Private Investor Participation and Commercialization Rates for Government-Sponsored Research and Development: Would a Prediction Market Improve the Performance of the SBIR Programme?

By: Albert N. Link and John T. Scott

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Abstract:

An objective of the US Small Business Innovation Research (SBIR) programme is the private sector commercialization of funded R&D projects. However, our estimate of the actual or expected probability of commercialization of such R&D is fairly low; our analysis of Department of Defense (DoD) Phase II awards suggests that the estimated probability of commercialization is only 0.47. We investigate econometrically whether outside private investors have useful information about proposed SBIR projects' prospects for commercialization. Our findings suggest that they do, thereby providing support for the possibility that a prediction market could improve the performance of the SBIR programme.

Keywords: economics | small businesses | business innovation | small business innovation research program | private sector commercialization | research and development | research funding

Article:

INTRODUCTION

An objective of the Small Business Innovation Research (SBIR) programme is the private sector commercialization of the funded research and development (R&D) projects. Yet, a number of analyses have shown that actual or expected probability of commercialization is fairly low (Cahill 2006; Wessner 2000). In this paper, after establishing that there is considerable room to improve the SBIR programme regarding its commercialization objective, we provide a first look at the possibility that a prediction market could be used to increase the commercialization of the output from SBIR projects.

In particular, public sector investments in SBIR projects are gambles with the public's monies. The key question is whether a prediction market would be a feasible mechanism for improving the odds for the success of such gambles. The answer entails many issues. With our evidence, we hope to focus attention on one central issue – whether outside private investors have useful information about proposed SBIR projects' prospects for commercialization. We ask: Does outside private investor participation lead to higher commercialization rates for government-sponsored R&D?

Section I provides a brief overview of the SBIR programme. Our hypothesis is stated in Section II, and the sample of SBIR projects used to test our hypothesis is described. Our econometric model and the variables used in the estimation are defined in Section III. Section IV presents the econometric results to test our hypothesis. In the context of our key finding about the probability of commercialization for an SBIR project, Section V discusses the possibility of a prediction market being used to improve the commercialization performance of the SBIR programme. Our conclusions are in Section VI.

I. A BRIEF OVERVIEW OF THE SMALL BUSINESS INNOVATION RESEARCH PROGRAMME

The Small Business Innovation Research (SBIR) programme is a public–private partnership that leverages private R&D through direct governmental support.1 The SBIR programme began at the National Science Foundation (NSF) in 1977 (Tibbetts 1999). At that time, the goal of the programme was to encourage small businesses, long believed to be engines of innovation in the US economy, to participate in NSF-sponsored research, especially research that had commercial potential. Because of the early success of the programme at NSF, Congress passed the Small Business Innovation Development Act of 1982 (P.L. 97–219; hereafter, the 1982 Act).

Total factor productivity growth, a measure of technological advancement, slowed in the United States, and in most industrial nations, in the early 1970s and then again in the late 1970s. The latter slowdown extended to the early 1980s. In response, a number of technology-based policies were initiated, including the 1980 R&D Tax Credit and the National Cooperative Research Act of 1984. The 1982 Act is one such initiative, although public support for enhancing innovation in small firms can be traced to as early as the 1960s (Turner and Brown 1999).

The 1982 Act required all government departments and agencies with external research programmes of greater than $100 billion to establish their own SBIR programmes and to set aside funds equal to 0.20% of the external research budget. In 1983, this amount totalled $45 million.

SBIR is a set-aside programme; it redirects existing R&D rather than appropriating new monies for R&D. As stated in the 1982 Act, to be eligible for an SBIR award, the small businesses must be: independently owned and operated; other than the dominant firms in the field in which they are proposing to carry out SBIR projects; organized and operated for profit; the employer of 500 or fewer employees, including employees of subsidiaries and affiliates; the primary source of employment for the project's principal investigator at the time of award and during the period when the research is conducted; and at least 51% owned by US citizens or lawfully admitted permanent resident aliens.

In 1992, the SBIR programme was reauthorized until 2000 through the Small Business Research and Development Enactment Act (P.L. 102–564). Under the 1982 Act, the set aside had increased to 1.25%; the reauthorization increased that amount over time to 2.50% and re-emphasized the commercialization intent of SBIR-funded technologies (see point (4) of the 1982 Act below). The percentage increased to 1.5 in 1993 and 1994, and then to 2.0 in 1995 and 1996, and then to 2.5 in 1997. The Small Business Reauthorization Act of 2000 (P.L. 106–554) extended the SBIR programme until 2008, and it kept the 2.50% set-aside amount. The Reauthorization Act of 2000 also called for an assessment of the SBIR programme by the National Research Council. The data analysed in this paper (discussed below) were collected as part of that assessment exercise and graciously made available to us.

The 1982 Act stated that the objectives of the programme are: (1) to stimulate technological innovation, (2) to use small business to meet federal research and development needs, (3) to foster and encourage participation by minority and disadvantaged persons in technological innovation, and (4) to increase private sector commercialization of innovations derived from federal research and development.

The SBIR's awards are structured by three phases (National Research Council 2004). Phase I awards are small, generally less than $100,000 for the six-month award period. The purpose of Phase I awards is to assist firms as they assess the feasibility of an idea's scientific and commercial potential in response to the agency's objectives. Phase II awards typically range up to $750,000 over two years. These awards are for the firm to develop further its proposed research, ideally leading to a commercializable product, process or service.2 The Phase II awards of public funds for development are sometimes augmented by private funding from outside the firm. For example, the Department of Defense's Fast Track initiative gave priority in selection for Phase II awards to firms that arranged outside financing for their Phase II development project even before the award was granted (Wessner 2000). Further work on projects launched by SBIR awards occurs in what is called Phase III, and Phase III does not involve SBIR funds. It is the stage when the firm, if it needs additional outside finance, should obtain outside funding from sources other than the SBIR programme to ensure that the product, process or service can move into the marketplace.

From an economic perspective, the SBIR programme can be justified on at least two grounds. First, SBIR expenditures correct for market failures that would result in under-investment in socially-valuable R&D (Audretsch et al. 2002: 148). The sources of the market failures are varied, including not only the difficulties appropriating returns to innovation but also financial market failures inhibiting investments by viable small businesses (Martin and Scott 2000). Second, the SBIR programme can also be justified as a way to promote diversity in the economy as an independent goal in itself (see point (3) above from the 1982 Act), subsidizing small business research investments in particular geographic regions and minority-owned companies when the private sector would not provide funding to support such diversity (Scott 2000).3

The 11 agencies currently participating in the SBIR programme are the Environmental Protection Agency, the National Aeronautics and Space Administration, the National Science Foundation and the Departments of Agriculture, Commerce, Defense, Education, Energy, Health and Human Services, Transportation and, most recently, Homeland Security. Among the many agencies with SBIR programmes, the Department of Defense (DoD) maintains the largest programme, and we shall focus on it for this paper. Of the $2.01 billion budget in 2004, DoD awarded $1.02 billion or about 51% of total awards in that year.

II. HYPOTHESIS OF THE PAPER AND THE DATASET

Our analysis in this paper focuses on objective (4) of the 1982 Act and its restatement in the 1992 reauthorization, namely the objective: '… to increase private sector commercialization of innovations derived from federal research and development.'We hypothesize that commercialization will be more likely when there are outside private investors–private investors other than the firm winning the SBIR award or its principals–in the SBIR project. We test the foregoing broad hypothesis, and we find evidence consistent with the narrower hypothesis that outside private investors have good information about an SBIR project's commercialization prospects.

We expect a positive correlation between commercialization and the presence of outside investment funding – defined as not including either the firm's or its principals' own funds or the SBIR award funds – for three reasons. The first reason, and the one on which we hope to focus attention, is that we expect that outside private investors have useful information about a firm's commercial prospects using the output of its Phase II project and they signal that information by investing funds in projects that are most likely to be successful. There is, however, a second reason for the expected positive correlation. Outside investors' support is expected not only to provide capital funding, but also to provide useful business and management guidance that will help to bring about the commercialization of the project. Thus, even if the outside investors did not have unique insights about the prospects for commercialization, once on board they could provide advice that increases the probability of commercialization. Finally, there is a third systematic reason for the positive correlation; firms winning SBIR awards will gear up for full-scale commercialization efforts and be more likely to need and seek outside finance when they realize the commercialization prospects for their SBIR projects are strong. Thus, the outside investors may not identify the best prospects; instead, the best prospects may seek them out.

Observe that we have information about the presence of outside private investments; however, we do not know the exact timing of those investments. In particular, we do not know whether the outside funding occurred before, during or after the completion of Phase II of the SBIR project. Although the three reasons for a positive correlation between commercialization and the presence of outside private finance remain even if we knew the timing of the outside finance, not knowing the timing strengthens the ambiguity about the reason behind the positive correlation.

The National Research Council (NRC) dataset on DoD Phase II awards was constructed for the broader purpose of assessing the SBIR programme, as requested by Congress as part of the Reauthorization Act of 2000. This is the dataset used to test our hypothesis.

As shown in Table 1, there were 5650 DoD Phase II awards between 1992 and 2001, all of which were completed at the time of the NRC survey in 2005. These funded projects represent the population of projects considered herein. From these, the NRC surveyed 3055 projects, most of which were randomly selected, and the NRC received completed or partially-completed project responses relevant to 920 projects. Of the 3055 surveyed projects, 3026 are considered in our analysis.

Table 1. POPULATION AND SURVEY SAMPLE OF DEPARTMENT OF DEFENSE PHASE II PROJECTS AWARDED BETWEEN 1992 AND 2001

Population of projects	**Survey sample of projects**	**Sampling proportion**	**Random sampling proportion**	**Population category**
1048	1047	0.9990	0.9990	Firms receiving 1 Phase II award
651	622	0.9955	0.9955	Firms receiving 2 Phase II awards
3951	1386	0.3508	0.3435*	Firms receiving 3+Phase II awards
5650	3055			

Twenty-nine projects in this category were not randomly selected and thus were deleted from consideration. The random-sampling percentage for this category is [100 × (1386−29)/3951]=34.35%. The random-sampling proportions are used to calculate the sampling weights used in the econometric analysis. For each category, the sampling weight equals the reciprocal of the random-sampling proportion, or 1.0 for firms receiving 1 Phase II award, 1.05 for firms receiving 2 Phase II awards, and 2.91 for firms receiving 3 or more Phase II awards.

Twenty-nine projects were not randomly selected by the NRC to receive a survey. Of those 29 projects, 24 non-randomly selected projects were added to the NRC survey sample because they were projects that had realized significant commercialization and the NRC wanted to be able to describe such outstanding success stories; five more non-randomly selected projects were added to the survey sample at the request of a multi-project survey firm. These 29 non-randomly surveyed projects were deleted from consideration and from the calculation of sampling weights used in the econometric analysis discussed below.

The NRC also conducted a firm survey to obtain certain background information on the firm and its founders. Data from this firm survey were also used for several variables in our models.

III. THE ECONOMETRIC MODELS AND VARIABLES

The econometric model to test our hypothesis that commercialization will be more likely when there are outside private investors in a Phase II project is a standard probit model of the probability of commercialization estimated with control for selection into the sample by response to the survey. The probability of commercialization is modeled as a function of whether or not there is outside private finance, a set of additional explanatory variables and random error. Commercialization is represented by dSALES, a dichotomous variable equaling 1 if to date (i.e. 2005) there has been commercialization – defined as sales of products, processes, services, rights to the technology, or spin off companies – and 0 otherwise. The presence of outside private finance is represented alternatively in two ways. First, dOUTPRIFIN is a dichotomous variable equaling 1 if to date there has been private investment from US venture capital, foreign investment, other private equity or other domestic private companies, and 0 otherwise. Second, OUTPRIFIN/INVSTMNT is a continuous variable measuring the ratio of the outside, private financing to the total amount (including the SBIR funding) invested in the project. Various project and firm variables to be discussed below constitute the other explanatory variables.

Our hypothesis is that outside, private finance – measured alternatively as dOUTPRIFIN or as OUTPRIFIN/INVSTMNT– will have a positive effect on the probability of commercialization. We identified above three systematic reasons to expect that positive effect. In addition to those systematic reasons, it is also possible that the error in the underlying probit index generating the probability of commercialization is positively correlated with error in an underlying stochastic process generating dOUTPRIFIN or OUTPRIFIN/INVSTMNT.4 The model of commercialization is estimated simultaneously with a model of the probability of response to the project survey. The model of response is a function of several explanatory variables, discussed below, and random error.

Table 2 lists the variables used in the model of commercialization and in the model of response to the survey. In addition to the two variables indicating outside private finance, the explanatory variables in the model of commercialization are the following, and data on each variable, with the exception of AGE, come from the NRC surveys. AGE is the age of the project at the time of the survey, and it is defined as the year of the survey, 2005, minus the year of the SBIR Phase II award for the project. The date of a project's award is institutional information. We expect that AGE will have a positive effect on the probability of commercialization because older projects will have had more time to develop commercial results.

Table 2. DEFINITIONS OF THE VARIABLES IN THE MODELS*

Variable	**Definition**
dSALES	0/1 with 1 indicating commercialization
dOUTPRIFIN	0/1 with 1 indicating outside private investment
OUTPRIFIN/INVSTMNT	Ratio of outside private investment to total investment in the project
AGE	Project's age
REVENUE	Firm's total revenue
BUSFNDR	0/1 with 1 indicating a founder with business background
PHIITPRJ	Number of Phase II awards that the firm had received over time as of the time of the award for the project
RLTDPHII	Number of the firm's prior Phase II awards that are related to the Phase II project
NOCOM	0/1 with 1 indicating no planned commercial use for project's results
SOFTWARE	0/1 with 1 indicating the project planned to commercialize software
HARDWARE	0/1 with 1 indicating the project planned to commercialize hardware
PROCESS	0/1 with 1 indicating the project planned to commercialize process technology
SERVICE	0/1 with 1 indicating the project planned to commercialize a service
RESEARCH	0/1 with 1 indicating the project planned to commercialize a research tool
EDUCATION	0/1 with 1 indicating the project planned to commercialize educational materials
OTHER	0/1 with 1 indicating the project planned commercialization not covered in the other categories
AWARDAMT	Amount of the Phase II award
PHIITSVY	Firm's number of Phase II awards that were among the population of 1992–2001 projects for sampling in the survey
NUMSVYD	Number of the firm's Phase II projects surveyed

* More detailed definitions are provided in the Section III discussion.

REVENUE is the firm's total revenue for the previous fiscal year at the time of the firm survey.5 We also expect that REVENUE will have a positive effect on the probability of commercialization. Larger firms may realize economies of scale in R&D and in the marketing of their innovations (Kohn and Scott 1982); if so, larger firms are more likely to see commercial benefits outweighing final development and marketing expenditures and to commercialize the results of the SBIR projects.

BUSFNDR is a dichotomous variable equaling 1 if at least one of the firm's founders had a background in business, and 0 otherwise. Data for this variable came from the firm survey. On the one hand, experience in business is expected to be positively associated with commercialization. Yet, on the other hand, the SBIR programme could be seen as looking for business entrepreneurs who have innovative ideas yet would not (because of market failures that could include the financial market's failure to support some entrepreneurs lacking business experience yet having socially desirable projects) receive sufficient R&D funding from the private sector alone. Given the SBIR support, such award recipients, vigorously pursuing and championing perhaps their first foray into business, may actually have greater success in commercializing than award winners with business backgrounds.

PHIITPRJ is the number of Phase II awards that the firm, at the time of the award for the project being observed, had received. It is therefore the firm's number of previous Phase II awards plus one for the award for the project being observed at the time of the award for that project, or its experience with Phase II awards as of the time of the project. Data on this variable came from the project survey. On the one hand, such experience may improve the probability of commercialization. On the other hand, such experience may be a proxy for firms that are known as ‘SBIR mills’. There are firms that exist, at least in part, for the purpose of securing Phase I and Phase II awards. Such firms may be less innovative and less likely to commercialize than less experienced, and perhaps more entrepreneurial, firms that have a passion for an extraordinarily innovative idea and a commitment to seeing it through to commercialization.

RLTDPHII is the number of the firm's prior Phase II awards that are specifically related to the Phase II project being observed. Thus, RLTDPHII equals the number of projects that are complementary to the one being observed plus one for that project, and it provides a measure of the firm's experience that is especially relevant to the current project, and we hypothesize that it is positively related to the probability of commercialization. Data on this variable came from the project survey.

To control for different types of R&D activity across projects, we include among the explanatory variables dichotomous variables that characterize the type of commercialization planned from the project at the time of the award. Some firms indicated multiple categories for the type of commercialization. For example, 65 of the 891 projects (891=920−29) in our sample were reported as both hardware and process, and 32 were reported as both software and services. Of the 891 projects in our sample, there are 359, or 40.3%, for which the respondent did not provide a particular qualitative assessment of commercialization type; those projects are subsumed in the estimated intercept term in our model underlying the results in Table 4 below. Data on these variables came from the project survey. The qualitative variables for the following types of expected commercialization equal 1 if the type was indicated, and 0 otherwise. NOCOM is for projects when no commercial product, process or service was planned; SOFTWARE when the project commercialized or expected to commercialize software; HARDWARE when a final product, component or intermediate hardware product was commercialized or expected; PROCESS when the project commercialized or expected to commercialize process technology; SERVICE when a new or improved service was commercialized or expected; RESEARCH when a research tool was commercialized or expected; EDUCATION for actual or expected commercialization as educational materials; and OTHER was a category on the survey where companies could indicate they planned other forms of actual or expected commercialization.

Table 4. THE PROBABILITY OF COMMERCIAL SUCCESS WITH CONTROL FOR RESPONSE TO THE SURVEYa

	Coefficient (robust standard error)[b]	
Variable	**Probit model for *dSALES***	
	(1)	**(2)**
dOUTPRIFIN	0.555 (0.187)****	
OUTPRIFIN/INVSTMNT		1.33 (0.469)****
AGE	0.0758 (0.0272)****	0.0712 (0.0270)****
ln(*REVENUE*)	0.150 (0.0549)****	0.161 (0.0538)****
ln(*RLTDPHII*)	0.182 (0.121)*	0.163 (0.122)

Variable	Coefficient (robust standard error)[b]	
	Probit model for *dSALES*	
	(1)	**(2)**
BUSFNDR	−0.272 (0.137)***	−0.285 (0.140)***
ln(*PHIITPRJ*)	−0.133 (0.0626)***	−0.117 (0.0635)**
NOCOM	2.54 (0.436)*****	2.54 (0.431)*****
SOFTWARE	1.60 (0.204)*****	1.63 (0.197)*****
HARDWARE	1.35 (0.157)*****	1.38 (0.156)*****
PROCESS	0.466 (0.207)***	0.497 (0.207)***
SERVICE	0.864 (0.244)*****	0.867 (0.248)*****
RESEARCH	0.547 (0.255)***	0.581 (0.255)***
EDUCATION	1.06 (0.725)*	1.02 (0.707)*
OTHER	0.686 (0.363)**	0.699 (0.359)**
Constant	−4.04 (1.25)*****	−4.21 (1.15)*****
Probit model for response to the survey		
ln(*AWARDAMT*)	−0.0365 (0.0769)	−0.0367 (0.0772)
AGE	−0.0647 (0.0106)*****	−0.0647 (0.0106)*****
ln(*PHIITSVY*)	0.126 (0.0500)***	0.126 (0.0498)***
NUMSVYD	0.0390 (0.0183)***	0.0391 (0.0182)***
Constant	0.134 (1.066)	0.136 (1.071)
Rho	−0.0970 (0.495)	−0.0633 (0.466)
No. obs.	2897	2897

Variable	Coefficient (robust standard error)[b]	
	Probit model for *dSALES*	
	(1)	**(2)**
Censored	2135	2135
Uncensored	762	762
Wald chi-squared(14)	204.4*****	220.4*****
Log pseudo-likelihood	−3797.26	−3795.85
Wald Chi-squared(1) test of independent equations (rho=0):	0.04	0.02

a Explanation of the total number of observations and the number of uncensored observations is given in Table 3. Estimation with probability weights (also called sampling weights) and standard errors adjusted for clusters by company. b Significance levels (two-tails excepting chi-squares) : ***** =0.001 , **** =0.01 , *** =0.05 , ** =0.10 , * =0.15.

A variable that was not included, that might at first appear to be a sensible explanatory variable, is the total dollar amount of investment in the project. A priori, we did not expect any relationship across projects between the amount invested in a SBIR project and the probability of commercialization. The optimal amount of investment in R&D for a project varies substantially across projects, and commercialization will require larger investments for some projects than for others. Indeed, if one includes in our model an explanatory variable that measures the sum of all of the investments made by the firm and all of the outside investors including the public, the results shown in Table 4 below are essentially unchanged and the investment variable is wholly insignificant.6

The variables in the model of response to the survey are as follows, and the data on each variable came from background institutional information about DoD SBIR awards known prior to the surveys being administered. AWARDAMT is the amount of the Phase II award received by the firm. Generally, Phase II awards are close to $750,000, but recently DoD, like other agencies, has been supplementing the awards for especially promising Phase II projects with additional funds. AWARDAMT is hypothesized to have a positive effect on the probability of response because firms receiving larger awards might be more inclined to respond as a quid pro quo for the greater SBIR support.

AGE is included in the response model and is hypothesized to have a negative effect on the probability of responding to the survey because the information requested is farther in the past.

PHIITSVY is the firm's number of Phase II awards that were among the population of 1992–2001 projects for sampling in the NRC survey. Thus, it is the firm's number of Phase II awards in the sampling pool. PHIITSVY measures a different aspect of firm size than did REVENUE in the model of commercialization. Larger firms are hypothesized to be more likely to respond to the survey because they have the resources available to do so.

NUMSVYD is the number of a firm's Phase II projects that were surveyed by the NRC. On the one hand, the variable might have a negative effect if a larger reporting burden lowered the probability of response. On the other hand, the firms with larger numbers of surveyed projects are those that have received more SBIR projects, so they might be inclined to be responsive because of that fact. Further, such firms might have the resources at hand to respond more readily to the surveys than the firms with fewer awards.

Unweighted summary statistics for the variables in our models are in Table 3. The variables REVENUE, PHIITPRJ, RLTDPHII, AWARDAMT and PHIITSVY range from quite small to very large. In the econometric model, they are measured by their natural logarithms because we expect that their effects diminish as the variables increase.

Table 3. DESCRIPTIVE STATISTICS FOR THE VARIABLES IN THE MODELS*

Complete sample: respondents and nonrespondents

Variable	**No. Obs.**	**Mean**	**Std. Dev.**	**Min.**	**Max**
Project variables					
AGE	3026	8.167	2.873	4	13
AWARDAMT	3026	697,105.9	327,073	50,000	6,19,0970
ln(*AWARDAMT*)	3026	13.38	0.3905	10.82	15.64
Firm variables					

Complete sample: respondents and nonrespondents

Variable	No. Obs.	Mean	Std. Dev.	Min.	Max
PHIITSVY	3026	7.602	16.84	1	127
ln(*PHIISVY*)	3026	1.101	1.167	0	4.884
NUMSVYD	3026	2.746	3.779	1	31

Respondents only

Variable	No. Obs.	Mean	Std. Dev.	Min.	Max
Dependent variable for the project					
dSALES	891	0.4231	0.4943	0	1
Other variables for the project					
dOUTPRIFIN	826	0.2058	0.4045	0	1
OUTPRIFIN/INVSTMNT	826	0.0654	0.173	0	0.986
AGE	891	7.397	2.853	4	13
NOCOM	891	0.0191	0.1369	0	1
SOFTWARE	891	0.1919	0.3940	0	1
HARDWARE	891	0.3558	0.4790	0	1
PROCESS	891	0.1392	0.3463	0	1
SERVICE	891	0.1077	0.3102	0	1
RESEARCH	891	0.0954	0.2939	0	1
EDUCATION	891	0.0123	0.1105	0	1
OTHER	891	0.0561	0.2303	0	1

Respondents only

Variable	**No. Obs.**	**Mean**	**Std. Dev.**	**Min.**	**Max**
AWARDAMT	891	725,405.5	350,927	69,673	6,190,970
ln(*AWARDAMT*)	891	13.42	0.3828	11.15	15.64
Firm variables					
REVENUE	848	1.36e+07	2.58e+07	50000	1.25e+08
ln(*REVENUE*)	848	15.00	1.846	10.82	18.64
BUSFNDR	857	0.4364	0.4962	0	1
PHIITPRJ	788	9.322	26.17	1	194
ln(*PHIITPRJ*)	788	0.9495	1.259	0	5.268
RLTDPHII	788	1.864	1.611	1	29
ln(*RLTDPHII*)	788	0.4316	0.5621	0	3.367
PHIITSVY	891	12.64	25.66	1	127
ln(*PHIISVY*)	891	1.431	1.346	0	4.844
NUMSVYD	891	3.816	5.646	1	31

* Of the 891 projects for which completed or partially-completed responses were available, 129 projects were missing one or more of the variables dOUTPRIFIN, OUTPRIFIN/INVSTMNT, REVENUE, BUSFNDR, PHIITPRJ or RLTDPHII leaving 2897 (3026−129) total observations with 762 (891−129) uncensored observations to estimate the models in Table 4.

IV. ECONOMETRIC RESULTS

The probability of commercialization, with control for response to the project survey, was estimated by fitting a maximum likelihood probit model with sample selection. The econometric results from the estimated model for the 2897 sampled observations for which all of the data are available for the estimation are reported in Table 4. Table A1 in the Appendix provides the correlation matrix for the key variables in the model of substantive interest – the model of the probability of commercialization.

All of the variables in the probit model for the probability of commercialization enter significantly, although just marginally so for ln(RLTDPHII), and with the hypothesized effects. In the cases of BUSFNDR and ln(PHIITPRJ), the negative effects support the hypotheses, respectfully, that new business entrepreneurs without a business background have a greater likelihood of commercializing, and that 'SBIR mills' are less likely to commercialize the results of their projects. The key finding for the purposes of this paper is that the presence of outside private financing is associated with a large and statistically significant increase in the probability of commercialization. We illustrate the size of that effect in Section VI.

The model of response to the survey is estimated significantly, although the variable ln(AWARDAMT) is not significant. The probit models of response and of commercialization are independent of one another; the correlation of the errors in the two models is not significantly different from zero. Thus, although a priori control for response is necessary, it turns out that with or without such control the results are essentially the same, as we discuss now in an overview of the robustness of the results.

Although Table 4 presents the complete specification that includes all of the variables we considered to be important, we emphasize again that the essential results – and in particular the central finding that the presence of outside private financing is strongly associated with the probability of commercialization – are robust. The results remain if the three variables ln(RLTDPHII), BUSFNDR and ln(PHIITPRJ) – arguably non-central variables – are dropped. The results are also robust to dropping all of the commercialization-type dichotomous variables. Also, the results are robust to dropping both the set of three variables ln(RLTDPHII), BUSFNDR and ln(PHIITPRJ) and the set of commercialization-type variables. Further, the results are robust to not deleting the 29 observations that were added by the NRC to the random sample for the survey (although there is a statistical reason for excluding these 29 non-random observations as we have done). Also, the essential qualitative results remain if we do not use the sampling weights, or if the standard errors are not clustered by the firm. However, those two estimating techniques are important to ensure correct estimates and inferences. Moreover, as noted when discussing the correlation in the errors of the commercialization and response models, the results remain when sample selection is ignored and the simple probit model for commercialization is estimated. Table A2 in the Appendix provides the simple probit model and also shows that the basic result remains when just subsets of the explanatory variables are used. Finally, Table A3 in the Appendix shows that the simple linear probability model (i.e. ordinary least squares (OLS)) yields essentially the same conclusions, although of course the assumptions making ordinary least squares appropriate are not satisfied.

Using the probit estimates in Table 4, which control for selection into the sample, to compute the expected probability of commercialization for each of the 762 uncensored observations, the average of those probabilities of commercialization predicted for each observation is 0.47 for specification (1) and is 0.46 for specification (2). In other words, on average, the probability of commercialization from a representative Phase II project is slightly less than the probability of either a head or a tail in the flip of a fair coin.7 Thus, with respect to the stated objective of the SBIR programme on which this paper focuses, realizing commercialization from a Phase II project is a gamble with, on average, slightly less than a 0.50 probability.

To put this probability of commercialization in perspective, consider the following facts (Cahill 2006). Between 1994 and 2003, DoD funded about 15% of all Phase I applications; Phase I awards are based entirely on scientific merit. About 66% of completed Phase I projects are invited by DoD to apply for a Phase II award and about 71% of those applications are funded. Of this 71%, slightly less than one-half −0.47 – are likely to commercialize a product or process from the research. The projects that were examined econometrically have been evaluated at two stages for scientific merit. The likelihood of commercialization is thus based mainly on issues of market demand, business acumen and access to financial markets, and not on technical issues, yet still the average probability of commercialization is less than 0.50.

The results in Table 4 show that the probability of commercialization is substantially higher when outside private investors have chosen to finance a Phase II SBIR project; moreover, the greater the proportion of investment that is financed by outside investors, the greater the probability of commercialization. The estimated coefficients on dOUTPRIFIN and, alternatively, on OUTPRIFIN/INVSTMNT for the probit index are positive, large and highly significant. To illustrate the magnitude of the importance of outside private financing, consider, as one of many possible examples, the predicted probability of commercialization for a project if the firm has no founders with a business background, if the project's product is hardware, if the project is of average age, if the firm has average ln(REVENUE), average ln(RLTDPHII) and average ln(PHIITPRJ). Using specification (1) in Table 4 to summarize the effect, for such a project with outside private financing the probability of commercialization is 0.75. For the same firm without outside private financing, the probability of commercialization decreases to 0.55.8 Although, as we have explained, there are other possible interpretations, we interpret this result as evidence that outside private investors have relevant information about the prospects for commercializing the output of Phase II SBIR projects, choosing to support the most promising of those projects.

V. AN SBIR PREDICTION MARKET

In this section, we address the possibility of using a prediction market to improve the commercialization performance of the SBIR programme, its Phase II awards in particular. Consider the following sketch of how such a winner-take-all or all-or-nothing contract offered in an SBIR prediction market might work.9

For each Phase I SBIR project that is to be invited by the DoD to apply for a Phase II award, the DoD (or analogously any agency sponsoring SBIR awards) could issue a block of tradeable securities with each security having a face value of, say, $1000. The securities promise to pay the face value if the Phase II award is granted and if the resulting project commercializes a product, process or service by a pre-defined date. Of course, prediction market participants would have to have access to the Phase II application. As Wolfers and Zitzewitz (2004) emphasize, clarity of the contract is crucial if the prediction market is to work well; thus, necessary are a clear definition of ‘commercialization’, a certain date by which that commercialization must occur, a date for the close of bidding, and accurate publicly-available information.

The typical size of an initial Phase II award is in the order of $750,000, so a block of, say, 100 securities with face value $1000 each would represent a modest investment by the DoD in each project – just 13.33% of the typical initial grant. This payout amount would be an upper bound on the DoD's liability, offset by revenues from the sale of the securities. Further, if the prediction market serves to increase the probability of commercialization because it allows DoD to better select Phase II award recipients, there would be additional social benefits from the SBIR programme more frequently meeting its commercialization goal.

Suppose DoD invited two firms with completed Phase I projects to apply for a Phase II award, and suppose that the securities traded in the prediction market for one of those proposed Phase II projects had a market value of $560 while the other had a market value of $230. Roughly speaking, if the discount rate equaled zero, the market is indicating that the probability of commercial success is 0.56 for the one project and 0.23 for the other. At those probabilities, a risk-neutral purchaser of the securities expects the value of the securities to equal their price. Such investors would want to purchase the securities, bidding up their prices from $560 and $230 if the expected probabilities of commercialization were higher; they would want to sell, creating excess supply of the securities and causing prices to fall, if the expected probabilities were lower. Thus, the market prices determined by the trading of the SBIR prediction-market securities provide insight into the likelihood of commercialization of the different Phase II projects; theoretically the distribution of prices could be used to determine Phase II funding priorities.

The idea that the prices determined in a well-specified prediction market for winner-take-all contracts reflects the probability of an event, and that collections of such contracts can be used to develop even more information about the parameters of the probability distribution for a future event, is both commonsensical and intuitive. Yet, many questions about the idea are still open; there is complex discussion about whether and to what extent and under what circumstances the prices determined in a prediction market actually reflect the parameters of a probability distribution that determines the market's fundamentals that underlie the prices.

Manski (2004) observed that theory was not fully developed to support the use of prediction-market prices of winner-take-all contracts as predictions of probabilities; indeed, he adduces a theoretical scenario in which the prices are not predictions of the mean subjective probabilities of the market's participants. Subsequently, Wolfers and Zitzewitz (2006b) have provided analytic foundations for the use of prediction market prices as average beliefs in the market. Their examination of the evidence leads them to conclude that the prices in prediction markets ‘typically provide useful (albeit sometimes biased) estimates of average beliefs about the probability an event occurs’ (Wolfers and Zitzewitz, 2006b, abstract). They conclude (2006b: 13) that the evidence from many studies shows prediction market prices to be accurate predictors of probabilities and that such evidence agrees with their theory, ‘in which traders have heterogeneous beliefs that are correct on average. … In most cases we find that prediction market prices aggregate beliefs very well. Thus, if traders are typically well-informed, prediction market prices will aggregate information into useful forecasts.’

How practical is the idea of using a prediction market to evaluate the likelihood of commercialization of SBIR Phase II projects? We have focused on the winner-take-all contract, but for all of the types of contracts the same essential issues about the practicality of designing a successful prediction market must be addressed. Wolfers and Zitzewitz (2004) enumerate several key issues for the design and implementation of a successful prediction market. Key issues include the clarity of the contracts; as discussed above, the contracts for an SBIR prediction market must specify clearly the criteria for commercialization and should specify a date by which those criteria are to be met. The key condition addressed in this paper is perhaps the most fundamental of the conditions that must be met for a prediction market to succeed – namely, we adduce evidence to address ‘whether a diversity of information exists in a way that provides a basis for trading’ (ibid.: 120). The other key design issues discussed by Wolfers and Zitzewitz –

such as the method by which buyers are matched to sellers, the clear specification of the contracts, and whether or not real money is used – are at least relatively straightforward to address administratively.10

The key condition on which we focus is the need for informed traders in the market, and, as the literature about prediction markets explains, there must be uninformed traders as well (Wolfers and Zitzewitz 2004, 2006a). Having uninformed traders – those trading based on relatively less reliable information or using relatively less reliable models to process the information – is at least arguably something to be expected. Possibly there will be traders who enjoy gambling on the success of R&D projects that capture their fancy, yet are not fully understood in terms of either the technical challenges to be overcome during the Phase II R&D investment or the subsequent business challenges. The issue we have addressed with empirical work is whether there would be a large number of informed traders, and it is on that score that our findings in Section V are important. Our econometric results suggest that outside private investors are able to choose the right projects to support. The probability of commercialization is significantly higher for projects on which outside private investors have placed their bets, gambling that the project will pay off once commercialized.

VI. CONCLUSIONS

Thus, we find that the average expected probability of commercialization for a project is about 0.47 for our random sample of 762 uncensored observations. Yet, there is considerable room for improving the performance of the SBIR programme regarding its commercialization goal, both because the average expected probability of commercialization could be higher and because there is substantial variation in the expected probability of commercialization across projects. The standard deviation for the expected probability of commercialization is 0.33 for our sample of 762 projects. The expected probabilities of commercialization, predicted by our model for these sampled projects, range from close to zero −0.01 – to essentially 1.0. An SBIR prediction market possibly could help DoD's SBIR programme choose the higher probability projects.

One might reasonably ask: Rather than use a prediction market, why not just use the observations of outside private participation in the investments directly when ranking proposed SBIR projects? The answer is that private participation will often not materialize until after a Phase II award has been granted. The reason is that the public funding is needed to raise the rate of return for the private investors above their hurdle rates (Link and Scott 2000).

There are already prediction markets for forecasting the probability of success of new products. For example, http://NewsFutures.com has prominent business clients who subscribe to its service providing prediction markets to glean information about the business prospects for, among other things, implementing new product developments.11Wolfers and Zitzewitz (2006a) cite this example and other applications of corporate prediction markets that are being used to forecast business prospects, and in particular observe prediction markets being used to make business decisions.12 In these decision markets, the payoffs for the securities traded are based on outcomes such as revenue from a product conditional on the making of a particular decision. Wolfers and Zitzewitz (2006a) use the decision of the product being launched; in our proposal for an SBIR prediction market, the outcome of commercialization is conditional on the SBIR programme making the decision to invest in a proposed project with an SBIR Phase II award.

Wolfers and Zitzewitz (2006a) recognize that their summary of the evidence and prospects for the usefulness of prediction markets in their earlier article (2004) is an optimistic one. They emphasize (2006a) the several questions about the theory and evidence that must be resolved before we can be confident in using prediction markets for forecasts. We have presented evidence consistent with the existence of good outside private information about SBIR Phase II projects, although in this initial look at the issue we cannot disentangle the possibilities that the correlation of commercialization and outside private finance reflects the effect of guidance provided by the outside interests or the fact that firms with commercializable SBIR output are perhaps more likely to seek outside finance. Further, as noted above, because we do not have good instruments for the measures of outside finance, we cannot eliminate the possibility that the positive correlation reflects correlation in the errors of the underlying stochastic processes for the presence of commercialization and for outside private finance.

Thus, we have evidence consistent with the presence of relevant outside private information, and also evidence that the average Phase II project has a substantial probability of commercialization. Yet there is a large variation across projects in the probability of commercialization and substantial room to improve that probability for the typical project.13 We think plausible the conjectures that a mix of traders with various degrees of information could be attracted to an SBIR Phase II prediction market, that the circumstances allow the writing of clear SBIR prediction-market contracts, and that there would be the expectation of large losses to traders attempting to manipulate the market. The SBIR prediction market could encourage short sales, and traders could develop information about manipulation, sell the manipulated securities short, and reveal the information to the SBIR programme. The projects with manipulated securities would then be unlikely to win an SBIR Phase II award and the value of their prediction-market securities would plummet, causing big losses for the manipulators. Citing Hanson and Oprea

(2004), Wolfers and Zitzewitz (2006a: 63) observe: '[m]anipulation can be made more expensive by allowing free entry into these markets and by providing a means for entrants to invest in becoming informed.' They also observe: '[k]nown attempts to manipulate public prediction markets have largely failed.' However, they also observe that, 'acquiring the information to become an informed trader may be costly enough that free entry does not offset the trading activity of manipulators.'

Our evidence taken together with the foregoing conjectures suggests to us that a prediction market to provide information about the probability of commercialization of SBIR Phase II projects could help the SBIR programme focus on the projects with the greatest likelihood of realizing the programme's commercialization goal. However, we must acknowledge that for many readers, it will seem an exceptional leap to get to SBIR prediction markets. While many investors may know something about a proposed new product or process or service, that knowledge will not necessarily imply that many investors have a good understanding of the innovative research required for SBIR projects. Our results support the belief that there are informed outside private investors; whether there are sufficiently many informed – and uninformed – investors to drive a useful prediction market remains to be seen.

Appendix

Table A1. CORRELATION MATRIX FOR VARIABLES (*n*=762) IN THE COMMERCIALIZATION MODEL

	dSALES	***dOUTPRIFIN***	***OUT~/ INV~***	***AGE***	**ln (*REV~*)**	**ln (*RLTD~*)**	***BUSFN~***	**ln (*PHII~*)**
dSALES	1.000							
dOUTPRIFIN	0.257	1.000						
OUT~/INV~	0.225	0.751	1.000					
AGE	−0.026	−0.082	−0.027	1.000				
ln(*REV~*)	0.045	−0.007	−0.031	0.126	1.000			
ln(*RLTD~*)	0.181	0.147	0.136	−0.069	0.047	1.000		

	dSALES	*dOUTPRIFIN*	*OUT~/ INV~*	*AGE*	**ln (*REV~*)**	**ln (*RLTD~*)**	*BUSFN~*	**ln (*PHII~*)**
BUSFN~	−0.085	−0.025	−0.008	−0.034	0.086	0.019	1.000	
ln(*PHII~*)	−0.079	0.034	−0.032	0.047	0.459	0.043	−0.020	1.000

Table A2. THE PROBABILITY OF COMMERCIALIZATION WITHOUT CONTROL FOR RESPONSE TO THE SURVEY: PROBIT MODEL FORdSALESa

Variable	**Coefficient (robust standard error)[b]**		
	(1)	**(2)**	**(3)**
dOUTPRIFIN	0.84 (0.15)*****	0.56 (0.17)*****	0.56 (0.19)****
AGE		0.085 (0.023)*****	0.073 (0.024)****
ln(*REVENUE*)		0.10 (0.044)***	0.16 (0.045)*****
ln(*RLTDPHII*)			0.18 (0.12)*
BUSFNDR			−0.27 (0.14)***
ln(*PHIITPRJ*)			−0.12 (0.056)***
NOCOM		2.67 (0.43)*****	2.55 (0.43)*****
SOFTWARE		1.69 (0.20)*****	1.61 (0.20)*****
HARDWARE		1.42 (0.15)*****	1.35 (0.16)*****
PROCESS		0.54 (0.20)****	0.47 (0.20)***
SERVICE		0.91 (0.24)*****	0.87 (0.24)*****
RESEARCH		0.59 (0.26)***	0.54 (0.26)***
EDUCATION		1.02 (0.71)	1.07 (0.72)*
OTHER		0.68 (0.37)**	0.69 (0.36)**

	dSALES	*dOUTPRIFIN*	*OUT~/ INV~*	*AGE*	**ln (*REV~*)**	**ln (*RLTD~*)**	*BUSFN~*	**ln (*PHII~*)**

Constant	−0.35 (0.065)*****	−3.75 (0.73)*****	−4.23 (0.72)*****
No. obs.	826	796	762
Wald chi^2(df)	32.79(1)*****	196.9(11)*****	205.17(14)*****
Log pseudo-likelihood	−535.55	−331.49	−320.89
Pseudo R^2	0.0527	0.392	0.389

a Estimation with probability weights (also called sampling weights) and standard errors adjusted for clusters by company. bSignificance levels (two-tails excepting chi-squares) : ***** 0.001 ; **** 0.01 ; *** 0.05 ; ** 0.10 ; * 0.15.

Table A3. SIMPLE LINEAR PROBABILITY MODEL OF COMMERCIALIZATION: dSALESa THE DEPENDENT VARIABLE

Variable	**Coefficient (robust standard error)[b]**	
	(1)	**(2)**
dOUTPRIFIN	0.149 (0.0498)****	
OUTPRIFIN/INVSTMT		0.352 (0.0975)*****
AGE	0.0149 (0.00537)****	0.0150 (0.00495)****
ln(*REVENUE*)	0.0371 (0.0109)*****	0.0345 (0.00954)*****
ln(*RLTDPHII*)	0.0466 (0.0311)*	0.0461 (0.0299)*
BUSFNDR	−0.0709 (0.0346)***	−0.0848 (0.0320)****
ln(*PHIITPRJ*)	−0.0327 (0.0132)***	−0.0279 (0.0143)**
NOCOM	0.729 (0.0788)*****	0.702 (0.0879)*****

Variable	Coefficient (robust standard error)[b]	
	(1)	(2)
SOFTWARE	0.431 (0.0461)*****	0.428 (0.0422)*****
HARDWARE	0.378 (0.0385)*****	0.373 (0.0366)*****
PROCESS	0.111 (0.0555)***	0.105 (0.0493)***
SERVICE	0.238 (0.0578)*****	0.246 (0.0543)*****
RESEARCH	0.144 (0.0626)***	0.123 (0.0621)***
EDUCATION	0.0761 (0.177)	0.0353 (0.142)
OTHER	0.171 (0.0997)**	0.170 (0.0859)***
Constant	−0.531 (0.165)*****	−0.477 (0.138)*****
No. obs.	762	762
$F(14, 489)$	51.25*****	56.14*****
R^2	0.433	0.407

a Estimation with probability weights (also called sampling weights) and standard errors adjusted for 490 clusters by company. b Significance levels (two-tails excepting F) : ***** 0.001 ; **** 0.01 ; *** 0.05 ; ** 0.10 ; * 0.15.

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NOTES

1. This section draws on Link and Scott (2000), Audretsch et al. (2002) and National Research Council (2004).

2. As an example, in 1996, the Department of Defense (DoD) funded, through its SBIR programme, a Georgia-based company to conduct Phase II research on hexavalent chromium. Hexavalent chromium is widely used on battleships in the Navy as well as in many industrial applications. It is, however, a known carcinogen and thus creates a toxic waste problem. The US Environmental Protection Agency had been aware of this problem but had not yet mandated that it cease being used because no replacement was available. Congress gave DoD an internal directive to find a replacement material. The Georgia-based company won the competition and received a Phase II award to develop such a material. The replacement material is based on a thin-film oxide that can be applied to metal. The thin film is sprayed on metal with a flame, and the residual gas contains a replacement molecular coating that performs like hexavalent chromium but is more environmentally friendly. See Link (2000).

3. Our idea of using a prediction market to improve commercialization performance of the SBIR programme need not impede the promotion of diversity. On the contrary, information about commercialization potential could be used to choose projects with good commercial prospects from among those projects with the desired characteristics to promote diversity.

4. Unfortunately, we do not have good instruments for the measures of outside private finance. Among other things, previous work (Scott 2000) identified minority ownership of an SBIR firm as a key reason that an SBIR firm does not have outside private financing, and the latest NRC firm survey that we use does not have information about minority ownership. Further, the collection of variables available does not predict well the presence of outside financing.

5. On the NRC firm survey, respondents were asked to denote total revenue for the previous fiscal year as a range: less than $100,000; $100,000 to $499,999; $500,000 to $999,999; $1,000,000 to $4,999,999; $5,000,000 to $19,999,999; $20,000,000 to $99,999,999; and $100,000,000 or more. The variable REVENUE is defined as the midpoint of each stated range, with the lower bound defined as $50,000 and the upper bound defined as $125,000,000.

6. These results are available on request from the authors.

7. Each of the two linear probability model specifications in Table A3 yields the average probability of commercialization of 0.46. The predicted value of the dependent variable is found

for each observation as the linear combination of the variables multiplied by their OLS coefficients; the simple average of those predictions is 0.46.

8. The probit index in these circumstances with outside private financing equals $0.687 = -4.04 + 0.555\ (dOUTPRIFIN=1) + 0.0758\ (AGE=8.17) + 0.150\ (\ln(REVENUE)=15.00) + 0.182\ (\ln(RLTDPHII)=0.432) - 0.133\ (\ln(PHIITPRJ)=0.949) + 1.35\ (HARDWARE=1)$. In these same circumstances without outside private financing (dOUTPRIFIN=0), the probit index is 0.132.

9. As Wolfers and Zitzewitz (2004) explain, there are several other types of prediction market contract, with the different types capable of revealing 'the market's' expectations about different aspects of the future event. In the case of an SBIR prediction market, the different types of contract would ideally reveal the market's expectations about the commercialization potential of a proposed SBIR Phase II project.

10. In the context of an SBIR prediction market, Eric Zitzewitz notes (personal correspondence, 11 December 2006) there are special questions to address: 'One would have to give some thought to how much information about the new technologies firms would disclose, and to whom the market would be open. This may especially be an issue for DoD projects (i.e. would they need to be US citizens, require clearances, etc.).'

11. See http://us.newsfutures.com/home/decisions.html.

12. Zitzewitz (personal correspondence, 11 December 2006) observes: 'There are several companies that provide off-the-shelf prediction market software/consulting (such as NewsFutures, Inkling Markets, Zocalo, Tradesports, Yahoo). Of these, NewsFutures, Tradesports and Yahoo also run public prediction markets and could set up the [proposed SBIR prediction] markets as part of a common platform, which would be very helpful in getting a critical mass of liquidity. These three have different clienteles, with associated strengths and weaknesses. For some technologies, the best may be Yahoo's Tech Buzz markets.' He also notes: 'Especially in the early going, subsidizing the markets slightly through an automated market maker may be helpful and/or necessary.'

13. Zitzewitz observes (personal correspondence, 11 December 2006): ‘One of the places where the market seems most likely to improve on the existing process is in filtering out the SBIR mills (which exist presumably because the existing process can’t filter them out). This probably does require that traders get enough SBIR history to help them identify the mills.’ Further, he observes that the prediction market could even improve the commercial success of the commercialized SBIR projects: ‘If this market is successful, one could imagine it turning into a great vehicle for getting exposure for the companies in question. If this market happens, and you can somehow get a random component into the opportunity to participate, you could potentially try and identify this exposure effect.’

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