When Does Funding Research by Smaller Firms Bear Fruit?: Evidence from the SBIR Program*

by

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This paper evaluates whether the relative concentration of funding for small, research-oriented firms in a small number of high-technology industries is related to differences across industries in the appropriability level facing small firms. We exploit a novel test based on the relationship between industry-level private venture financing and the performance of government-subsidized R&D projects. If industries differ in their appropriability level, then private funding and subsidized project performance should be positively correlated. Our principal finding is that subsidized project performance is higher in industrial segments with higher rates of private venture capital investment. Industrial sectors therefore seem to differ in the degree of appropriability and this variation helps explain why venture capital is concentrated. *Journal of Economic Literature* Classification Numbers: G24, O31 & O38.

Keywords: innovation, appropriability, subsidy, capital constraints, technological opportunity, venture capital.

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* We would like to thank the firms who participated in the MIT Commercialization Strategies Survey for their time and effort. Josh Lerner, Scott Wallsten, Scott Shane, two referees, the Editor, participants at various universities, and especially Iain Cockburn provided thoughtful comments and suggestions. David Hsu and Mercedes Delgado provided outstanding research assistance. We also gratefully acknowledge funding for this research by the MIT Center for Innovation in Product Development under NSF Cooperative Agreement # EEC-9529140 and a Large Grant from the Australian Research Council. Any remaining errors or omissions are our responsibility.
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I. Introduction

At least since Nelson (1959) and Arrow (1962), economists have been aware that competitive markets may fail to provide the socially optimal level of R&D investment. Technological innovation is beset by uncertainty, imperfect monitoring and imperfect property rights, leading many to conclude that R&D investment by private firms is too low (Griliches, 1998; Romer, 1990). In this context, special attention is paid to the role of small, entrepreneurial firms, since such firms may be particularly susceptible to the capital and product market imperfections identified by Arrow and Nelson. Specifically, technology-based entrepreneurs may be unable to raise R&D investment capital (Kamien and Schwartz, 1982; Holmstrom, 1989) and may be poorly positioned to extract the social value created by their innovations (Teece, 1987; Anton and Yao, 1994).

From an empirical perspective, perhaps the most puzzling fact about innovation by small technology-based firms is its concentration in a small number of economic sectors. Relative to the distribution of aggregate economic activity (even confined to the manufacturing sector), a few sectors (such as the pharmaceutical, computer equipment, and transportation industries) account for most of privately financed R&D.[1] This relative concentration becomes even more pronounced when one examines venture capital financing (or the financing of R&D in small and medium-sized firms). Using data drawn from Kortum and Lerner (2000), Figure 1 compares the relative distribution of venture financing by industrial segment relative to (already concentrated) privately financed

[1] For example, using data drawn from the 1992 NSF Science and Engineering Indicators, the Gini coefficient of cumulative private R&D expenditures compared against cumulative value added is equal to 0.604.

R&D investment. A few sectors receive most of the overall funds from venture capital sources (the Gini coefficient is .54).[2] These patterns raise a critical question: what are the drivers of inter-industry variation in small firm R&D financing?

We address this question by considering three (not mutually exclusive) forces: technological opportunity, appropriability and capital constraints. To the extent that economic sectors vary according to these factors, R&D expenditures and realized rates of technological innovation will vary accordingly. For example, sectors may vary in their level of technological opportunity (i.e., the social value created by a given level of R&D expenditure may vary by industry and over time), and sectors with a high level of technological opportunity may be associated with high rates of R&D investment and realized innovation.[3]

However, when considering the distribution of innovative activity by smaller, more entrepreneurial, firms, concentration may also result from differences in the salience of either product market imperfections (i.e., appropriability) or capital market imperfections (i.e., capital constraints). Appropriability is the degree to which technological innovation results in spillovers to consumers or more established firms, thus limiting the extent to which an innovator extracts the marginal social product associated with their innovation. Small firms face particular appropriability problems, either because they are less likely to possess "complementary assets," such as a brand-

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[2] Indeed, while economists have mostly ignored this observation, its validity is a widely accepted and well-documented feature of the venture finance industry (www.ventureone.com). As well, similar concentration is observed for R&D expenditures by small-to-medium sized businesses (National Science Foundation, 1999; tabulations available from the authors).

[3] Indeed, most prior analyses of the skewed distribution of R&D expenditures have focused on variation in the level of technological opportunity as the "culprit" for uneven financing and rates of technological change among economic sectors, with a particular focus on whether publicly financed basic research provides a spur to private R&D expenditures (Schmookler, 1966; Rosenberg, 1974; Adams, 1990; Toole, 1999). For a thoughtful review of this literature, see Hall and van Reenen (2000).

name reputation, a distribution system, or installed base (Teece, 1987), or because of their relative inability to obtain complete intellectual property for their innovations (Anton and Yao, 1994; Gans and Stern, 2000). To the extent that sectors differ substantially in terms of the importance of complementary assets or the strength of intellectual property, it is likely that sectors with low levels of appropriability will be associated with low levels of investment and innovation by small research-oriented firms.

Finally, R&D investment may be constrained by capital market imperfections (i.e., contracting problems between *investors* and *inventors*). By its very nature, R&D investment by external investors engenders information asymmetries and contractual incompleteness between the financier and the research firm (Kamien and Schwartz, 1982; Holmstrom, 1989). Information asymmetry can result in, among other things, moral hazard, adverse selection, or the potential for expropriation. To the extent that the salience of these imperfections for small firms varies across different industrial segments, R&D expenditures and the level of technological innovation will reflect this variation.

Several researchers have attempted to understand each of these drivers of R&D intensity. For example, several empirical studies offer evidence suggesting substantial variation in appropriability across industrial sectors, focusing mostly on the environment facing larger established firms (Levin, et. al., 1987; Cockburn and Griliches, 1988; Klenow, 1996; Cohen, Nelson, and Walsh, 2000). At the same time, prior empirical research on the impact of capital market imperfections focuses on the sensitivity of R&D expenditures to measures of capital liquidity such as cash flow (Hall, 1992; Hao and Jaffe, 1993; Geroski, 1994; Himmelberg and Petersen, 1994; Hubbard, 1998). Overall, prior research attempts to identify the influence of appropriability and capital market imperfections by examining the impact of privately financed R&D investment.

This paper builds on this prior work by developing and implementing an empirical framework that begins to disentangle these alternative sources of inter-industry variance. Our test relies on evaluating the empirical relationship between the performance of R&D projects performed by small firms but *subsidized* by the Federal government (more specifically, through the Small Business Innovation Research (SBIR) program) and the level of *private* venture finance for small firms in those sectors. By examining performance differences across *subsidized* projects, this paper differs from prior attempts to evaluate inter-sectoral differences in the environment for small-firm R&D. By and large, such studies have analyzed samples that are subject to an important selectivity – they have indeed been funded by the private sector (Mansfield, 1995; Griliches, 1998; Hall, 1988; Hall, 1992; Himmelberg and Petersen, 1994).

In our framework, after controlling for project-specific technological opportunity, if subsidized project performance is highest in those sectors where private funding is lowest, this suggests that differences in funding across segments are, at least in part, the result of differences in capital constraints. Alternatively, if subsidized project performance is highest in those sectors where private funding is high, this suggests that differences are the result, at least in part, of variation in the level of appropriability.

We explore these ideas using a novel dataset of SBIR-funded projects.[4] As described further in Section III, the survey identifies private performance measures at the

[4] As such, our approach differs from prior work on the SBIR (in particular Lerner (1999) and Wallsten (2000)). These prior studies identify the incremental benefits of an SBIR grant relative to privately funded research; in contrast, we examine the differences *across funded firms* to understand how segments differ in terms of the economic environment facing smaller firms.

project level and incorporates detailed controls for firm size, organizational and financial structure, and the commercialization strategy associated with each innovation. Our main measure of private performance – project level revenues – incorporates a great deal of the variance in outcomes experienced by firms, conditional on technological feasibility of an invention. As well, our analysis includes a number of control variables, such as the type of production (made-to-order versus mass manufacturing) and whether the product undergoes upgrades, which allow us to control for variation in costs faced by the firms in our sample.

The main empirical exercise evaluates the relationship between project-level performance and the level of private venture financing in the industrial sector to which each project belongs. Our principal finding is that project-level performance is strongly *positively* correlated with the level of private venture capital. Even after incorporating various controls (including two distinct measures to control for technological opportunity), a doubling of the level of private venture capital is associated with over a 50% increase in expected project performance. Simply put, the most successful subsidized projects (in terms of their ability to generate revenues for the firm) are in those industrial segments that have attracted a high rate of private investment. We interpret these results to suggest that industrial sectors vary in their degree of appropriability for research-oriented small businesses; in other words, variation in appropriability helps explain the relative concentration of venture capital activity in a small number of industrial segments.

The remainder of the paper proceeds as follows. Section II provides a model of the determinants of start-up innovative performance and a test of the relative importance of appropriability and capital market imperfections in explaining inter-industry variance in the private funding of start-ups. We then describe the SBIR program, our data collection efforts, and the dataset used in the analysis. Section V presents our empirical findings, and a final section concludes.

II. A Simple Model of Sector-Level Variation in Innovative Expenditure

This section derives a test for the sources of variation among sectors resulting in the concentrated nature of venture financing activity. Our test relies on the association between the "performance" of government-subsidized projects (defined here as the private returns from innovation) and the level of private financing available in different economic sectors. We demonstrate that, if variation in capital constraints is important for understanding differences across sectors, the average performance of SBIR grantees is likely to be negatively associated with observed levels of venture capital funding. This is because the funding mechanism identifies high potential performers only in industries where those are not otherwise likely to be funded. Alternatively, a positive association between average performance and venture capital funding will be indicative of the relative importance of appropriability as explaining differences across industries in terms of small firm research financing. To derive this empirical test, we first develop a model of the equilibrium level of private funding for small firm research in the presence of both appropriability and capital constraints and then derive the implications for the performance of subsidized projects. In addition, our discussion highlights several potential limitations (and associated remedies) for our proposed test, including those arising from (a) the importance of controlling for technological opportunity (b) alternative funding mechanism for SBIR project selection and (c) the direct impact of government subsidy on project performance.

Players, Payoffs and Choice Variables

Our model focuses on the relationship between funding and performance of research projects undertaken by independent research units (each is denoted as an RU). A single RU, j, can potentially engage in R&D for a single project requiring a single unit of capital investment. Capital financing may be provided by two sources: a venture capitalist (VC) or by a government subsidy. We assume that the capital contribution of the VC is contractible and competitive (i.e., there are a potentially large number of homogenous VCs who contemplate financing RU projects). If the project is financed, a commercializable innovation is generated with probability p. p may be endogenous, in that the success probability may depend on either the effort or ability (type) of RU j.

If the R&D project is technologically successful, the innovation creates a total social value, V_j, of which the RU (and their equity partners) appropriate $v_j(V_j, \gamma_i)$ where γ_i parameterizes the 'distance' between V_j and v_j in industry i. $v_j(.)$ is assumed to be non-decreasing in V_j and γ_i. Therefore, γ_I measures the level of appropriability in industry i. Of course, there are many potential determinants of γ_i, including the strength of intellectual property and ease of technological imitation (Arrow, 1963; Anton and Yao, 1994), the degree of product market competition (Kremer, 1998), and asymmetries among innovators and competitors in the ownership of "complementary assets" necessary for effective commercialization (Teece, 1987; Bresnahan, Stern, and Trajtenberg, 1997).

Variation in each of these factors can result in differential levels of appropriability for independent RUs, insofar as each may increase the "wedge" between the private and social returns associated with innovation.

As well, for each industry *i*, there is a distribution of the total social returns across potential projects. Specifically, we assume that each project is drawn from an industry-level distribution that is uniform over $[0, \overline{V}_i]$. By construction, then, a shift in $\overline{V}_i$ is equivalent to shifting out the level of *technological opportunity* in industry *i*.

The Level of VC Funding

The equilibrium level of private venture finance in industry *i* will be determined by the measure of projects whose private expected benefits exceed the marginal private cost of project funding (Gompers and Lerner, 2002). We assume that, for each industry *i*, these costs are determined according to $c(F_i, \theta_i)$ where F_i is the total level of industry funding, θ_i parameterizes the industry-specific difference between the private and social cost of capital, and $c(.)$ is non-decreasing in both F_i and θ_i. That is, the supply curve of capital for RU projects is upward-sloping and, relative to the socially efficient schedule, capital market imperfections shift upward this supply schedule.

This is obviously a reduced-form specification; the net impact of imperfections in the capital market reflects more specific contracting hazards between investors and inventors, including (a) inefficient effort provision as the result of imperfect monitoring (Holmstrom, 1989; Aghion and Tirole, 1994; Hellman, 1998a), (b) inefficient grouping of projects with different *v* as the result of imperfect observability of project quality (Stiglitz and Weiss, 1981), (c) potential ex-post expropriation of the rents from innovation by the investors as the result of imperfect property rights over the inventor's knowledge (Anton and Yao, 1994; Gans and Stern, 2000a), and (d) potential hold-up of investors by the research firm (Anand and Galetovic, 2000). Each of these effects raises the private cost of capital above its social cost; however, we do not disentangle these separate mechanisms in the empirical work but aggregate the effects into a single index of the level of capital market imperfections, θ_i.[5]

The demand for capital from VCs depends on the distribution of expected private returns for projects, pv_j, and so will be downward-sloping as the result of the distribution of project quality. The number of funded projects, F_i, is determined by the distribution of project value in the industry. The social value of the marginal project is equal to $\hat{V}_i = \overline{V}_i - F_i$, and its private value is denoted $\hat{v}_i$. This relationship allows us to derive how the equilibrium level of funding and marginal expected performance relate to the structural parameters of the model, determined by the interaction between private capital demand and the upward-sloping marginal cost of funding (see Figure 2):

$$p\hat{v}_i(\overline{V}_i - \hat{F}_i, \gamma_i) = c(\hat{F}_i, \theta_i) \qquad (1)$$

In terms of total funding, $\hat{F}_i(\overline{V}_i, \gamma_i, \theta_i)$ is increasing in $\overline{V}_i$ and γ_i but falling in θ_i. That is, an increase in technological opportunity ($\overline{V}_i$) or appropriability (γ_i) shift demand and hence $\hat{F}_i$ upwards, while an increase in capital imperfections (θ_i) shifts supply upward, reducing $\hat{F}_i$. Of course, since projects are undertaken only if $pv_j(V_j, \gamma_i) \geq c(F_i, \theta_i)$, the level of private investment will be less than socially desirable as long as there are any capital market imperfections or less-than-perfect appropriability.

[5] Gans and Stern (2000b) includes a short appendix deriving each of these effects and motivating θ_i..

Marginal Project Performance and Private Funding Levels

Expected marginal project performance ($p\hat{v}_i(\overline{V}_i - \hat{F}_i(\overline{V}, \theta_i, \gamma_i), \gamma_i)$) will be sensitive to the degree of capital imperfections and the level of appropriability. While greater capital market imperfections will be associated with higher $\hat{v}_i$ (as the result of upward shifts of the capital supply curve along the capital demand curve), lower levels of appropriability will be associated with lower expected marginal project returns (as the result of movement down the capital supply curve).

These comparative statics motivate our empirical test. After controlling for technological opportunity, the sign of the correlation between private funding and marginal project performance provides a test for the presence of variance in either the level of capital constraints or appropriability:

Proposition 1. *Consider a set of industries where the level of private funding and marginal project performance are determined according to (1). Then*

(a) *If* $\mathrm{Var}(\gamma_i) = 0$, $Cov[\hat{v}_i, \hat{F}_i | \overline{V}_i] \leq 0$

(b) *If* $\mathrm{Var}(\theta_i) = 0$, $Cov[\hat{v}_i, \hat{F}_i | \overline{V}_i] \geq 0$

In other words, if there is no variance in the level of appropriability (capital constraints), then, after controlling for the level of technological opportunity, the correlation between private funding levels and marginal project performance will be non-positive (non-negative). Consequently, a finding of a positive (negative) correlation allows us to reject $\mathrm{Var}(\gamma_i) = 0$ ($\mathrm{Var}(\theta_i) = 0$). Proposition 1 follows from the fact that if only θ_i varies (and there is no variance in appropriability and we control for technological opportunity), then the industry equilibrium pairs $(\hat{v}_i, \hat{F}_i)$ lie along a single capital demand curve.

If we are willing to assume specific functional forms for $c(.)$ and $v(.)$ we can extend Proposition 1 and derive the structural relationship inherent in the covariance between industry-level R&D funding and marginal project performance. In the simplest (linear) case, the covariance of $\hat{F}_i$ and $\hat{v}_i$ is negatively correlated if and only if the variance of θ_i exceeds the variance in $pv(.)$ (and vice versa).

Proposition 2. *Suppose that* $c(F_i,\theta_i)=F_i+\theta_i$ *and* $v(V_i,\gamma_i)=V_i-(\alpha-\gamma_i)$ *and that* $\overline{V}_i$, γ_i and θ_i *are independent random variables and* $\gamma_i\in[0,\alpha]$. *Then the correlation between marginal project performance and industry-level funding is a linear function of the difference in the variance of* $v(.)$ *and* θ_i*:* $\operatorname{cov}[\hat{v}_i,\hat{F}_i]=\frac{1}{(1+p)^2}\left(p\left(\operatorname{Var}\left[\overline{V}_i\right]-\operatorname{Var}\left[\alpha-\gamma_i\right]\right)-\operatorname{Var}\left[\theta_i\right]\right)$.

PROOF: For this case, from (1) and the fact that $\hat{V}_i=\overline{V}_i-F_i$, $\hat{F}_i=\frac{1}{1+p}\left(p(\overline{V}_i-\alpha+\gamma_i)-\theta_i\right)$ and, from (1), $\hat{v}_i=\frac{1}{1+p}\left(\overline{V}_i-\alpha+\gamma_i+\theta_i\right)$. Then:

$$\begin{aligned}\operatorname{cov}[\hat{v}_i,\hat{F}_i]&=E\left[\tfrac{1}{1+p}\left(\overline{V}_i-\alpha+\gamma_i+\theta_i\right)\tfrac{1}{1+p}\left(p(\overline{V}_i-\alpha+\gamma_i)-\theta_i\right)\right]-E\left[\tfrac{1}{1+p}\left(\overline{V}_i-\alpha+\gamma_i+\theta_i\right)\right]E\left[\tfrac{1}{1+p}\left(p(\overline{V}_i-\alpha+\gamma_i)-\theta_i\right)\right]\\&=\tfrac{1}{(1+p)^2}\left(pE\left[\overline{V}_i^2\right]-pE\left[(\alpha-\gamma_i)^2\right]-E\left[\theta_i^2\right]-pE\left[\overline{V}_i\right]^2+E\left[\alpha-\gamma_i\right]^2+E\left[\theta_i\right]^2\right)\\&=\tfrac{1}{(1+p)^2}\left(p\left(\operatorname{Var}\left[\overline{V}_i\right]-\operatorname{Var}\left[\alpha-\gamma_i\right]\right)-\operatorname{Var}\left[\theta_i\right]\right)\end{aligned}$$

where the second step follows from the independence assumption.

An Empirical Test for the Presence of Variance in the Level of Appropriability and/or Capital Constraints

To translate Propositions 1 and 2 into a concrete empirical test, we need to identify measures of the equilibrium pair $(\hat{F}_i,\hat{v}_i)$ across different industries. In that regard, given a selection of industrial segments, $\hat{F}_i$, the level of private R&D financing (for small firms), is readily observable. However, if the sample of projects are funded and performed by the private sector, it will be difficult (if not infeasible) to identify a measure for $\hat{v}_i$, the performance of the "marginal" project for each industry. Since private R&D financing is provided to projects which *exceed* the funding criterion, only a small set will be "on the margin" in terms of funding viability in any given industry. Instead, we propose to use the performance of projects that are *subsidized* by the government but performed by small and medium sized firms in the private sector as our measure of $\hat{v}_i$, namely a set of SBIR-funded projects.

By using a sample of SBIR-funded projects, our test improves on prior attempts to disentangle the drivers of variation in industry R&D intensity. First, from a public finance perspective, an efficient R&D subsidy program would funds projects that satisfy the social but not the private criterion for investment. As a result, under efficient funding, subsidized projects will consist of those just below the private funding threshold (i.e., the marginal projects in each industrial segment), providing an extremely useful sample of firms to evaluate $\hat{v}_i$. Even if the SBIR does not seek to identify marginal projects but offers a "less preferred" funding source from the perspective of entrepreneurs, SBIR-funded projects will be on the margin of the private funding threshold. As a result, the performance of subsidized projects offers a reasonable estimate of the performance of marginal projects within industrial segments. Second, by examining SBIR-funded projects, we examine smaller firms, who may face substantial variation in their appropriability and capital market environment. While our sampling choice is subject to several limitations and our results must be interpreted with caution, our approach provides a concrete methodology for determining the salience of capital constraints and appropriability in explaining the variance of small-firm venture financing.

Limitations and Potential Remedies

Without further amendment or caveats, it would seem that the proposed procedure provides a consistent test for the hypotheses in Proposition 1 under relatively stringent conditions: variance in technological opportunity is either absent or controlled for, the government-subsidized projects are at the margin of industry performance, and there is no direct impact of the government subsidy on project performance itself. While relaxing these assumptions requires a somewhat more nuanced interpretation of our results, we can address each concern and are able to implement the test implied by Proposition 1.

First, as Proposition 1 highlights, a consistent hypothesis test for the presence of variance in the level of capital constraints or appropriability is conditioned on a control for the level of technological opportunity. Indeed, traditional evaluations of the sources of R&D funding are often unable to disentangle the salience of market imperfections from the overall level of technological opportunity.[6] However, we employ two separate mechanisms to provide a consistent control for the level of technological opportunity for each project in our sample. First, we employ a direct measure of technological opportunity – a measure of the public "stock" of scientific and technological knowledge associated with each project in the sample (similar to Adams (1990)). As the level of public funding for basic research in a technology area increases, the marginal returns to private applied R&D in these areas will tend to increase (David et al, 2000). Second, we control for overall R&D expenditures in an industry (by *both* large and small firms)

[6] This inability to disentangle these factors is made difficult for two distinct reasons. First, most prior analyses focus on the funding and performance of projects which are themselves funded by the private sector and so each project, at least in expectation, has sufficiently overcome the presence of market imperfections to take advantage of market opportunity (see, for example, Cockburn and Griliches, 1988; Hall and Van Reenen, 2000). Second, because prior analyses examine all firms within an industry, there is no "reference" group for which market imperfections should be less salient but for which the level of

allowing us to isolate out the effects specific to R&D financing for small firms. For example, in the pharmaceutical industry, the level of funding by established pharmaceutical firms provides a useful measure of perceived technological opportunity ($\bar{V}_i$) in that industry relative to the impact of market imperfections (γ_i, θ_i) specific to (smaller) biotechnology firms.[7] Between these two measures, our analysis includes (reasonably) consistent controls for technological opportunity.

Second, our proposed implementation to test Proposition 1 is based on the assumption that subsidized projects are "marginal" – those projects in a given industrial segment just below the threshold of private funding. Of course, the subsidy program could use other selection criteria for allocating funds. For example, if projects are selected to ensure the political success of the program, then the subsidized projects may be "cherry-picked" – the best possible projects available to program administrators rather than the set which are socially but not privately worthwhile.[8] On the one hand, the possibility of cherry-picking qualifies our interpretation of the results. Specifically, under a cherry-picking selection mechanism, the specification continues to provide a consistent test for the existence of variation in the level of appropriability but becomes a less powerful test for identifying variance in capital constraints. Specifically, if only the "best" projects are observed, we will be performing a powerful test for variation in appropriability at the expense of power to identify variance in capital constraints. On the other hand, even if project administrators are *attempting* to cherry-pick projects, they may

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technological opportunity should be similar to the focus group.

[7] Of course, smaller and larger firms may have differential incentives to respond to a given technological opportunity (perhaps because of incumbency, scale economies, or the like). However, at an industry level, there is likely a positive correlation between the overall incentives of these two classes of firms; we abstract away from strategic effects in the present analysis.

[8] Indeed, Wallsten provides evidence that SBIR administrators in fact do attempt to choose the "best"

be greatly limited in that strategy, since subsidized funding is a less preferred source of capital. For example, whereas the usual delay between application and grant of a subsidy is several months, venture financiers can immediately fund projects that they deem worthwhile. As well, VCs provide valuable additional services, including access to a network of contacts and expertise in managing research-oriented start-up firms (Stuart and Poldony, 1999; Hsu, 2000). Moreover, while the government has only limited abilities to identify particularly promising companies, venture capitalists undertake active search to identify promising entrepreneurial ventures, reinforcing the degree to which the SBIR is left with "marginal" candidates. Indeed, most of the respondents in our sample of SBIR firms reported (qualitatively) that they would have preferred to attract venture finance to their projects if it had been available to them. As such, when interpreting our results, we keep in mind the possibility of cherry-picking incentives on the part of program administrators while recognizing that SBIR-funded projects may end up being marginal because of the funding preferences of entrepreneurs.

Third, even if the government is selecting projects that are marginal from the perspective of the private sector, the program may have a direct impact on the performance of subsidized projects. By construction, the SBIR alleviates the capital constraints facing funded firms. In contrast to the tradeoff that emerges between the provision of incentives and the taking of equity in the analysis of private investment, the SBIR extracts neither equity nor debt from the grantee. Effort incentives are preserved and incentives to divert the fruits of research away from equity holders are minimized. However, as a hands-off subsidy, SBIR grants cannot alleviate product market

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projects and interprets his evidence to suggest that the SBIR funds many projects which would have received private funding anyway (Wallsten, 2000).

imperfections. If intellectual property rights are weak, SBIR funding cannot overcome this weakness in the appropriability environment.[9] Thus, the SBIR program may reduce the power of the test for identifying the impact of variance in capital constraints (since subsidization overcomes some incentive constraints) and increase the power of the test for variance in the level of appropriability (since the SBIR does not affect sector-level differences along this dimension).

Overall, the proposed test should be interpreted conservatively. Even under the best of circumstances, the procedure can only reject a hypothesis of no variance in the level of appropriability (or capital constraints); rejecting this zero-variance hypothesis along one dimension (e.g., appropriability) does not preclude variance along the other dimension. Indeed, under Proposition 2, the estimated parameter will be equal to the *difference* in the variances and so we interpret our results so that evidence in favor of one source of variance by no means rejects variance along the other dimension. Moreover, it is likely that the test will be more powerful for finding evidence for differences in appropriability; the project selection mechanism and the incentive effects of the program mitigate against finding direct evidence for capital constraints.

III. The SBIR Program and R&D Investment by Small Firms

To implement our test, we exploit data about projects funded by the Federal government's SBIR, the largest individual source of R&D financing for small to medium-sized firms in the United States. SBIR funding provides a unique and informative source of variation in the funding of small, research-oriented firms. First

[9] Indeed, relative to the active participation of a VC, SBIR contributes very little in the way of

authorized as an NSF program in 1982, the SBIR program requires that all Federal agencies that support a minimal level of R&D activity are required to set aside a certain percentage of their funds for extramural grants to fund R&D projects by small business.[10] The principal legislative goals of the program are to:

(a) increase the commercialization rate of innovations resulting from Federal research,
(b) enhance the 'competitiveness' of small firms in technology-intensive industries; and
(c) enhance the participation of small firms as well as women and minority-owned businesses in the Federal contracting process (GAO, 1995).

As described earlier, the economic impact of the program is to alleviate some of the capital constraints facing funded firms while having no direct impact on the product market environment. However, from a political perspective, the program's support seems to derive in part from political demand to focus R&D expenditures towards near-term development projects and to areas which have a clear relationship to medium-term economic growth (Cohen and Noll, 1993). Combined with political rhetoric assuming that research-oriented start-up firms are the engine of long-term economic growth, and that such firms face a severe "funding gap" arising from the unwillingness of investors to shoulder the risks of early-stage financing, the SBIR has been a popular program whose scope has been consistently expanded since its inception (GAO, 1995).[11] Indeed, during the 1990s, the SBIR was the single largest source of early–stage R&D financing for small firms in the United States with annual expenditures over $1 billion.

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commercialization assistance.

[10] This percentage has varied over time (from 1.25 in the 1980s up to 2.5% as of 1997). As well, the SBIR defines a small business as a US-owned firm with less than 500 employees. Further details of the SBIR are discussed extensively in GAO (1995), Wallsten (1998), and Lerner (1999).

[11] In part, this political demand derives from economists' near-consensus assessment that the social rate of return on innovation, particularly by small firms, is substantially higher than the private rate of return to R&D activities (Jones and Williams, 1998).

Despite its political support, the program has been somewhat controversial. In part, this is because neither the legislative nor regulatory rules governing the program mandate the program fund projects *on the margin*. In most cases, SBIR-funded firms exploit both government and private funds for performing R&D, raising the possibility that subsidies are funding projects which would have otherwise been funded by the private sector. Indeed, as highlighted dramatically by Wallsten (2000), the program's funding guidelines seem to focus on funding the *most attractive* grant applications from either a technical or commercialization perspective.[12] Moreover, Lerner finds that firms funded by the program do tend to have an accelerated rate of growth compared to similar firms (Lerner, 1999). However, Lerner emphasizes that this "boost" to firm-level growth seems to be localized according to the location or technology focus of the firm, a contention that our framework implicitly revisits and explores in much greater detail.

More generally, we refocus analysis of the SBIR away from program assessment and towards exploiting the structure of SBIR to evaluate the sources of R&D concentration. First, because the program is administered through a variety of Federal agencies (Agriculture, Defense, HHS, etc.), whose missions span the scope of the economy's activities, the expenditures of the SBIR program are much more widely dispersed (across industries and technological areas) than privately funded R&D. This wedge between SBIR expenditures and private funding is particularly salient if one focuses on investment or R&D expenditures specifically for small (or venture-backed)

[12] As a result, the main focus of prior research (GAO, 1995; Lerner, 1999; Wallsten, 1998; 2000) has been on the assessment of the marginal contribution of SBIR funding (and government venture capital more generally) to the performance of subsidized firms. Towards this goal, these analyses are framed in terms of the counterfactual of the expected behavior or performance of these firms, in the absence of the subsidy program. Indeed, both Lerner (1999) and Wallsten (1998; 2000) focus their results around the comparison of a group of SBIR-funded firms and a "matched sample" of firms who are observationally similar *ex ante* but who do not receive SBIR funding.

firms. In other words, a specific if unintended contribution of the SBIR program is to expand the supply of capital to research-oriented, smaller firms to a set of industries and technologies which, for one reason or another, do not currently attract high levels of such funds. As a result, the program is extremely useful for identifying projects across a set of industrial segments that vary greatly in terms of their level of private venture financing.

Second, to the extent that the SBIR funds marginal projects in each industrial sector, the impact of the SBIR in a given sector is to shift the capital supply curve to the right. By looking at the performance of these subsidized projects, we are able to identify, at least in principle, the marginal private return of projects by industrial sector. While it is possible that the program does potentially experience some cherry-picking (which mitigates against this benefits), SBIR funding tends to be a less "preferred" source of external capital. As such, the SBIR-funded sample offers a superior sample for performing our test, relative to a sample of firms financed exclusively by the private sector.

IV. Data

This paper presents results from a novel dataset based on 100 projects funded by the SBIR since 1990. The data were gathered via a field-based proprietary survey conducted by the authors. This project-level data was supplemented with public data on each firm's patenting behavior, SBIR grant history, and covariates relating to the industry, business segment, and scientific underpinning associated with each project. In this section, we first review our procedure and survey (highlighting the sample selection and data gathering process) and then review the summary statistics for the sample (Table 1 includes the definitions of all variables; Table 2 provides summary statistics).

Survey Data Sources and Sample Selection Method

The data exploits the MIT Commercialization Survey, conducted between December and February 1999.[13] The sample is drawn from a list (compiled by the Small Business Administration) of the (approximately) 200 largest historical beneficiaries of SBIR grants.[14] For survey participants, we requested information about their most successful project funded by the SBIR (for most firms, there was only one (or at most two) SBIR-funded projects which the firm considered technologically successful). As such, the data provides information about the economic returns of projects in different industries that are at least successful in a technical sense.

At the firm level, we collected background information on the organization's employees and promotion policies; financial information about corporate ownership, expenditures and revenues; and corporate governance. At the project level, each company was asked to provide information on the commercialization and financing history of the technology project, including revenues through sales and licensing of the technology, the importance of the technology in achieving various goals of the firm, key

[13] The Survey, provided in Gans and Stern (2000b), is being used to study the incentives, strategies, and performance of research-oriented start-ups.

[14] The overall response rate was approximately 50%. Firms contacted but not responding seemed randomly mixed between firms not having a commercial product and those too busy or not willing to respond. Within the organization, the respondent was typically the director of R&D, the director of sales or marketing, or the CEO. Most of the surveys (approximately 75%) were filled out over the telephone, with the balance either faxed or mailed back. All respondents were guaranteed confidentiality of individual responses.

personnel involved in setting the commercialization strategy of the company, and information about the commercialization strategy itself.[15]

From this survey, we construct both project-specific and firm-specific variables (see Table 1 for definitions). First, we define the project-level variables. We define private project performance in terms of the aggregate annual revenues from product sales, licensing, and intellectual property exchanges (REVENUE 98).[16] Since this measure does not capture the costs associated with each project, we include several project-level controls proxying for the type of manufacturing process (MADE-TO-ORDER) and whether additional development work has been undertaken (UPGRADE). Additionally, we identify the number of PATENTS awarded to capture the potential appropriability of the project. While PATENTS may be correlated with the unobserved quality of the project, we do not interpret the coefficient on this variable in terms of the marginal benefit to receiving a patent, but as a more general control capturing the appropriability environment (i.e., is it possible to get formal intellectual property rights in this technology area?) and the quality of the project. To control for the overall size of the project, we measure the project-level SBIR AWARD SIZE. While most SBIR awardees access both private and public financing to fund overall firm operations, the majority of funding for most *projects* in our sample are received from public funds. Across sectors, the distribution of SBIR AWARD SIZE is relatively constant; the only exception is biotechnology, with a mean award size of just over $600K, substantially below the mean

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[15] Whenever possible, we used publicly available databases to verify information. For example, we verified the number of patents assigned to each organization through the USPTO patent database.

[16] All of the qualitative results are robust to using the data on total project revenues (indeed, they are highly correlated). However, this would reduce the number of usable surveys by approximately one-third.

of all other sectors. While SBIR AWARD SIZE clearly reflects the overall quality of the project, the awards process is sufficiently noisy, reducing concerns about endogeneity.[17]

In addition, we identify all firms who receive at least some of their overall revenues not through direct product market sales but through licensing arrangements or intellectual property sales. We denote these firms COOPERATORS insofar as nearly all of these firms are involved in cooperative contracting with more established product market incumbents.[18] We further calculate a measure of overall product development efficiency (TIME-TO-MARKET) that equals the time from initial product conception to the first sale of this product to any customer (either directly or through licensing).

As well, we include several firm-specific variables describing the financial and organizational structure of the firm. In terms of the measurement of performance, some of the analysis is organized around the determinants of current firm size (EMPLOYMENT 98). We use the initial value of this measure as a key control in most of our empirical analysis (BASELINE EMPLOYEES), in order to control for the size of the firm at the time of the initial SBIR award. As well, we measure variables related to financial structure, VC EQUITY SHARE and INSIDER EQUITY SHARE. These two variables allow us to evaluate the impact of VC financing and maintaining a closely held organization on project-level performance.

[17] While the focus of our analysis is on the relationship between project-level performance segment-level funding, several of these control variables might be endogenous. Since we do not have any instruments to explicitly control for this endogeneity, we present results including and excluding each of these factors; as well, while this leads us to interpret the coefficients for the control variables cautiously, there is little reason to believe that these effects bias the coefficient on VC FUNDING STOCK, the main variable of interest.

[18] This cooperative behavior with incumbents is often in lieu of competition with these same firms (Anton and Yao, 1994; Gans and Stern, 2000a; Gans, Hsu, and Stern, 2002).

Sources and Definitions of Industry and Segment-Level Variables

A critical element of the analysis is the relationship of project-level performance to measures of private and public investments in technology segments, industries and scientific areas associated with each project. Specifically, we want to distinguish four concepts: the level of venture capital financing in a given industrial segment, aggregate private R&D in a given industry, the size of each industry, and the scientific and engineering opportunities present in the technological areas inherent in the project.

To capture the first, we assigned each project to one of ten technology segments, building on a classification system developed by Venture One. For each segment, we measure the VC FUNDING STOCK as the (undiscounted) sum of venture investing in that segment between 1985 – 1992. The projects were approximately broadly distributed among these segments; the maximum number of projects in an individual segment was in Industrial Products and Services, with 18 projects in our sample. We also assign each firm to a single three-digit SIC; the NSF Science and Engineering Indicators provides SIC-LEVEL R&D EXPENDITURES and SIC SALES at this level of aggregation. By the nature of the SBIR program, the projects are distributed broadly across these sectors; except for a concentration of 18 projects in SIC code 382 (scientific instruments), fewer than 10 projects are observed in any other three-digit SIC code. Finally, we measure the project's association with scientific or engineering opportunity by constructing a SCIENCE STOCK for each project. First, we defined 14 specific scientific and engineering areas (e.g., physics or chemical engineering), and, for each, we calculated the (discounted) Federal Funding stock in that area (equal to 1990 FUNDING + .8 1988 FUNDING + .6 1986 FUNDING). We then assigned each SBIR project to one or more of these 14 scientific and engineering fields. In contrast to the mutually exclusive nature of the prior variables, the science base of each project can depend on multiple sources of scientific and engineering knowledge. Each project's SCIENCE STOCK is equal to the sum of the individual field-level stocks for fields associated with that project.

We also attempt to provide additional controls for the environmental heterogeneity among firms. First, we include several variables that relate to the relative importance and salience of intellectual property (PATENT LIKERT, LITIGATION LIKERT, SECRECY LIKERT, and SPEED TO MARKET LIKERT), each of which is measured as a 5-point Likert scale variable. We also define a combination dummy, STRONG FORMAL IPR, which is equal to one if either PATENT LIKERT or LITIGATION LIKERT is greater than three.

As well, we include several (five-point Likert scale) variables measuring the importance associated with the control and cost-effectiveness of specific complementary assets (MANUFACTURING LIKERT, DISTRIBUTION LIKERT, BRANDING LIKERT, and SERVICING LIKERT). Not surprisingly, the mean of these Likert scale variables varies from just below 3 to just over 4. We define EXPENSIVE COMP ASSET OWNERSHIP as a dummy variable equal to one if the maximum score over this set is less than five.

Summary Statistics

Out of a total 100 responses, 74 were fully usable for the empirical work reported here.[19] However, for most of the analysis, we exclude three observations that seemed to

[19] Most of the non-responses were because of non-reporting of all 1998 revenues (e.g., sales reported but not licensing revenue). We have checked our results including all results, even those for whom the data was

be SBIR "mills" that have an unusually high number of overall SBIR awards; these organizations have a much more diverse research portfolio from the rest of the sample and also have a different relationship with funding agencies. This leaves us with 71 total observations for the majority of our analysis.

Among these 71, the average project reports approximately 6.5 million dollars in revenue, compared with an average award size of 1.6 million (but note the high standard deviations associated with each). As well, these organizations seem to be highly productive in a technical sense. On average, each has been issued over 9 patents that were applied for since the first SBIR grant associated with the specific project here (all chosen projects have their first funding date after 1990). In addition, almost a third of the sample earns at least some its revenue through cooperative licensing or IP exchanges (most often with product market incumbents). As well, the average commercialization length of projects is a little under four years, though some outliers in part drive this result (from biotechnology and the like). Finally, at the firm level, while most of these organizations are quite small at inception (36 employees on average), they tend to experience substantial growth over time (the average firm has nearly 86 employees by 1998).[20]

As suggested earlier, the principal empirical exercise of this paper will be to relate project-level performance measures (REVENUE 98 and EMPLOYMENT 98) to segment-level measures of private investment activity and the technological environment. The three principal measures we use to capture these effects are 1992 VC FUNDING

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incomplete; the qualitative results are unchanged.

[20] As well, in terms of the internal organization and finance of the firms, over 50% of equity is retained by insiders; perhaps surprisingly, while 25% of the sample had attracted some form of VC or "angel" financing, the equity share of these investors is quite small (the average level of equity held by these outside investors across the full sample is less than 7%). In addition, in nearly 60% of the firms, the CEO is one of the original founders of the firm. Finally, the firms are reasonably concentrated geographically (nearly half the companies are located in either California or Massachusetts).

STOCK, SIC-LEVEL R&D EXPENDITURES and the SCIENCE STOCK. Each of these variables provides a distinct way of capturing the degree of environmental heterogeneity facing different SBIR-funded projects. VC FUNDING STOCK measures the skewed distribution of entrepreneurial activity and is divided into several segments which do not precisely map into the traditional SIC classifications. On the other hand, SIC-LEVEL R&D EXPENDITURES and SCIENCE STOCK measure differences across sectors in terms of aggregate R&D expenditures and differences in Federal investment in alternative scientific and engineering fields upon which many of these innovations draw. While SCIENCE STOCK and SIC-LEVEL R&D EXPENDITURES will tend to be sensitive to differences across sectors in terms of technological opportunity, only VC FUNDING STOCK will be sensitive to differences across sectors in the degree of appropriability or the salience of capital market constraints specifically facing small research-oriented firms.

V. Empirical Results

We now turn to the core of the empirical analysis. Specifically, we are concerned with the degree of variation across sectors in technological opportunity (Var($\overline{V}$)), the degree of appropriability (Var(γ)), and the relative salience of capital constraints (Var(θ)). Our empirical test provides evidence about the relative salience of these factors in explaining the large differences in R&D funding for small firms across industries that we highlighted in Section I. Specifically, we test for the relationship between project-level performance and the level of private investment in each project's industry or technological segment. Overall, controlling for project-level, firm-level and other environmental characteristics that may affect revenue performance, revenue is increasing in the level of venture capital funding for small firms in a given technology segment and, more tentatively, in the science stock associated with a given technology. In contrast, performance is not statistically related to overall R&D investment in a given area or the overall size of an industrial segment. These basic findings are robust to several alternative specifications, including the inclusion of additional controls for appropriability, project-level and firm-level factors, as well as variation in the measurement of the level of financing for small research-oriented firms. As well, there is a positive relationship between employment growth (EMPLOYMENT 98) and the level of venture financing.

The Performance of SBIR-funded Development Projects

We begin in Table 3 with the relationship between L REVENUE 98 and each of the alternative measures of private investment and technological opportunity. The most striking result is that, whereas SCIENCE STOCK, SIC-LEVEL R&D EXPENDITURES, and SIC SIZE are uncorrelated with project-level performance, 1992 VC FUNDING STOCK is both statistically significant and quantitatively important: doubling the level of venture funding in an industrial segment is associated with over a 50% increase in measured revenue (see (3-1)). As well, in (3-5), we demonstrate that our principal result concerning the VC FUNDING STOCK is robust to the inclusion of the alternative measures of the segment-level environment (which remain themselves insignificant and lower in magnitude). When considering these results, it is useful to recall that the inclusion of SCIENCE STOCK and SIC-LEVEL R&D EXPENDITURES allow us to distinguish overall technological opportunity from variation in the level of appropriability facing small, entrepreneurial firms. In other words, under the logic of Proposition 1, these results suggests the presence of differences across industrial segments in terms of their appropriability environment (i.e., Var(γ) > 0), even after incorporating two measures capturing variation in technological opportunity across segments.

Figure 3 illustrates this finding. While average project revenue is mostly associated with the level of venture financing by segment, the performance of the SBIR projects seems, at best, to be negatively associated with SIC-LEVEL R&D EXPENDITURES (which is primarily driven by expenditures by larger firms). It is useful to note that while average project revenue within segments seems to be increasing with the level of venture financing, there is a dip in average revenue among the computer and information technology segments, for which we observe a very small number of distinct projects (3 and 2, respectively).

Of course, it is possible that these results are driven by "project-level" factors rather than segment-level variation related to the VC FUNDING STOCK. Table 4 therefore extends the analysis by controlling for various project-level, firm-level, and industry-level controls. In (4-1), we include the simplest "control," the level of initial employment at each firm. This simple measure should capture some degree of the heterogeneity among firms in their initial conditions in terms of generating products associated with a given level of revenue; however, its inclusion does not impact our main result at all. We then extend the analysis by including controls for the firm's perception of their appropriability and complementary asset environment, as well as other project-level controls. The results from the analysis in (4-2) and (4-3) are interesting in their own right: revenues are increasing in the ownership of a patent, in environments where complementary asset ownership is not critical for earning returns on innovation, and for projects where the product has been upgraded over time or commercialized with the cooperation of a more established market player.[21] More importantly, VC FUNDING STOCK remains roughly the same magnitude and statistically significant, despite the large number of control variables included and given the relatively small number of observations in the sample. Indeed, in (4-4), we include all of the control measures simultaneously with no impact on the underlying result regarding VC FUNDING STOCK. Finally, in equation (4-5), we additionally include the other measures of industry and segment-level funding (SCIENCE STOCK and SIC-LEVEL R&D EXPENDITURES). Even with the additional firm and project controls, our principal finding regarding the impact of the VC FUNDING STOCK remains robust, and SCIENCE STOCK also is observed with a positive impact.

Table 5 further establishes the robustness of these results. We include additional firm-level covariates, including measures of the financial organization of the firm ((5-1) and (5-2)), as well as additional environmental covariates associated with the firm's geographic location (5-3). Both VC FUNDING STOCK and SCIENCE STOCK remain significant and at a similar magnitude.

Overall, even after we control simultaneously for various project-level controls as well as measures associated with technological opportunity and aggregate R&D expenditures, the highest performing SBIR-funded projects tend to be associated with those industrial segments with high rates of venture capital funding. Given the logic of

[21] A number of these measures, most notably COOPERATOR, are likely endogenous, as established firms will likely select to cooperate with firms with higher overall technological quality. We include the variable in this robustness check, however, to capture the potential impact of cooperation on our results and to distinguish this effect from the role of segment-level private venture financing. The results are similar

Proposition 1, these results suggest variation across sectors in terms of the degree of appropriability facing small firms, and that such differences are reflected in the ability of *subsidized* firms to earn returns on their innovations in specific industrial segments. While we caution that our results are based on a limited sample size, we are encouraged by the fact that we are able to identify the impact of the VC FUNDING STOCK even within this small sample and even after including a number of additional controls.

It is important to recall that the results do not *reject* variation in capital constraints; instead, the impact of variation from appropriability outweighs the impact of variation from capital constraints in these data. Given some of our earlier concerns about the details of the project selection mechanism (i.e., the possibility of cherry-picking) and the impact of subsidized funding on project performance (which will tend to ameliorate the impact of capital constraints), it is perhaps not surprising that our main empirical findings are in support of variation in the level of appropriability. Indeed, we are not aware of prior quantitative evidence demonstrating that segment-level differences in the appropriability environment drive the industry concentration of venture financing.

Finally, in Table 6, we compare our results regarding REVENUE 98 to an alternative analysis focused on the determinants of firm-level employment (EMPLOYMENT 98). In some sense, this analysis is more directly comparable to the analysis pursued by Lerner (1999), in that Table 6 focuses on the determinants of firm-level performance among SBIR-funded firms. The analysis is straightforward and echoes our earlier finding: while employment growth seems to be relatively unrelated to environmental measures associated with SCIENCE STOCK or SIC-LEVEL R&D

when excluding COOPERATOR and/or other potential endogenous variables (such as PATENTS and SBIR AWARD SIZE) from the analysis.

EXPENDITURES, there is a quantitatively important and statistically significant relationship between EMPLOYMENT 98 and VC FUNDING STOCK, even after controlling for BASELINE EMPLOYMENT (as well, this result is generally robust to the inclusion of various controls, similar to the earlier analysis). In conjunction with our earlier findings regarding REVENUE 98, Table 6 provides additional evidence that there is a robust positive relationship between the performance of SBIR-funded projects and segment-specific levels of venture activity, consistent with the presence of differences across sectors in the appropriability environment facing small research-oriented firms.

VI. Conclusions

The main conclusions of this study result from its core quantitative finding: SBIR project performance is highest for those projects in industrial segments which themselves receive the highest level of venture financing. Such a finding should be of some direct interest to policymakers: if program administrators are given strong incentives to identify projects with the highest performance, then there may be pressures to focus SBIR funding precisely on those segments for which venture financing is readily available. Or, from another perspective, the fact that the SBIR program is run through a variety of different agencies may have the (unintended but) beneficial effect of increasing the availability of funding to precisely those segments of the economy where small-firm research faces the highest hurdles, either in terms of appropriability or capital constraints.

More generally, this study allows us to begin to disentangle the relative salience of alternative sources of the concentration of venture financing. While we view our results as suggestive rather than definitive, this is the first evidence to our knowledge for the importance of variation in appropriability in helping to understand the concentration of R&D among a small number of industrial segments. Specifically, whereas most prior analyses have had difficulty distinguishing between the response to overall technological opportunity and the level of appropriability, our focus on specific technologies being commercialized by smaller firms subsidized by the U.S. government provides extremely useful controls for technological opportunity: patterns of aggregate spending by larger firms and the stock of scientific knowledge used by individual projects. More generally, our results suggest that rather than simply being the result of "herding" by venture capitalists in response to diffuse priors about technological opportunity, the economy seems to offer small "pockets" where the appropriability environment facing small, research-oriented start-ups is particularly favorable. Indeed, understanding how such pockets emerge is a promising area for further study.

As well, our results suggest that there may be some benefits from addressing the appropriability environment facing small firms. At least in part, the low level in funding for small firm research in some areas may be the result of specific (and potentially remediable) weaknesses in the appropriability regime, such as the availability of intellectual property or antitrust rules which limit the ability of smaller firms to access the complementary assets required for commercialization in a competitive market.

As we have emphasized several times, our results are provocative but not the final word. Even beyond issues such as the sample size, our approach only allows us to estimate a "reduced-form" parameter and so our evidence in favor of variance in appropriability comes at the expense of simultaneously identifying the salience of capital constraints. While our results are consistent even if the project selection mechanism satisfies a “cherry-picking” regime, distinguishing among the separate effects of each of these factors seems important. Perhaps a careful integration of the program evaluation methodologies of Wallsten and Lerner with the within-program evaluation pursued here will allow for more nuanced examination of the role played by market imperfections in shaping the level and productivity of small firm innovation.

Figure 1. Concentration of VC Disbursement vs. Private R&D Expenditures (Lorenz curve, millions of 1992 dollars) Gini Coefficient = 0.560

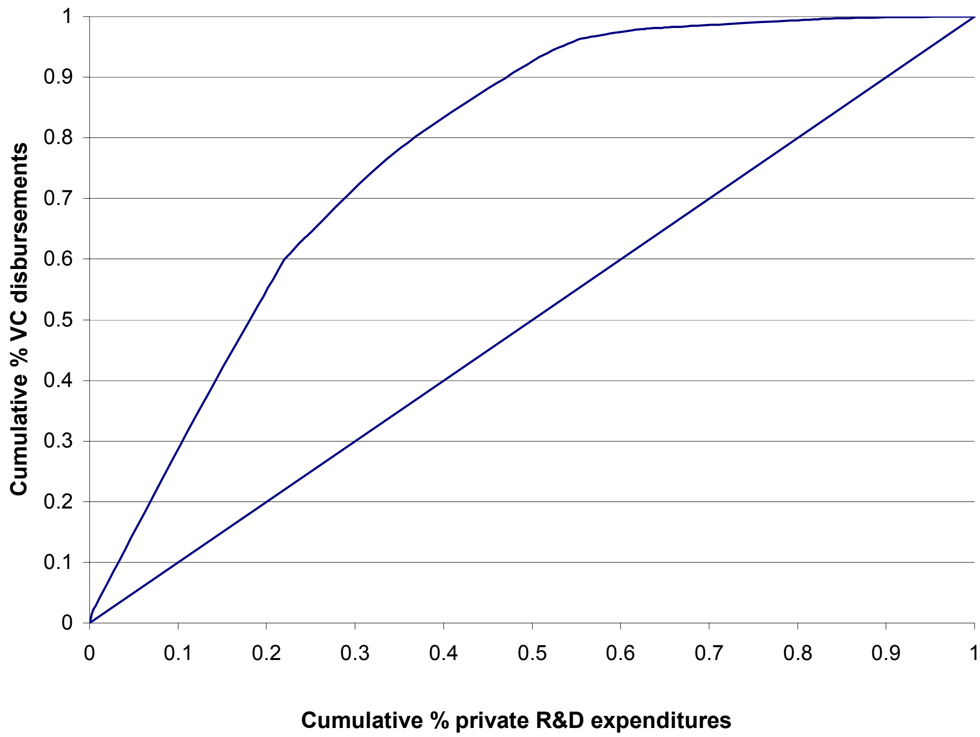
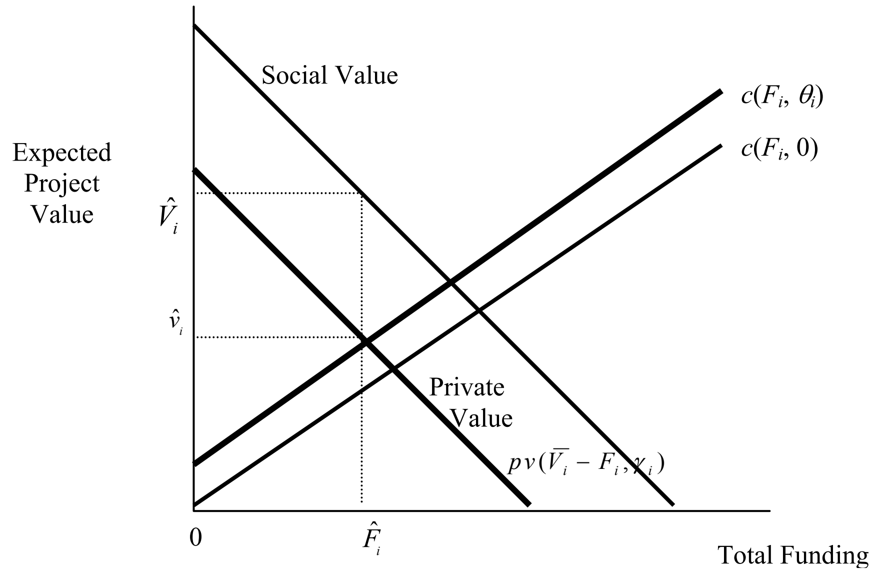
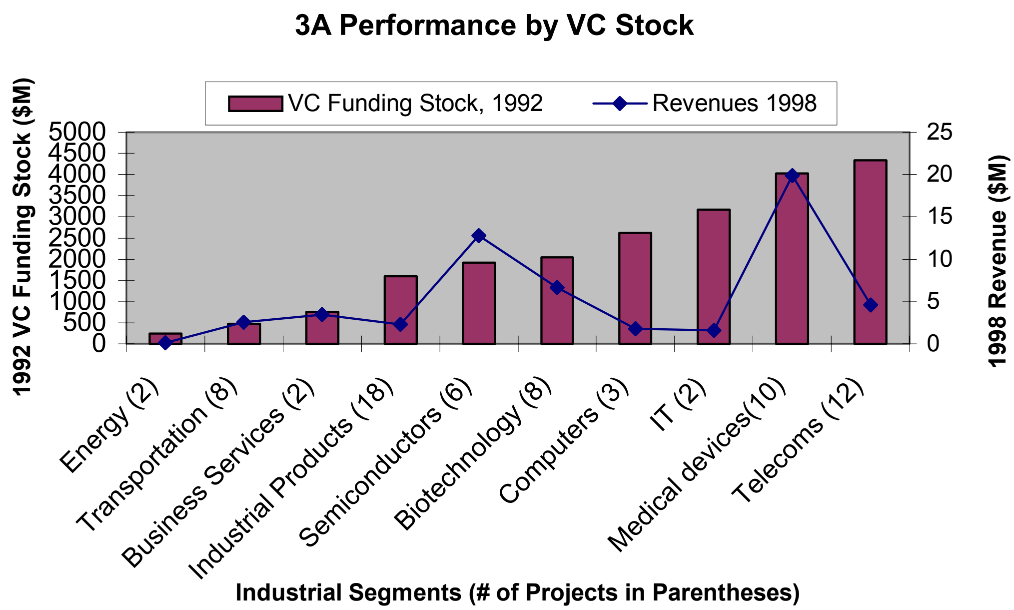


Figure 2: Equilibrium Industry Funding and the Impact of Marginal Subsidies




3A Performance by VC Stock
VC Funding Stock, 1992
Revenues 1998
1992 VC Funding Stock ($M)
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
25
20
15
10
5
0
1998 Revenue ($M)
Energy (2)
Transportation (8)
Business Services (2)
Industrial Products (18)
Semiconductors (6)
Biotechnology (8)
Computers (3)
IT (2)
Medical devices(10)
Telecoms (12)
Industrial Segments (# of Projects in Parentheses)

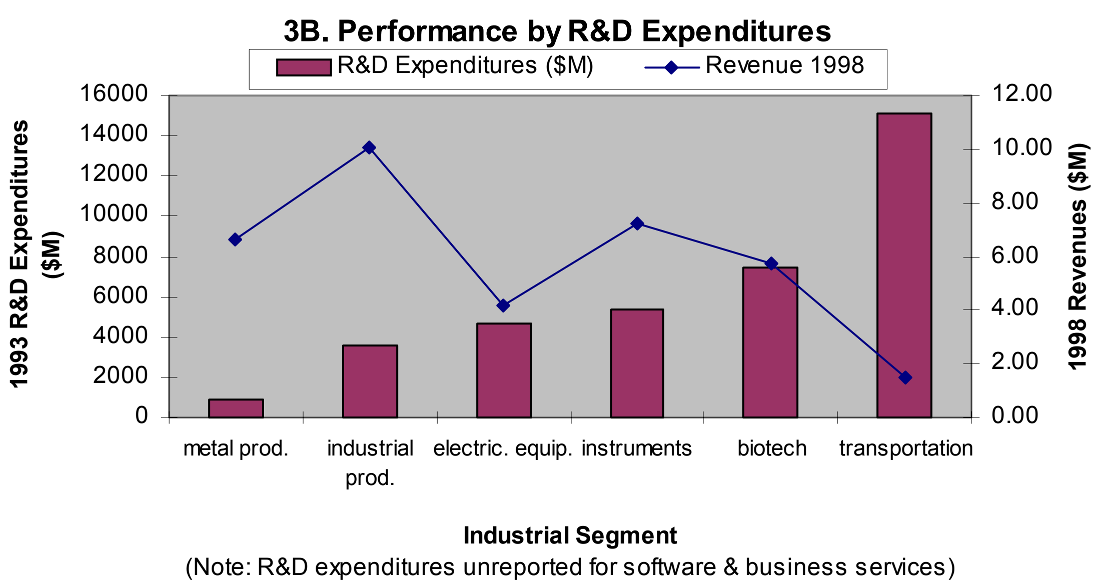

3B. Performance by R&D Expenditures
R&D Expenditures ($M)
Revenue 1998
1993 R&D Expenditures ($M)
16000
14000
12000
10000
8000
6000
4000
2000
0
12.00
10.00
8.00
6.00
4.00
2.00
0.00
1998 Revenues ($M)
metal prod.
industrial prod.
electric. equip.
instruments
biotech
transportation
Industrial Segment
(Note: R&D expenditures unreported for software & business services)

TABLE 1
VARIABLES & DEFINITIONS

VARIABLE	*DEFINITION*	*SOURCE*
PROJECT-LEVEL PERFORMANCE		
REVENUE 98	Total 1998 Revenues from Project	MIT Survey
EMPLOYMENT 98	Total Employees in 1998	MIT Survey
INDUSTRY OR SEGMENT-LEVEL VARIABLES		
1992 VC FUNDING STOCK	Total (undiscounted) stock of venture capital investment in technology segment most closely associated with project	MIT Survey; Venture One
SCIENCE STOCK	Total (discounted) stock of Federal expenditures on scientific and engineering areas closely related to project technology. See text for details. NB: Stock is linear in all areas related to project	MIT Survey; NSF S&E Indicators
SIC-LEVEL R&D EXPENDITURES	1993 R&D Expenditures in Project 3-digit SIC	MIT Survey; NSF S&E Indicators
SIC SALES	1993 Total SIC Sales	NSF S&E Indicators
APPROPRIABILITY VARIABLES		
PATENTS	Patents awarded since SBIR grant	USPTO
PATENT LIKERT	5-Point Likert Scale Rating of Importance of Patents for Appropriating Returns	
LITIGATION LIKERT	5-Point Likert scale rating of importance of patent or copyright litigation for appropriating returns	
STRONG FORMAL IPR	Dummy = 1 if PATENT LIKERT > 3 or LITIGATION LIKERT > 3	MIT Survey
SECRECY LIKERT	5-Point Likert Scale Rating of Importance of Secrecy for Appropriating Returns	
SPEED LIKERT	5-Point Likert Scale Rating of Importance of being First to Market to Appropriate Returns	
COMPLEMENTARY ASSET VARIABLES		
MANUFACTURING LIKERT	5-Point Likert Scale Rating of the Importance of Control over Manufacturing	
DISTRIBUTION LIKERT	5-Point Likert Scale Rating of the Importance of Control over Distribution Channels	
BRANDING LIKERT	5-Point Likert Scale Rating of the Importance of Control over Branding Resources in Earning Returns from the Project	MIT Survey
SERVICING LIKERT	5-Point Likert Scale Rating of the Importance of Control over Servicing Resources in Earning Returns from the Project	
EXPENSIVE COMP ASSET OWNERSHIP	Dummy = 1 if the Max over 5-point Likert scales measuring the *importance and effectiveness of ownership* of complementary assets (Branding, Manufacturing, Distribution, & Service) is less than 5	Authors Calc
PROJECT AND FIRM-LEVEL CONTROL VARIABLES		
COOPERATOR	Dummy = 1 if Project Revenues include licensing revenues, intellectual property sales, or merger and acquisition, 0 else	
UPGRADE	Dummy = 1 if Project Technology has been "substantially upgraded" since market introduction or prototype, 0 else	
TIME-TO-MARKET	Months From Conception of Initial Project Idea Until Product Market Introduction	MIT Survey
MADE-TO-ORDER	Dummy = 1 if Firm Sells "Made-to-order" Technologies, 0 else	
SBIR AWARD SIZE	SBIR Grant Awards Related to Project Technology	
BASELINE EMPLOYEES	Total Employees in Firm at Start of Project	

* The natural logarithm of a variable, X, will be denoted L X

TABLE 2
MEANS & STANDARD DEVIATIONS

VARIABLE	MEAN	STD. DEVIATION
PROJECT-LEVEL PERFORMANCE		
REVENUE 98	6.508	13.378
EMPLOYMENT 98	85.690	96.580
INDUSTRY OR SEGMENT-LEVEL VARIABLES		
1992 VC FUNDING STOCK	2378.842	1369.250
SCIENCE STOCK	6897.383	4247.940
SIC-LEVEL R&D EXPENDITURES	4597.366	3024.385
SIC SALES	73152.020	32122.980
APPROPRIABILITY VARIABLES		
PATENT LIKERT	3.771	1.290
LITIGATION LIKERT	2.444	1.307
STRONG FORMAL IPR	0.400	0.492
PATENTS	9.106	13.353
SECRECY LIKERT	3.822	1.302
SPEED LIKERT	3.592	1.279
COMPLEMENTARY ASSET VARIABLES		
MANUFACTURING LIKERT	4.155	1.065
DISTRIBUTION LIKERT	3.555	1.179
BRANDING LIKERT	3.200	1.272
SERVICING LIKERT	3.533	1.140
EXPENSIVE COMP ASSET OWNERSHIP	0.288	0.458
PROJECT- AND FIRM-LEVEL CONTROL VARIABLES		
COOPERATOR	0.352	0.481
UPGRADE	0.845	0.364
TIME-TO-MARKET	45.397	42.981
MADE-TO-ORDER	0.620	0.489
SBIR AWARD SIZE	1.644	1.315
BASELINE EMPLOYEES	36.127	45.980

TABLE 3
PROJECT-LEVEL PERFORMANCE EQUATIONS
(NO PROJECT-LEVEL CONTROLS)

	Dependent Variable = L REVENUE 98 N= 71 observations, excludes "mills"				
	(3-1) VC STOCK only	**(3-2)** SCI STOCK only	**(3-3)** SIC R&D only	**(3-4)** SIC SIZE only	**(3-5)** Combination Model
L 1992 VC FUNDING STOCK	**0.567** **(0.255)**				**0.586** **(0.265)**
L SCIENCE STOCK		0.383 (0.267)			0.281 (0.271)
L SIC-LEVEL R&D EXPENDITURES			0.463 (0.347)		0.278 (0.347)
L SIC SALES				0.251 (0.504)	0.400 (0.507)
Constant	**-3.680** **(1.931)**	-2.703 (2.308)	-3.220 (2.931)	-2.112 (5.605)	**-12.975** **(6.700)**
R-Squared	0.067	0.029	0.041	0.020	0.125
Adjusted R-Squared	0.054	0.015	0.013	-0.009	0.058

NOTE: Standard errors are in parentheses, and coefficients significant at 5 percent level and 10 percent are set in bold and italic, respectively.

TABLE 4
PROJECT-LEVEL PERFORMANCE
(PROJECT, FIRM, AND INDUSTRY-LEVEL CONTROL VARIABLES)

N= 71 observations	**Dependent Variable = L REVENUE 98**				
	(4-1) Control for Initial Firm Size	**(4-2)** (4-1) with Comp Asset and Appropriability Controls	**(4-3)** (4-1) with Project-level Controls	**(4-4)** Combination Model	**(4-5)** (4-4) with All Controls
L 1992 VC FUNDING STOCK	**0.537** **(0.265)**	**0.535** **(0.261)**	**0.646** **(0.265)**	**0.566** **(0.275)**	**0.653** **(0.270)**
L SCIENCE STOCK					**0.729** **(0.288)**
L SIC-LEVEL R&D EXPENDITURES					-0.169 (0.336)
STRONG FORMAL IPR		-0.257 (0.513)		0.153 (0.528)	-0.072 (0.516)
PATENTS		*0.028* *(0.016)*		**0.036** **(0.017)**	**0.036** **(0.016)**
SECRECY LIKERT		0.325 (0.200)		0.232 (0.206)	*0.350* *(0.205)*
SPEED LIKERT		0.265 (0.254)		0.234 (0.251)	0.192 (0.244)
EXP. COMP ASSET OWNERSHIP		*1.070* *(0.567)*		0.521 (0.577)	0.867 (0.573)
COOPERATOR			*0.755* *(0.393)*	0.554 (0.042)	0.806 (0.508)
UPGRADE			*0.961* *(0.518)*	*0.947* *(0.523)*	0.961 (0.551)
TIME-TO-MARKET			-0.006 (0.004)	-0.008 (0.005)	**-0.10** **(0.005)**
MADE-TO-ORDER			0.282 (0.426)	0.421 (0.446)	*0.799* *(0.468)*
L SBIR AWARD SIZE			-0.239 (0.170)	-0.228 (0.174)	-0.162 (0.172)
BASELINE EMPLOYEES	0.125 (0.152)		0.188 (0.145)	0.151 (0.155)	0.240 (0.154)
Constant	*-3.763* *(1.953)*	**-6.877** **(2.613)**	**-4.697** **(2.328)**	**-7.560** **(2.946)**	**-13.581** **(4.232)**
R-Squared	0.081	0.240	0.283	0.387	0.464
Adjusted R-Squared	0.040	0.128	0.163	0.191	0.250

NOTE: Standard errors are in parentheses, and coefficients significant at 5 percent level and 10 percent are set in bold and italic, respectively.

TABLE 5
EQUITY & GEOGRAPHY CONTROLS

	Dependent Variable = L REVENUE 98 N= 71 observations, excludes "mills"		
	(5-1) Control for VC EQUITY SHARE	**(5-2)** Control for Management and Employee Equity Share	**(5-3)** Exploring Geographic Effects
L 1992 VC FUNDING STOCK	**0.640**	**0.561**	**0.692**
	(0.276)	**(0.274)**	**(0.276)**
L SCIENCE STOCK	**0.634**	**0.662**	**0.803**
	(0.323)	**(0.303)**	**(0.301)**
L SIC-LEVEL R&D EXPENDITURES	-0.164	-0.166	-0.173
	(0.341)	(0.333)	(0.356)
	-0.006		
VC EQUITY SHARE	(0.014)		
INSIDER EQUITY SHARE		-0.010	
		(0.007)	
LOCATED IN NY			1.391
			(0.975)
LOCATED IN CA			0.023
			(0.494)
LOCATED IN MA			-0.235
			(0.618)
APPROPRIABILITY REGIME CONTROLS	YES	YES	YES
COMPL. ASSET CONTROLS	YES	YES	YES
PROJECT AND FIRM-LEVEL CONTROLS	YES	YES	YES
Constant	**-11.888**	**-11.472**	**-14.257**
	(5.164)	**(5.042)**	**(4.281)**
R-Squared	0.469	0.494	0.490
Adjusted R-Squared	0.226	0.262	0.241

NOTE: Standard errors are in parentheses, and coefficients significant at 5 percent level and 10 percent are set in bold and italic, respectively.

TABLE 6
FIRM EMPLOYMENT EQUATIONS
(NO PROJECT-LEVEL CONTROLS)

	Dependent Variable = L EMPLOYMENT 98 N= 71 observations, excludes "mills"	
	(6-1) VC STOCK only	**(6-2)** Combination Model
BASELINE	**0.324**	**0.339**
EMPLOYMENT	**(0.010)**	**(0.103)**
L 1992 VC	**0.334**	**0.380**
FUNDING STOCK	**(0.174)**	**(0.182)**
L SCIENCE STOCK		0.128
		(0.183)
L SIC-LEVEL R&D		-0.065
EXPENDITURES		(0.236)
L SIC SALES		0.421
		(0.344)
Constant	0.377	-5.252
	(1.279)	(4.523)
R-Squared	0.217	0.244
Adjusted R-Squared	0.182	0.160

NOTE: Standard errors are in parentheses, and coefficients significant at 5 percent level and 10 percent are set in bold and italic, respectively.

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