.005]
University Equipment	–	–	1.032*	1.618**
			(0.530)	(0.336)
			[0.052]	[0.020]
University Graduate Students	–	–	1.136**	1.611***
			(0.473)	(0.254)
			[0.016]	[0.002]

Robust standard errors in parentheses; p values in brackets
*p<0.10; **p<0.05; ***p<0.01

When only University is included as an independent variable (see columns (1) and (2) in Table 4), the marginal effect estimate shows that university involvement is associated with an additional 1.5 submitted scientific papers, compared to research projects without collaboration with a university partner. The IRR estimate shows that the average number of submitted papers is about 2.2 times larger when a university partner is involved in the research project, or an increase of about 120%.

Replacing the University indicator with five separate indicators yields the estimates in the columns labeled (3) and (4) in Table 4. As already apparent from Table 3, the largest marginal effect appears for University Developed Technology. Including an individual from the university who originally developed the technology being pursued by the firm in its Phase II project is associated with about 3.6 additional submitted scientific papers, or an average number of submissions that is about 3.2 times higher, compared to projects that did not involve such an individual. Having a university faculty member as principal investigator is associated with about 2.1 additional submitted papers, or an average number of submissions that is about 2.2 times larger. The use of university facilities or equipment in the research project has a more modest though still statistically significant impact: such projects are associated with 1.0 additional submitted papers and an average number of submissions that is 1.6 times larger than for projects that did not use such facilities or equipment. Finally, involvement of university graduate students in the Phase II project is associated with 1.1 additional submitted papers, or an average increase by a factor of 1.6.

To verify the robustness of our results, we also estimate a bivariate count model with the numbers of scientific papers submitted for publication and patent applications as outcome variables. Specifically, we used the bivariate negative binomial specification of Famoye (2010). In this model, the two outcomes have negative binomial distributions (conditional on control variables) which are linked together through a dependence parameter λ. The sign of λ is the same as the sign of the correlation between the two counts (after controlling for the independent variables). We estimate this model by maximum likelihood in Stata (Xu and Hardin 2016).

The results from this alternative model are given in Table 5. Columns (1) and (2) show estimates of the equations for scientific papers submitted for publication and patent applications when only the University variable is included to measure university involvement in the Phase II project. The estimates for scientific papers submitted for publication are very similar, in terms of magnitude and statistical significance, to the univariate estimates in column (1) of Table 3. University involvement is associated with an increase in both scientific papers submitted for publication and the number of patent applications. The estimate of λ is positive and highly significant, so that conditional on the independent variables, the numbers of scientific papers submitted for publication and patent applications remain positively correlated. This is consistent with the results in column (1) of Table 3, where Patents is used as an independent variable.

Columns (3) and (4) show the bivariate estimates when the single involvement indicator is replaced by five categorical indicators. Again, the estimates in column (3) are very similar to the univariate estimates in column (3) of Table 3. Except for University Licenses, all indicators are positively related to the number of scientific papers submitted for publication. The relationship is strongest for University Developed Technology, followed by University Faculty. Interestingly, column (4) suggests that involvement of university faculty is associated with fewer patent applications. A potential explanation for this is that university faculty may only choose to become involved if the Phase II project has strong publication potential, thereby shifting focus and effort away from pursuing patent applications. The estimate of λ is again positive and highly significant, pointing to a positive correlation between the numbers of scientific papers and patent applications (after controlling for the independent variables). This is also consistent with the estimates in column (2) of Table 3.

Table 5 Bivariate negative binomial regression estimates (n = 1554)

Variable	(1) *Scientific Papers*	(2) *Patents*	(3) *Scientific Papers*	(4) *Patents*
ln (R&D per Employee)	0.122***	0.163***	0.130***	0.175***
	(0.038)	(0.046)	(0.037)	(0.055)
	[0.001]	[0.000]	[0.001]	[0.001]
Project Age	−0.086	0.139	−0.092	0.185
	(0.129)	(0.147)	(0.122)	(0.168)
	[0.506]	[0.344]	[0.448]	[0.271]
(Project Age)^2	0.009	−0.011	0.009	−0.013
	(0.008)	(0.009)	(0.008)	(0.011)
	[0.268]	[0.260]	[0.236]	[0.209]
Previous Awards	0.497***	0.409***	0.565***	0.432***
	(0.113)	(0.136)	(0.101)	(0.149)
	[0.000]	[0.003]	[0.000]	[0.004]
University	0.814***	0.387**	–	–
	(0.127)	(0.160)		
	[0.000]	[0.016]		
University Faculty	–	–	0.712***	−0.468*
			(0.223)	(0.262)
			[0.001]	[0.075]
University Licenses	–	–	0.049	0.396
			(0.350)	(0.246)
			[0.889]	[0.107]
University Developed Technology	–	–	1.044***	−0.193
			(0.387)	(0.212)
			[0.007]	[0.361]
University Equipment	–	–	0.472**	0.509***
			(0.193)	(0.168)
			[0.015]	[0.003]
University Graduate Students	–	–	0.489***	0.292
			(0.165)	(0.226)
			[0.003]	[0.195]
Intercept	−0.539	−1.441**	−0.584	−1.629**
	(0.499)	(0.677)	(0.458)	(0.750)
	[0.280]	[0.033]	[0.203]	[0.030]
Agency Fixed Effects	Yes	Yes	Yes	Yes
ln (α)	0.879***	0.786***	0.853***	0.779***
	(0.078)	(0.136)	(0.073)	(0.161)
	[0.000]	[0.000]	[0.000]	[0.000]
λ	0.971***		0.971***	
	(0.166)		(0.167)	
	[0.000]		[0.000]	
LR statistic	147.458		194.733	
p value	0.000		0.000	
log-likelihood	−4321.590		−4308.816	

Robust standard errors in parentheses; p-values in brackets; α is the overdispersion parameter of the negative binomial model; λ is a measure of dependence between the count variables and has the same sign as the
correlation
*p<0.10; **p<0.05; ***p<0.01

Concluding observations and future research

Nobel Laureate Milton Friedman famously observed that "There's no such thing as a free lunch." The knowledge production function model, introduced by Griliches (1979), suggests that Friedman's famous dictum applies to innovation as well. Generating innovative output, in general and in terms of scientific papers submitted for publication, requires inputs—not any inputs but, in particular, inputs dedicated to creating new knowledge and ideas that are the key ingredients fueling innovative activity.[24]

A rich and robust literature has found systematic and consistent empirical evidence that R&D as a measure of knowledge inputs is positively related to innovative output. This paper, however, provides new empirical evidence suggesting that the model of the knowledge production function may be more nuanced than has generally been portrayed in the economics literature. While the results of this study do confirm that knowledge inputs in the form of R&D certainly play an important role in generating innovative publication outputs, so too do key characteristics of the firm and its research partners within the institutional context of the university. In particular, this paper finds that projects that have been ongoing for a longer duration within firms, that have enjoyed previous awards, and that involve a university are projects that result in more scientific papers submitted for publication. In addition, the impact of university involvement on innovative activity represented through scientific papers submitted for publication is significantly greater when the technology researched was originally developed at the university and when university faculty were involved with the SBIR Phase II project.

The SBIR program is often characterized as providing financial resources to small innovative firms. The findings in this paper also suggest that there is a behavioral aspect of the SBIR program that has previously been less noticed, namely bringing together partners from the private sector and the academic sector. A result of that partnership is greater innovative output that might not otherwise occur. This finding suggests that the impact of the SBIR program goes beyond simply providing financial resources for R&D in small firms; the provision of financial resources also enhances the efficacy of those investments in R&D by facilitating partnerships with universities. Thus, to go one step further, from a program management perspective, the proposed collaboration with a university as a research partner, in general or by specific use, might be used in the evaluation process of Phase II proposals by U.S. funding agencies.

Although the research purpose of the SBIR program has not changed through several program reauthorizations as we note in footnote 14, two important questions might be asked regarding our empirical findings.[25] First: Are our findings from an analysis of 1992 through 2001 Phase II SBIR projects generalizable to the post-2001 period? And second: Do our empirical findings have policy implications for university administrators?

Regarding the generalizability of our findings, we have no fact-based reason to think that our findings, at least qualitatively, would no longer hold if data from the post-2001 period had been available. However, one might question this assertion by pointing out the White House's nearly decade-long emphasis on technology transfers from federal laboratories. Through President Barack Obama's 2011 Presidential Memorandum—Accelerating Technology Transfer and Commercialization of Federal Research in Support of High-Growth Businesses,Footnote26 and President Donald Trump's President's Management Agenda,[27] one might conjecture that SBIR funding agencies could exert suasion on Phase II awardee firms to engage in technology transfers through collaborative scientific publications with agency laboratory scientists, especially if complementary technology research is involved. If this were to occur, which we do not think is feasible as we explain below, then the relationship between funded firm scientific publications and university involvement might change.

While scientific publications are an important technology transfer mechanism, they are not as visible at the laboratory level as are patents, licenses, and cooperative research and development agreements (CRADAs), and CRADA activity was a primary focus of President Obama's 2011 Memorandum. Perhaps for that reason, publicly available time series data on scientific publications from federal laboratories are scarce. There is one exception, and that exception relates to a time series of data on scientific publications from the National Institute of Standards and Technology (NIST), the largest Federally Funded R&D Centers (FFRDC) (i.e., laboratory) within the Department of Commerce. However, as rich as these NIST data are, they do not note whether there was co-authorship with a scientific researcher from a private-sector firm much less from a private-sector firm that received a Phase II SBR award. Albeit limited information, Link and Scott (2019) report the number of scientific publications from NIST over the period 1973 through 2008, and holding constant NIST R&D expenditures, there is no empirical evidence that the annual trend in the number of scientific publications changed between the pre- and post-2001 periods.[28]

Regarding university policy implications from our findings, we refer back to Tables 3 and 4 in which we show that university involvement in a Phase II SBIR project has the greatest impact on awardee firms' scientific publications when university involvement is through university developed technology and through faculty engagements. The potential implication of this finding for university administrators is that universities that are so involved should attempt to remain involved even after the SBIR funded portion of the research is completed. There is anecdotal evidence in the NRC agency reports related to the 1992 through 2001 Phase II project data as well as the data collected as part of the 2012 program reauthorization to suggest that firms with successful Phase II projects patent their developed technologies, as we have already discussed, and even pursue initial public offerings.[29] The technology transfer activities at universities are, in response to the Bayh-Dole Act of 1980, designed to enhance university revenue (Leyden and Link 2015). Purposeful efforts on the part of universities and their technology transfer officers to thus encourage university involvement in Phase II SBIR projects might have financial benefits over time.[30]

Finally, as Link and Sarala (2018) show, university knowledge is an important element of a university ecosystem. Their findings show that the effect of university knowledge on firm performance is positive, but it is not independent of characteristics of firms that absorb that knowledge. We suggest that future research pursue firm-by-firm differences in their absorptive capacity for university-based technical knowledge, including not only the absorptive channels that are used but also the underlying factors that brought those channels into being. This should be done on a country-by-country basis for comparability purposes and to engender the spirit of public accountability. Relatedly, what has not been studied with respect to the U.S. SBIR program, or to the best of our knowledge in any study of publicly supported innovative activity, is the commercialization trajectory resulting from the publicly supported innovative activity, and how that trajectory, over time, is influenced by university involvement or the involvement of other external sources of technical knowledge.

Notes

1. The emphasis on the innovative capabilities of small firms in the United States traces in the economics literature at least to the scholarship of Jewkes et al. (1958). From a legislative perspective, U.S. President Jimmy Carter's 1979 Domestic Policy Review was a motivating seed for the passage of the 1982 Act. See: http://www.presidency.ucsb.edu/ws/index.php?pid=31628.

2. Each government agency with an SBIR program is currently required to set aside and allocate 3.2% of its extramural research budget to U.S. small firms with less than 500 employees. See Link and Scott (2012) and Leyden and Link (2015) for institutional background on the SBIR program including regulations about criteria for agencies to have an SBIR program and for firms to be eligible for an SBIR award.

3. When the 1982 Act was reauthorized in 1992 through the Small Business Research and Development Enactment Act (Public Law 102-564), the language of purpose (3) above was modified and broadened to focus on women as well as disadvantaged persons: "to provide for enhanced outreach efforts to increase the participation of socially and economically disadvantaged small business concerns, and the participation of small businesses that are 51% owned and controlled by women".

4. See Hur (2017) and Amoroso et al. (2008) for excellent background on various sources of knowledge spillovers.

5. The production of knowledge or the sources of knowledge certainly predates the scholarship of Griliches. It can be dated at least to John Locke's famous 1690 treatise, An Essay Concerning Human Understanding.

6. To the best of our knowledge, ours is the first paper to consider empirically scientific papers for publication within a traditional knowledge production framework. See Perkmann et al. (2013), and see Colombo et al. (2019). See Bacchiocchi and Montobbio (2009) for a study of university knowledge spillovers and public research using aggregate patent data. See Cohen et al. (2002) who report on the basis of survey data that publications and technical reports from universities and public research institutions are an important pathway of knowledge to industrial R&D firms. See also Zhang et al. (2018) for a study of publications as an innovative output from publicly funded research within the context of a partial least squares model; see Link and Scott (2019) for a study of publications at the U.S. National Institute of Standards and Technology (NIST) as a function of R&D using a Solow (1957) accounting framework. Finally, Hayter and Link (2018) discuss the tradeoff between publications and patents as innovative outputs within small entrepreneurial firms. However, as discussed in detail in Hessels and van Lente (2008), the so-called new knowledge production function literature explicitly acknowledges not only knowledge production within universities and scientific institutions, it is explicit about the importance of heterogeneous sources of complementary knowledge. We thank an anonymous referee for pointing this out to us. A recent excellent example of the application of the new knowledge production function literature is by Onyancha and Maluleka (2011) who emphasize knowledge production through collaboration.

7. As Gonzalez-Brambila and Veloso (2007) point out in their study and in the references therein, there is a rich literature on human capital and technical capital determinant of research output. Much of the literature referenced relates to research outputs from individuals or from economic entities for which more background information is required than we have available at the project level in the NRC data set, discussed below.

8. See Jaffe (1998) who makes a spillover argument with reference to the Advanced Technology Program within the National Institute of Standards and Technology.

9. We have written about the SBIR program in numerous publications and books; some duplication of text is thus unavoidable.

10. About 50% of all SBIR Phase II awards are funded by DoD. See Link and Scott (2012).

11. Under certain conditions, an agency can increase Phase I and Phase II awards above these caps by up to 50%.

12. The NRC went to great lengths to formulate a random sample of projects including addressing and deleting the biasing issue of SBIR grant "mills" from the final sample. Two of the authors of this paper were advisory members of the 2005 NRC SBIR study team, and they participated in this randomizing process. See Wessner (2008).

13. We thank an anonymous reviewer for encouraging us to present more information about the final random sample of 1554 projects that we use in the analyses below. We do so here for the complete sample, but agency-by-agency information on this topic is available from the authors on request. From 1992 to 2001, there were 11,214 completed Phase II projects. The final Phase II sample size of surveyed projects was 6408. The response rate was 30% across all five agencies yielding a final sample of 1916. The NRC surveyed a number of nonrandomly selected projects because they were projects that had realized significant commercialization, and the NRC wanted to be able to use that information for describing success stories. We deleted these nonrandomly selected projects, thus reducing the number of projects in the sample to 1878. Independently, the NRC undertook studies to verify that the final sample mirrored the original sampling population of 6408. As noted in Table 2 below, only 1554 projects are used in the analysis in this paper due to some firms not responding to all of the survey questions that relate to the variables that we use. See Wessner (2008) for a discussion of the data reduction process and for the NRC's efforts to pretest the survey instrument to ensure its construct validity.

14. The SBIR program has been reauthorized a number of times over its history. Leyden and Link (2015) provide a chronological history of the temporary and permanent reauthorization legislations. Through all of the reauthorizations, the purpose of the program did not change with the exception noted in footnote 3; however, that exception did not change the research focus of the program. As pointed out to us by an anonymous referee, legislations complementary to SBIR's reauthorizations might affect the generalizability of our findings from our analysis of data over the 1992 through 2001

time period to later time periods. We address this important observation in "Concluding observations and future research" Section.

15. Two of the authors of this paper were advisory members of the 2005 NRC SBIR study team, and one of the authors was an advisory member of the 2012 study team. Both of these authors have sole and proprietary access to the data from both surveys.

16. While limited data were collected by the NRC on Small Business Technology Transfer (STTR) Phase II projects, those data were not made available to the authors of this paper.

17. Independently, we have identified such countries to include those in the EU (including the UK) and Australia, Canada, Japan, South Africa, Taiwan, and Turkey.

18. A Poisson regression model is less appropriate in our case because the number of submitted papers has a higher fraction of zeros and a higher fraction of large counts than predicted by the Poisson distribution. This is confirmed by the estimated overdispersion parameter in the negative binomial model, which is significantly different from zero. The Poisson estimates, however, are qualitatively similar to those in Table 3, and they are available from the authors on request.

19. Additional support for the hypothesis of more scientific papers submitted for publication from Phase II projects that include a university as a research partner is based on the fact that the reward structure for most university personnel is based on publications (Gulbrandsen and Smeby 2005). Thus, on the supply side, participation by university personnel will be greater when a firm is committed to publishing from the partnered project.

20. We thank an anonymous referee for pointing this out.

21. Recall, that the NRC survey ensures that the final sample of projects was random over the years 1992 and 2001 (inclusive). Thus, we generalize our findings to SBIR projects in general.

22. The fact that the coefficients of Project Age and (Project Age)2 are not significant might suggest that age of the project does not predict the number of scientific papers. However, if age is only included linearly, the coefficient of project age is positive and significant at 1%.

23. In our sample, all but one firm submitted 75 or fewer patent applications. Deletion of the project with 100 reported patent applications (see Table 2) from the model has a minimal impact. These results are available from the authors on request.

24. See also Tijssen (2004) who examined citations to corporate authored publications. His study focuses on the affiliation of the authors; unfortunately, there is no information in the 2005 NRC SBIR data set on affiliations.

25. We thank an anonymous referee for encouraging us to address these two questions.

26. See, https://obamawhitehouse.archives.gov/the-press-office/2011/10/28/presidential-memorandum-accelerating-technology-transfer-and-commerciali.

27. See, https://www.whitehouse.gov/omb/management/pma/, in particular see Goal 14.

28. These empirical results are available from the authors on request.

29. See reports at https://www.nap.edu/catalog/11989/an-assessment-of-the-sbir-program and http://sites.nationalacademies.org/PGA/step/sbir/.

30. By design, the Small Business Technology Transfer Research (STTR) program generally supports projects with a university as a research partner. The Small Business Technology Transfer Act of 1992 established the STTR program. The STTR program is modeled after the SBIR program, and it has the following goal, as stated in the 1992 Act: "[T]o facilitate the transfer of technology developed by a research institution through the entrepreneurship of a small business concern." Because university partners are relevant to scientific publications, as the empirical results in this paper show, we expect results similar to those herein if one examined scientific publications from STTR-funded projects because each one involves a research institution. We have no a priori opinion about how the number of scientific publications compares between similar SBIR and STTR projects. University administrators, including those involved in the university's technology transfer office, might consider incentives to involve university faculty in these programs as well.

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