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# Assessing the contribution of venture capital to innovation

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*We examine the influence of venture capital on patented inventions in the United States across twenty industries over three decades. We address concerns about causality in several ways, including exploiting a 1979 policy shift that spurred venture capital fundraising. We find that increases in venture capital activity in an industry are associated with significantly higher patenting rates. While the ratio of venture capital to R&D averaged less than 3% from 1983–1992, our estimates suggest that venture capital may have accounted for 8% of industrial innovations in that period.*

## 1. Introduction

■ Governments around the globe have been eager to duplicate the success of the fast-growing U.S. venture capital industry. These efforts share a common rationale: that venture capital has spurred innovation in the United States, and can do so elsewhere (see, for instance, European Commission (1995)).

The purported relationship between venture capital and innovation, however, has not been systematically scrutinized. We address this omission by exploring the experience of twenty industries covering the U.S. manufacturing sector over a three-decade period. We first examine in reduced-form regressions whether, controlling for R&D spending, venture capital funding has an impact on the number of patented innovations. We find that venture capital is associated with a substantial increase in patenting. The results are robust to a variety of specifications of how venture capital and R&D affect patenting and to different definitions of venture capital.

We then consider the limitations of this approach. We present a stylized model of the relationship between venture capital, R&D, and innovation. This model suggests

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that simple reduced-form regressions may overstate the effect of venture funding. Both venture funding and patenting could be positively related to a third unobserved factor, the arrival of technological opportunities.

We address this concern in two ways. First, we exploit the major recent event in the venture capital industry. In 1979, the U.S. Department of Labor clarified the Employee Retirement Income Security Act, a policy shift that freed pensions to invest in venture capital. This shift led to a sharp increase in the funds committed to venture capital. This type of exogenous change should identify the role of venture capital, because it is unlikely to be related to the arrival of entrepreneurial opportunities. We exploit this shift in instrumental-variable regressions. Second, we use R&D expenditures to control for the arrival of technological opportunities that are anticipated by economic actors at the time, but that are unobserved to us as econometricians. In the framework of our model, we show that the causality problem disappears if we estimate the impact of venture capital on the patent-R&D ratio, rather than on patenting itself.

Even after addressing these causality concerns, the results suggest that venture funding does have a strong positive impact on innovation. The estimated parameter varies according to the techniques we employ, but focusing on a conservative middle ground, a dollar of venture capital appears to be about three times more potent in stimulating patenting than a dollar of traditional corporate R&D. Our estimates therefore suggest that venture capital, even though it averaged less than 3% of corporate R&D from 1983 to 1992, is responsible for a much greater share—about 8%—of U.S. industrial innovations in this decade.

One natural concern is that changes in the legal environment may be confounding our results. In earlier work (1998), we have highlighted how the creation of a centralized appellate court for patent cases in 1982 nearly coincided with an increase in the rate of U.S. patent applications. To address this concern, we employ in all regressions dummy variables for each year, which should control for changes in either the propensity to file for patents or for these applications to be granted. Year effects control for changes in the overall legal environment unless the 1982 policy shift boosted patenting disproportionately in particular industries, which does not appear to have been the case (Kortum and Lerner, 1998).

The final section of the article addresses concerns about the relationship between the dependent variable in our analyses (patents) and what we really wish to measure (innovations). Venture capital may spur patenting while having no impact on innovation if venture-backed firms simply patent more of their innovations to impress potential investors or to avoid expropriation of their ideas by these investors. To investigate this possibility, we compare indicators of the quality of patents between 122 venture-backed and 408 non-venture-backed companies based in Middlesex County, Massachusetts. Venture-backed firms' patents are more frequently cited by other patents and are more aggressively litigated: venture backing does not appear to lead to lower-quality patents. Furthermore, the venture-backed firms are more frequent litigators of trade secrets, which suggests that they are not simply patenting more in lieu of relying on trade secret protection.

It is important to acknowledge the limits of our analysis. We have followed a somewhat crude "production function" approach to assess the contribution of venture capital. In so doing, we face many of the fundamental issues raised by Griliches (1979) in his critique of attempts to assess the contribution of R&D to productivity. Due to the lack of previous research in this arena, our article should be seen as a first cut at quantifying venture capital's impact on innovation. We hope that it will stimulate additional investigations of the relationship between the institutions through which innovative activities are financed and the rate and direction of technological change.[1]

The plan of the article is as follows. Section 2 provides an overview of the U.S. venture capital industry.[2] Section 3 presents the data and a set of reduced-form regressions. In Section 4 we build a simple model of venture capital, R&D, and innovation, in light of which we refine our estimates of the potency of venture capital. We address concerns about patenting as a measure of innovation in Section 5. The final section concludes.

## 2. Venture capital and the financing of young firms

▩ Venture capital—defined as equity or equity-linked investments in young, privately held companies, where the investor is a financial intermediary who is typically active as a director, an advisor, or even a manager of the firm—dates back to the formation of American Research and Development in 1946. A handful of other venture funds were established in subsequent decades. The flow of money into new venture funds between 1946 and 1977 never exceeded a few hundred million dollars annually and usually was much less.

As Figure 1 demonstrates, funds flowing into the venture capital industry increased dramatically during the late 1970s and early 1980s. An important factor behind this increase was the 1979 amendment to the "prudent man" rule governing pension fund investments. Prior to 1979, the Employee Retirement Income Security Act (ERISA) limited pension funds from investing substantial amounts of money into venture capital or other high-risk asset classes. The Department of Labor's clarification of the rule explicitly allowed pension managers to invest in high-risk assets, including venture capital.[3] The fundraising patterns are mirrored in the investments by venture capitalists into young firms, also depicted in Figure 1. In the second half of the 1990s, there was another leap in venture capital activity, which emerged as the dominant form of equity financing in the United States for privately held high-technology businesses.

## 3. Reduced-form regressions

▩ We begin our empirical analysis by investigating whether, conditional on R&D spending, venture capital funding influences innovation. After describing the dataset, we estimate and report on patent production functions in the next two subsections. In undertaking this analysis, we will employ many of the conventions of the literature on "innovation production functions" reviewed in Griliches (1990).[4] In the last subsection, we estimate a simpler linear specification that we will return to later in the article. Throughout Section 3, we treat venture financing as exogenous, deferring the discussion of its determinants until the next section.

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[1] In addition to the literature on the contribution of R&D to productivity (Griliches, 1979) and on the relationship between R&D and patenting (reviewed in Griliches, 1990), our article also relates to the empirical literature on the relationship between cash flow and R&D expenditures at the firm level (e.g., Bernstein and Nadiri, 1986, Himmelberg and Petersen, 1994). But as far as we are aware there is only one other study examining the relationship between innovation and the presence of particular financial institutions. Hellmann and Puri (1998) compare the survey responses of 170 venture-backed and non-venture-backed firms.

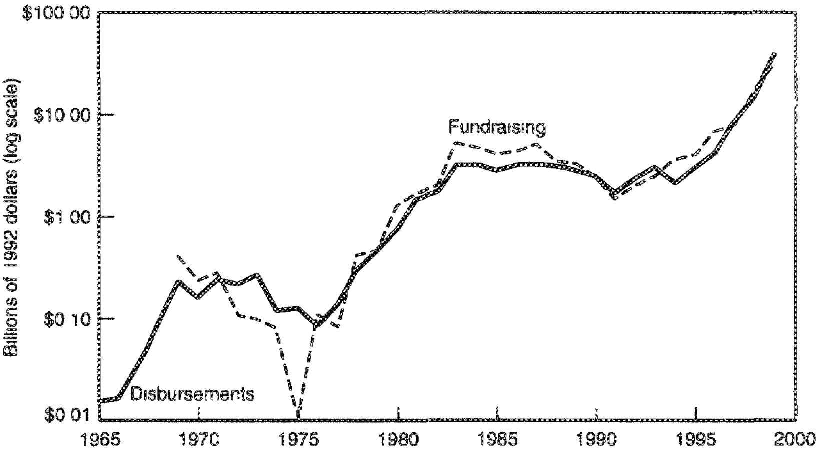
[2] This section is based in part on Gompers and Lerner (1998, 1999).

[3] In 1978, when $424 million was invested in new venture capital funds, individuals accounted for the largest share (32%). Pension funds supplied just 15%. Eight years later, when more than $4 billion was invested, pension funds accounted for more than half of all contributions.

[4] As in this literature, we initially ignore the impact of such factors as the uncertainty about technological success on the propensity to patent innovations. In Section 5 we show that the results are robust to the use of alternative measures that at least partially address these problems.

FIGURE 1

VENTURE CAPITAL FUNDRAISING AND DISBURSEMENTS, 1965–1999



Note: Data on venture capital fundraising are not available prior to 1969. No capital was raised by venture funds in 1975.

□ **The dataset.** We analyze annual data for twenty manufacturing industries between 1965 and 1992. The dependent variable is U.S. patents issued to U.S. inventors by industry and date of application. Our main explanatory variables are measures of venture funding collected by Venture Economics and industrial R&D expenditures collected by the U.S. National Science Foundation (NSF).

Before discussing the use of this data, we should acknowledge two challenges that these measures pose. First, our dependent variable is problematic. Since the U.S. Patent and Trademark Office (USPTO) does not compile patent statistics by industry and many firms have multiple lines of business, patenting in each industry can be only be indirectly inferred. We rely on a concordance that relates a patent's industry to the primary technological classification to which it is assigned by the patent examiner.[5]

Second, while we distinguish conceptually between R&D financed by corporations and R&D financed by venture capital organizations, the data do not allow a clean division. The industrial R&D data that we use, while based on a survey that overlooks the activities of many smaller firms, undoubtedly includes some research financed by venture capital organizations. Similarly, while the bulk of venture financing supports innovative activities at technology-intensive firms, some is used for other purposes. For instance, some of the venture financing goes to low-technology concerns or is devoted to marketing activities. It should be noted that by leaving some venture funding in our measure of corporate R&D, it is less likely that we will find an impact of venture capital on patenting conditional on the R&D measure.

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[5] This concordance relies on industry assignments of patents issued by Canada (the majority of which are issued to U.S. inventors) to determine the likelihood of a particular industry assignment given a patent's technological classification (Kortum and Putnam, 1997). Industry counts for the United States are based on the International Patent Classification assigned to each patent issued by the USPTO. The patent counts differ depending on whether the assigned industry corresponds to the user or the manufacturer of the patented invention. We focus on the industry of use series, but our results about the impact of venture capital are robust to replacing industry of use with industry of manufacture. In either case, the industry assignment of patents may not correspond precisely to the industry doing the R&D or receiving the venture capital funding that led to the underlying invention.

Venture funding and patents are then aggregated into essentially the industry scheme used by the NSF in tabulating its survey of industrial R&D. We consolidate a few NSF industries that account for little R&D.[6] The data are described in detail in the supplement to this article (available at http://www.rje.org/main/sup-mat.html).

Table 1 summarizes the main data series. The table highlights the rapid growth of the venture capital industry. The ratio of venture capital to R&D jumped sharply in the late 1970s and early 1980s, and fell a bit thereafter. Patenting declined from the early 1970s to the mid-1980s, but then rose sharply.[7] It should be noted that disbursements are concentrated in certain industries. The top three industries—drugs, office and computing, and communication equipment—represent 54% of the venture disbursements. The comparable figure for R&D expenditures is 39%.

☐ **The patent production function.** We estimate a patent production function of the form $P_{it} = (R^{\rho}_{it} + bV^{\rho}_{it})^{\alpha/\rho}u_{it}$. Patenting ($P$) is a function of privately funded industrial R&D ($R$) and venture disbursements ($V$), while an error term ($u$) captures shifts in the propensity to patent or technological opportunities, all indexed by industry ($i$) and year ($t$). We focus on the parameter $b$, which captures the role of venture capital in the patent production function. For any $b > 0$, venture funding matters for innovation, while if $b$ equals zero, the patent production function reduces to the standard form, $P_{it} = R^{\alpha}_{it}u_{it}$. The parameter $\alpha$ captures returns to scale, i.e., the percentage change in patenting brought about by a 1% increase in both $R$ and $V$. The parameter $\rho$ measures the degree of substitutability between $R$ and $V$ as means of financing innovative effort. When $\rho$ equals one, the function reduces to $P_{it} = (R_{it} + bV_{it})^{\alpha}u_{it}$. As $\rho$ goes to zero, the patent production function approaches the Cobb-Douglas functional form, $P_{it} = R^{\alpha/(1+b)}_{it}V^{\alpha b/(1+b)}_{it}u_{it}$.

☐ **Estimates.** Nonlinear least-squares estimates of the patent production function are shown in Table 2. The dependent variable is the logarithm of the number of (ultimately successful) patent applications filed by U.S. inventors in each industry and year. The two independent variables of interest are privately financed R&D in that industry and year and either the dollar volume of venture disbursements or the number of firms in the industry receiving venture backing.[8] We use as controls the logarithm of the federally funded R&D in the industry, as well as dummy variables for each industry (to control for differences in the propensity to patent) and year.

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[6] We focus on the manufacturing industries, since survey evidence (summarized in Cohen (1995)) suggests that the reliance on patenting as a means of appropriating new technological discoveries is much higher in these industries (as opposed to, for instance, trade secrecy or first-mover advantages). Patenting is thus likely to be a better indicator of the rate of technological innovation in the manufacturing sector. The time period is determined on one end by the availability of data on venture capital investment and on the other end by our inability to observe the detailed technological classifications of U.S. patent applications before they are issued (applications are held confidential until issue).

[7] A natural concern is the extent of correlation between the venture capital and private R&D measures. While the two variables are positively correlated, the extent of correlation is less than the aggregate numbers in Table 1 might lead one to believe. In particular, the correlation coefficient between the logarithms of the dollar volume of venture financings and private R&D in each industry is .43. The partial correlation, once the year and industry are controlled for, is .31. The correlation between the number of companies receiving venture financing and private R&D is even lower.

[8] The parameter $b$ is generally not invariant to the units in which venture activity is measured. To facilitate comparisons across regressions, we scale our measure of the number of companies funded by venture capitalists to have the same overall mean as the dollar disbursements measure (in 1992 dollars). For both measures of venture finance, we add a minuscule amount (the equivalent of $1,000) to each observation so that we can consider the Cobb-Douglas limiting case in which the log of venture funding is what matters.

**TABLE 1** **Patenting Activity of, R&D Expenditures by, and Venture Capital Disbursements for U.S. Manufacturing Industries, by Year**

| Year | Number of Patent Applications | R&D Expenditures ($M) | Venture Capital Disbursements: Number of Firms | Venture Capital Disbursements: Amount ($M) | Ratio of Venture Capital to R&D: All VC | Ratio of Venture Capital to R&D: Early-Stage Only |
|---|---|---|---|---|---|---|
| 1965 | 50,278 | 25,313 | 8 | 13 | .05% | .02% |
| 1966 | 48.740 | 27,573 | 3 | 2 | .01% | .00% |
| 1967 | 48,900 | 29,515 | 9 | 24 | .08% | .07% |
| 1968 | 49.980 | 31,387 | 25 | 37 | .12% | .08% |
| 1969 | 51,614 | 33,244 | 66 | 149 | .45% | .38% |
| 1970 | 53,950 | 32,883 | 63 | 126 | .38% | .24% |
| 1971 | 54,776 | 32,360 | 57 | 224 | .69% | .41% |
| 1972 | 49.777 | 33,593 | 52 | 209 | .62% | .44% |
| 1973 | 45,807 | 36,169 | 74 | 235 | .65% | .30% |
| 1974 | 44,465 | 37,323 | 42 | 81 | .22% | .13% |
| 1975 | 44,082 | 35,935 | 41 | 118 | .33% | .24% |
| 1976 | 44,026 | 38,056 | 47 | 83 | .22% | .10% |
| 1977 | 41.550 | 39,605 | 57 | 138 | .35% | .21% |
| 1978 | 42,648 | 42,373 | 116 | 255 | .60% | .37% |
| 1979 | 44,941 | 45,318 | 152 | 301 | .66% | .28% |
| 1980 | 41,726 | 48,700 | 231 | 635 | 1.30% | .80% |
| 1981 | 39,137 | 52,012 | 408 | 1,146 | 2.20% | 1.39% |
| 1982 | 38.039 | 55,033 | 466 | 1,388 | 2.52% | 1.29% |
| 1983 | 34,712 | 58,066 | 656 | 2,391 | 4.12% | 1.97% |
| 1984 | 33,905 | 63,441 | 709 | 2,347 | 3.70% | 1.95% |
| 1985 | 36.732 | 66,860 | 646 | 1,951 | 2.92% | 1.42% |
| 1986 | 41,644 | 68,476 | 639 | 2,211 | 3.23% | 1.62% |
| 1987 | 46,434 | 67,700 | 713 | 2,191 | 3.24% | 1.57% |
| 1988 | 51,355 | 69,008 | 660 | 2,076 | 3.01% | 1.54% |
| 1989 | 55.103 | 70,456 | 669 | 1,995 | 2.83% | 1.56% |
| 1990 | 58.358 | 69,714 | 557 | 1,675 | 2.40% | 1.11% |
| 1991 | 58.924 | 69,516 | 422 | 1,026 | 1.48% | .71% |
| 1992 | 60,771 | 70,825 | 469 | 1,571 | 2.22% | 1.05% |

Notes: Patent applications refer to the number of ultimately successful patent applications filed in each year. All dollar figures are in millions of 1992 dollars. The ratios of venture capital disbursements to R&D expenditures are computed using all venture capital disbursements and early-stage venture disbursements only.

The results suggest that venture funding matters. The magnitude of $b$ estimated in the unconstrained equation is substantial, in fact implausibly large, an issue we will return to below. Although the estimates are imprecise, a likelihood ratio test overwhelmingly rejects the special case of $b$ equal to zero (with a $p$-value of less than .005).

**TABLE 2** **Nonlinear Least-squares Regression Analysis of the Patent Production Function**

| | Using Firms Receiving Venture Backing | | Using Venture Disbursements | |
|---|---|---|---|---|
| | Unconstrained | Constrained ($\rho = 1$) | Unconstrained | Constrained ($\rho = 1$) |
| Returns to scale parameter ($\alpha$) | .22<br>(.02) | .23<br>(.02) | .20<br>(.02) | .20<br>(.02) |
| Venture capital parameter ($b$) | | | | |
| Firms receiving funding | 58.51<br>(67.31) | 39.57<br>(10.97) | | |
| Venture disbursements | | | 58.71<br>(77.52) | 46.94<br>(13.66) |
| Substitution parameter ($\rho$) | 1.08<br>(.24) | 1.00<br>— | 1.04<br>(.26) | 1.00<br>— |
| Federally funded industrial R&D | .01<br>(.01) | .01<br>(.01) | .01<br>(.01) | .01<br>(.01) |
| $R^2$ | .99 | .99 | .99 | .99 |
| $R^2$ relative to dummy variable only case | .26 | .26 | .27 | .27 |
| Number of observations | 560 | 560 | 560 | 560 |
| Likelihood ratio statistic | | .2 | | 0 |
| $p$-values, likelihood ratio test | | .65 | | .99 |

Notes: Standard errors are in parentheses. The dependent variable is the logarithm of the number of patents. Year and industry dummy variables are included in each regression.

We also find that R&D and venture capital are highly substitutable, with the point estimate of $\rho$ close to one. A likelihood ratio test does not come close to rejecting the restriction that $\rho = 1$. On the other hand, $\rho = 0$ (the Cobb-Douglas special case) is strongly rejected (with a $p$-value of less than .005). As a consequence, in the remainder of the article we focus on the restricted equation, $\ln P_{it} = \alpha \ln(R_{it} + bV_{it}) + \ln u_{it}$, in which R&D and venture funding are perfect substitutes. In the restricted equation, $b$ has the interpretation of the potency of a dollar of venture funding relative to a dollar of R&D (this interpretation of $b$ holds for either measure of venture funding, as discussed in footnote 8).

The results for the restricted equation are shown in the second and fourth columns of Table 2. Together, variation in R&D and venture funding explain over one-fourth of the variation in the logarithm of patenting not captured by industry or time effects.[9] The returns-to-scale parameter $\alpha$ is about one-fourth, small but not implausible. What does strain credibility, however, are the point estimates of $b$ in the two regressions, implying as they do that venture funds are about 40 times as potent as R&D. Below we explore a number of reasons why these estimates might be biased upward.

❑ **A linear specification.** Before turning to the more difficult issues arising from the endogeneity of venture funding (which we address in Section 4), we first consider

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[9] In all of the regression tables we present two measures of the goodness of fit: the overall $R^2$ and the $R^2$ when compared against a regression with just year and industry dummies. The latter is computed as $(\text{SSR}_{\text{dummy only}} - \text{SSR}_{\text{new regression}})/\text{SSR}_{\text{dummy only}}$, where SSR refers to the sum of squared residuals of the various regressions.

estimating $b$ through a linear approximation of the patent production function (again with $\rho = 1$). Such an approximation is valid when venture funding is small relative to R&D. The linear specification has the advantage of simplicity. It is also inherently conservative in its empirical implications for the potency of venture capital. It interprets the observed average impact of $V/R$ on patenting as the maximum marginal impact (i.e., the marginal impact as $V/R$ approaches zero). Since our task is to evaluate the null hypothesis that venture capital is impotent, we find this inherent conservatism reassuring.

After linearizing the equation, we get $\ln P_{it} = \alpha \ln R_{it} + \alpha b(V_{it}/R_{it}) + \ln u_{it}$. This approximation is analogous to that employed by Griliches (1986) in his analysis of the impact of basic research, which like venture capital represented a small fraction of total R&D expenditures, on productivity growth. Note that in this equation, the potency of venture funding is calculated by dividing the coefficient on $V/R$ by the coefficient on $\ln R$. Table 3 presents regressions employing the linear specification. The basic equations are in the first two columns. Consider the second regression, which estimates the coefficient on venture capital as 1.73. Because this is an estimate for the product of $\alpha$ and $b$, we must divide by our estimate of $\alpha$, .24, to obtain the implied potency of venture funding, $b = 7.26$. The implied estimates of potency and the associated standard errors (calculated using the delta method) are shown in the last two rows. In both regressions, the estimate of potency is significantly positive.[10] The estimates suggest that a dollar of venture capital is over seven times more powerful in stimulating patenting than a dollar of corporate R&D. Although these estimates are large, note that they are substantially more modest than the estimates of $b$ from the nonlinear regressions.

These linear results appear to be quite robust. We have explored changing the specification,[11] the measures of venture capital,[12] and the sample,[13] adding additional controls,[14] and using lags of the explanatory variables.[15]

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[10] Our error term consists of shocks to the propensity to patent and technological opportunities, which are likely to be persistent over time. To avoid inflating the statistical significance of the results, we calculate the standard errors using the autocorrelation-consistent covariance estimator of Newey and West (1987), with a maximum lag of three years.

[11] If the errors in the patent production function follow a random walk, then the equation should be estimated in differences rather than in levels. The difference regressions are shown in the last two columns of Table 3. To reduce the errors-in variables problem, which tends to be magnified in a first-difference approach (Griliches and Hausman, 1986), we compute averages of the logarithm of each variable over a four-year period. We then compute the change in the industry measures at eight-year intervals. Since we difference out the industry effects, we drop industry dummies from these regressions but maintain a set of period dummies (not shown). The results of the long-difference regressions are very similar to those of the levels regressions except that the precision of the estimates declines.

[12] It might be thought that the financing of startups and very young companies would pose the greatest information problems, and that the contributions of the venture capitalists would be most valuable here. In regressions reported in the supplement, we replace the venture funding measures with the count and dollar volume of only seed and early-stage financings. The estimated potency of a dollar of venture funding increases by 45% to 80%.

[13] Our analysis may be distorted by the inclusion of numerous industries with very little innovative activity. In the supplement, we report regressions in which we drop industries whose R&D-to-sales ratio was below the median in 1964, the year before the beginning of the analysis. Once again, there is an increase in the estimated potency of venture funding relative to our baseline regressions.

[14] In unreported regressions, we also control for the logarithms of gross industry product or of industry employment. The effect of adding these controls is to reduce the coefficient on the logarithm of R&D, $\alpha$ (although it remains significantly positive). Both the magnitude and significance of the coefficient on $V/R$ are essentially unchanged by the addition of either control.

[15] Another robustness check concerns possible lags between R&D spending, venture financing, and patenting. The empirical literature suggests that R&D spending and patent filings are roughly contempora-

**TABLE 3** **Ordinary Least-squares Regression Analysis of the Linear Patent Production Function**

| | Levels with Year and Industry Effects | | Long Differences with Period Effects | |
|---|---|---|---|---|
| Privately funded industrial R&D ($a$) | .25<br>(.06) | .24<br>(.06) | .24<br>(.07) | .22<br>(.07) |
| Venture capital/privately funded R&D ($ab$): | | | | |
| Firms receiving funding | 2.13<br>(.63) | | 2.42<br>(1.21) | |
| Venture disbursements | | 1.73<br>(.69) | | 2.29<br>(1.04) |
| Federally funded industrial R&D | .01<br>(.01) | .01<br>(.01) | .03<br>(.02) | .02<br>(.02) |
| $R^2$ | .99 | .99 | .81 | .82 |
| $R^2$ relative to dummy variable only case | .21 | .20 | .24 | .25 |
| Number of observations | 560 | 560 | 60 | 60 |
| Implied potency of venture funding ($b$) | 8.49<br>(2.62) | 7.26<br>(3.16) | 9.98<br>(5.82) | 10.39<br>(6.21) |

Notes: Standard errors are in parentheses. For the levels specifications they are based on the Newey-West autocorrelation-consistent covariance estimator (with a maximum of three lags). The standard errors for the parameter $b$ are calculated using the delta method.

## 4. Addressing the causality problem

▩ The empirical results in Section 3 suggest that there is a strong association between venture capital and patenting and that corporate R&D and venture funding are highly substitutable in generating innovations. The mechanisms behind this relationship and the extent to which our estimates of the impact of venture funding may be inflated by unobserved factors, however, are not addressed by our reduced-form regressions.

To explore these issues, we build a theoretical model of venture capital, corporate research, and innovation. We then use the model to illustrate under what conditions the approach of Section 3 is appropriate and when it may be problematic. The final two subsections present refinements of our empirical approach, motivated by the model. We do not seek to determine which single empirical specification is the best representation of the impact of venture capital on innovation. Rather, we seek to demonstrate the robustness of the results in Section 3 by showing that they hold up across a variety of specifications.

☐ **Modelling the relationship.** We consider an industry in which inventions can be pursued through either corporate R&D funding or venture capital. We make four major

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neous (Hall, Griliches, and Hausman, 1986). Furthermore, there is an institutional reason why there should not be long lags between venture capital and patenting: the ten-year life spans of venture partnerships lead to pressure on companies to commercialize products quickly after obtaining venture financing. Nevertheless, to explore this issue empirically, in unreported regressions we repeat the analyses in Table 3, including one-year and two-year lagged values of the R&D and venture capital variables along with the contemporaneous variables. We find that the contemporaneous variables have the bulk of the explanatory power (and their coefficients are significantly positive), while the lagged variables have coefficients that are smaller (and insignificantly different from zero).

assumptions. First, we assume that the production function for innovations $I$ in each industry $i$ and time period $t$ is essentially the one we settled upon empirically:

$$I_{it} = (R_{it} + bV_{it})^{\alpha} N_{it} = H_{it}^{\alpha} N_{it}, \tag{1}$$

where $0 < \alpha < 1$ and, for expositional ease, total innovative effort is denoted by $H_{it}$. The final term $N_{it}$ represents a shock to the invention production function, which we interpret as the exogenous arrival of innovative opportunities.

Second, we assume that innovations, on average, translate into patents in a proportional manner. Thus $P_{it} = I_{it}\epsilon_{it}$, where $P_{it}$ is the number of patented innovations generated in a particular industry and year and $\epsilon$ is an independent shock determining the propensity to patent innovations. Combining this equation with (1), we obtain

$$P_{it} = H_{it}^{\alpha} N_{it} \epsilon_{it}. \tag{2}$$

The unobserved factor driving patenting is thus $N\epsilon$, the product of technological opportunities and the propensity to patent.

Third, we assume that the expected value of a new innovation for a given time period and industry is $\Pi_{it}$. We take a simple partial equilibrium approach and do not model the determinants of $\Pi$, although we have in mind that it evolves with the size of the market, as in Schmookler (1966). We assume that individual firms are small relative to the industry, and therefore we take $\Pi$ as given. The expected value of a new invention incorporates the fact that some, but not all, innovations will be worth patenting.

Finally, we make assumptions about the marginal costs of innovating that deserve discussion at greater length. In addition to the direct expenditures on R&D and venture disbursements, we assume that there are associated indirect expenses. These might include the cost of screening opportunities, recruiting managers and researchers, and undertaking the crucial regulatory approvals to sell the new product. We argue that at each point of time, there is likely to be a spectrum of projects: some will be very appropriate for a corporate research laboratory, while others will be more suited for funding by a venture capitalist in an entrepreneurial setting. Raising venture activity as a fraction of total innovative effort pushes venture capitalists into areas farther from their comparative advantage, raising their costs, while corporate researchers are able to specialize in areas they have the greatest advantage in exploiting.

More specifically, we assume that given total research effort $H$, and venture financing $V$, the venture capitalist's cost of managing the last venture-backed project is $v_t f_V(V_{it}/\lambda_{it}H_{it})$, while the corporation's cost of managing the last corporate-backed project is $f_R(V_{it}/\lambda_{it}H_{it})$. We assume that the venture capitalist's function $f_V$ is strictly increasing while the corporation's $f_R$ is strictly decreasing in $V/\lambda H$. The term $\lambda_{it}$ governs the extent to which opportunities are conductive to venture finance. We interpret a rise in $\lambda$ to mean that technological opportunities have become more radical in nature, a shift that should lower the management costs of pursuing such projects in an entrepreneurial rather than a corporate setting. The $v_t$ term represents the venture capitalist's cost of funds, which we enter explicitly to enable us to consider the impact of the 1979 clarification of the prudent man rule (a fall in $v$).

From this set of assumptions, we derive several equilibrium conditions. The equilibrium level of venture capital and corporate R&D will equate the marginal cost of additional spending to the marginal benefit. Assuming that we are not at a corner solution where $V$ or $R$ is equal to zero,[16] the conditions are

$$\Pi_{it}\frac{\partial I_{it}}{\partial V_{it}} = \alpha\Pi_{it}N_{it}bH_{it}^{\alpha-1} = v_t f_V\left(\frac{V_{it}}{\lambda_{it}H_{it}}\right) \tag{3}$$

$$\Pi_{it}\frac{\partial I_{it}}{\partial R_{it}} = \alpha\Pi_{it}N_{it}H_{it}^{\alpha-1} = f_R\left(\frac{V_{it}}{\lambda_{it}H_{it}}\right). \tag{4}$$

Through a series of mathematical manipulations,[17] we obtain the expressions

$$H_{it} = \left[\frac{\alpha\Pi_{it}N_{it}}{g_1(v_t)}\right]^{1/(1-\alpha)} \tag{5}$$

$$\frac{V_{it}}{R_{it}} = \lambda_{it}\left[\frac{g_2(v_t)}{1 - b\lambda_{it}g_2(v_t)}\right], \tag{6}$$

where $g_1$ is an increasing function and $g_2$ a decreasing one. According to (5), total innovative effort is decreasing in the cost of venture funds, $v$, but stimulated by positive shocks to either the value of inventions or the arrival of technological opportunities. Venture funding relative to corporate R&D, (6), is increasing in the degree to which the opportunities are radical in nature, $\lambda$, and decreasing in the cost of venture funds.

A positive shock to $\lambda$ favors venture capital relative to corporate R&D, while a jump in $N$ not only stimulates both forms of finance but also leads to a jump in patenting conditional on the amount of innovative effort. Complicating matters, we suspect that the two shocks, $\lambda$ and $N$, will be positively correlated. A burst of innovative opportunities will often be associated with a radical shift in the technology, a shift that small venture-financed entrepreneurs rather than large corporations will be better able to exploit. It is this potential correlation between a shock to the patent equation and a shock that favors venture finance that leads us to be skeptical of our reduced-form regression results.

☐ **Implications for the estimation.** This set of equations allows us to illustrate the issues that we face in estimating the linear form of the patent production function,

$$\ln P_{it} = \alpha \ln R_{it} + \alpha b(V_{it}/R_{it}) + \ln N_{it} + \ln \epsilon_{it}, \tag{7}$$

with industry dummies, year dummies, and federally funded R&D included as controls. If technological opportunities, $N$, are totally captured by our controls, our estimates in Tables 2 and 3 should be valid. Variation in $\Pi_{it}$, according to (5), will lead to variation

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[16] An attractive feature of the model is that it can also address the empirically relevant case of $V = 0$. In that case, $\alpha\Pi_{it}N_{it}bR_{it}^{\alpha-1} \leq v_t f_V(0)$, where $R_{it} = \{\alpha\Pi_{it}N_{it}/[f_R(0)]\}^{1/(1-\alpha)}$.

[17] Specific steps were to (i) define $x \equiv \alpha\Pi_{it}N_{it}H_{it}^{\alpha-1}$, (ii) combine (3) and (4) to get

$$b/v = (1/x)f_V(f_R^{-1}(x)) \equiv h(x),$$

where $h(x)$ is a strictly decreasing function, (iii) solve for $x = h^{-1}(b/v) \equiv g_1(v)$, (iv) plug into (4) to get $V/H = \lambda f_R^{-1}(g_1(v)) \equiv \lambda g_2(v)$, (v) use $x \equiv g_1(v)$ to solve for $H$, and (vi), recalling that $H = R + bV$, solve for $V/R$.

in $H$ and hence $R$, which identifies $\alpha$. Variation in the cost of funds to venture capitalists, $v_t$, interacted with differences across industries in $\lambda$, will cause variation in $V/R$, which identifies $b$.

The more likely scenario, however, is one in which variation in technological opportunities is only partially explained by the controls. In that case, variations in $H$, and hence $R$, will be correlated with the disturbance. Similarly, variations in $V/R$ will also be correlated with the disturbance (if $\lambda$ and $N$ are in fact correlated). Simply regressing patents on R&D and venture funding could yield biased estimates of both $\alpha$ and $b$ and will probably overstate the potency of venture capital.

We consider two approaches to get around potential biases in our estimates of the potency of venture funding. First, we attempt to find good instruments. Our instrument for venture funding relative to corporate R&D relies on the U.S. Department of Labor's 1979 clarification of the "prudent man" rule (discussed in Section 2). We argue that this clarification lowered the cost of funds to venture capitalists, much like a drop in $v_t$ in our model. We propose an instrument based on the interaction of this 1979 change with the historical differences across industries in venture funding relative to corporate R&D.[18]

Our second approach is to use R&D to control for the unobservable term $N$, which is the source of our identification problems when estimating the patent production function. The basic idea is similar to Olley and Pakes (1996) and more recently to Levinsohn and Petrin (2000), who respectively use capital investment and purchased materials to control for unobservables in a standard production function. Combining (2) and (5), while noting that $R_{it} = H_{it}/(1 + bV_{it}/R_{it})$, we can solve for the patent-R&D ratio,

$$\frac{P_{it}}{R_{it}} = \left[\frac{\alpha \Pi_{it}}{g_1(v_t)}\right]^{-1} \left(1 + b\frac{V_{it}}{R_{it}}\right)\epsilon_{it}. \tag{8}$$

The striking feature of (8) is that normalizing patents by R&D eliminates technological opportunities $N$ from the right side of the equation. We no longer identify $\alpha$ (which was not essential in any case), but we can now estimate the potency of venture funding $b$ without worrying (subject to some caveats in how we treat $\Pi$) about correlation between $V/R$ and the disturbance in the equation.

□ **Instrumental-variables estimation.** We now turn to a more complete discussion of our instrument choice and to the results we obtain using instrumental-variables (IV) techniques to estimate (7). We start with our instrument for $V/R$. It is based on the Department of Labor's clarification of a rule that, prior to 1979, limited the ability of pension funds to invest in venture capital. One might first think of capturing this shift empirically through a dummy variable taking on the value of zero through 1979 and one thereafter. The problem with this simple approach is that patenting rates across all industries may change over time for a variety of reasons, including swings in the judicial enforcement of patentholder rights and antitrust policy. We are unlikely to be able to disentangle the shift in venture fundraising from that in the propensity to patent. As Table 1 makes clear, the filing of successful patent applications actually fell in the

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[18] This approach also faces another challenge, which we explore in depth below. Even if our instrument for $V/R$ is convincing, we are still faced with the endogeneity of total innovative effort. To address this issue, we consider demand-side instruments that are correlated with the value of inventions, $\Pi_{it}$, but potentially unrelated to technological opportunities.

years after 1979. But this was also a period during which the ability of firms to enforce intellectual property rights was under attack (Kortum and Lerner, 1998).

The 1979 policy shift, however, should have had a predictably greater impact on patenting in some industries than others. Industries with a high level of venture capital before the policy change should have experienced a greater increase in funding and, thus, a greater burst in patenting. Thus, in certain circumstances, we can use the level of venture financing before the shift, interacted with a dummy variable taking on the value zero through 1979 and one thereafter, as an instrumental variable.[19]

We can motivate the proposed instrument more formally by returning to the model. From (6) we see that the impact on $V_{it}/R_{it}$ of a change in $v_t$ (we argue above that $v$ declined dramatically in the late 1970s) is increasing in $V_{it}/R_{it}$ itself. In particular, the derivative of $V/R$ with respect to a change in $v$ in 1979 is $D_i = (-g_2'/g_2)(V_{i79}/R_{i79})(1 + bV_{i79}/R_{i79})$. Historically, differences between industries in venture funding relative to R&D have been highly persistent over time. Hence the industry-specific average of $V/R$ from 1965 through 1978, denoted $A_i$, should be highly correlated with $D_i$. To exploit this result, we propose an instrument that takes on the value of zero up through 1979 (before the effect of the policy shift is seen) but in each year after 1979, and for each industry $i$, takes on the value $A_i$.[20]

The validity of the instrument, however, requires that $\lambda_{it}$ not deviate for too long from its industry-specific mean. To ensure this property, we assume that $\ln \lambda_{it}$ can be decomposed into the sum of a permanent industry component $\lambda_i$ (which accounts for the persistent differences between industries in $V/R$) and a transitory component $\omega_{it}$. If the transitory component is independent across time, then from 1980 on it will not be correlated with $A_i$. Under this assumption, our instrument will not be correlated with technological opportunities ($\ln N_{it}$) as they vary from their industry-specific means (industry and year dummies will always be included in the regressions). More generally, if $\omega_{it}$ is a moving average process of order $m$, then the instrument is still valid as long as it is amended by calculating $A_i$ as the industry-specific average of $V/R$ from 1965 only up to $m$ years prior to 1980. We consider this extension in two of the regressions below, for the case of $m = 5$.

As noted above, we must also contend with the endogeneity of R&D expenditures. There is no point in instrumenting for $V/R$ while ignoring the potential correlation between R&D expenditures and the disturbance in the patent equation. The endogeneity problem, however, would be irrelevant if we already knew the value of the parameter $\alpha$. Thus, before undertaking the daunting task of searching for a valid instrument for R&D, we simply fix the parameter $\alpha$ at some preassigned values and instrument for $V/R$.

The results are shown in Panel A of Table 4. Here we have instrumented for $V/R$ in the linear specification of the patent production function, while fixing $\alpha = .2$ or $\alpha = .5$

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[19] The empirical relevance of this instrument is based on the observation that the increase in the ratio of venture capital activity to R&D following the 1979 shift was positively correlated with the level of $V/R$ prior to the shift. A regression of $y_i$ (the industry-specific change in the average ratio of venture capital disbursements to R&D spending between the 1985–1990 period and the 1965–1975 period) on $x_i$ (the average ratio in the 1965–1975 period) yields an $R^2$ of .42. The observed relationship is likely to derive from the inelastic supply of venture capitalists and the industry specialization of individual venture capitalists.

[20] Note that our instrument for $V/R$ is based on an average of the level of venture capital financing, $A_i$, over a number of years. Venture capital disbursements in each industry are "lumpy": a single large later-round financing may account for a substantial fraction of the total financing in a given industry and year. By better capturing the mean level of financing activity in a given industry, the instrument may alleviate errors-in-variables problems, and may even lead to an increase in the coefficient on venture capital.

**TABLE 4** **Instrumental-Variable (IV) Regression Analysis of the Linear Patent Production Function**

**Panel A: IV Regressions, Constraining $\alpha$**

| | IV: 1965–1978 Period<br>$\alpha$ = .20 | | IV: 1965–1978 Period<br>$\alpha$ = .50 | |
|---|---|---|---|---|
| Privately funded industrial R&D ($\alpha$) | .20<br>— | .20<br>— | .50<br>— | .50<br>— |
| Venture capital/privately funded R&D ($\alpha b$) | | | | |
| Firms receiving funding | 3.06<br>(.92) | | 2.51<br>(1.06) | |
| Venture disbursements | | 3.38<br>(1.13) | | 1.72<br>(1.10) |
| Federally funded industrial R&D | .01<br>(.01) | .01<br>(.01) | .02<br>(.01) | .02<br>(.01) |
| $R^2$ | .99 | .98 | .98 | .98 |
| $R^2$ relative to dummy variable only case | .19 | .14 | .07 | .07 |
| Number of observations | 560 | 560 | 560 | 560 |
| Implied potency of venture funding ($b$) | 15.28<br>(4.59) | 16.89<br>(5.63) | 5.02<br>(2.12) | 3.45<br>(2.21) |

**Panel B: IV Regressions, Instrumenting for R&D**

| | IV: 1965–1978 Period and Industry GDP | | IV: 1965–1975 Period and Industry GDP | |
|---|---|---|---|---|
| Privately funded industrial R&D ($\alpha$) | .52<br>(.10) | .48<br>(.12) | .52<br>(.10) | .54<br>(.13) |
| Venture capital/privately funded R&D ($\alpha b$) | | | | |
| Firms receiving funding | 2.48<br>(1.13) | | 2.12<br>(1.14) | |
| Venture disbursements | | 1.81<br>(1.40) | | .13<br>(1.70) |
| Federally funded industrial R&D | .02<br>(.01) | .02<br>(.01) | .02<br>(.01) | .02<br>(.02) |
| $R^2$ | .98 | .98 | .98 | .98 |
| $R^2$ relative to dummy variable only case | .07 | .07 | .05 | −.04 |
| Number of observations | 560 | 560 | 560 | 560 |
| Implied potency of venture funding ($b$) | 4.81<br>(2.67) | 3.74<br>(3.56) | 4.08<br>(2.58) | .25<br>(3.21) |

Notes. Standard errors (in parentheses) are based on the Newey-West autocorrelation-consistent covariance estimator (with a maximum of three lags). The standard errors for the parameter $b$ are calculated using the delta method. Year and industry dummy variables are included in each regression.

(which straddle our estimates from Tables 2 and 3).[21] We still obtain large and statistically significant estimates of the potency of venture funding. The magnitude of the

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[21] All of the instrumental-variable (IV) regressions that we report are based on the linear specification used in Table 3. We also experimented with nonlinear IV estimation based on the specification in the second and fourth regressions in Table 2. A feature of nonlinear IV is ambiguity about which functions of the

estimated parameter, however, is sensitive to the assumed value of $\alpha$. We find that venture capital is about fifteen times as potent as corporate R&D if $\alpha = .2$, but only three to five times as potent as R&D if $\alpha = .5$. In light of our uncertainty about the actual value of $\alpha$, and given its substantial impact on the results, we attempt to instrument for R&D as well as venture capital.

The perfect instrument for R&D would be a measure of shifts in industry demand that affect the value of an invention $\Pi_{it}$, but are unrelated to technological opportunities. Since this ideal instrument is not available, we settle on an instrument that we can measure—the value of the gross industry product $Y_{it}$—which under certain assumptions is the same as the ideal instrument. The value of industry product is almost certainly relevant, since the amount of R&D in an industry will be stimulated by an increase in the size of the market. Its validity as an instrument is less of a sure thing. In particular, the instrument will be valid only if technological opportunities (and the innovations stimulated by those opportunities) do not affect the size of the market.[22]

The regressions reported in Panel B of Table 4 use instruments both for venture funding relative to R&D and for R&D itself. The last two regressions in the panel also apply a modification of the instrument for $V/R$, as suggested above, to allow for the transitory component in entrepreneurial opportunities $\omega_{it}$ to be correlated for up to five years. Using the value of industry product as an instrument for R&D approximately doubles the estimate of $\alpha$. The effect is to lower our estimates of the potency of venture funding, much like in the last two regressions in Panel A (in which $\alpha$ is constrained to be .5). The large increase in $\alpha$ when we instrument for R&D can be understood in two ways. One possibility is that our earlier estimates of $\alpha$ are biased downward (due to errors in our measure of R&D, similar to the problem discussed in footnote 20). A second possibility is that gross industry product is not a valid instrument, because it is positively correlated with technological opportunities. Since we cannot resolve these issues within the context of our IV approach, we pursue instead a very different technique for dealing with the endogeneity of venture funding.[23]

☐ **Controlling for technological opportunities.** Our second approach for dealing with the endogeneity problem is to use R&D to control for unobserved technological opportunities. The basic idea follows from (8): conditional on the ratio of venture capital to R&D and the expected value of an innovation, the patent-R&D ratio does not depend on technological opportunities. Taking logarithms of (8) and linearizing around $V/R = 0$, we have

$$\ln P_{it} - \ln R_{it} = b(V_{it}/R_{it}) - \ln \Pi_{it} + \ln \epsilon_{it}. \qquad (9)$$

(The term $\ln[g_1(v_t)/\alpha]$ is subsumed in year effects. Industry effects are also included.) One approach to estimating this equation is to subsume any variation in the expected

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underlying instruments should be included in the instrument set. In some cases we obtained estimates of the potency of venture capital similar to the estimates reported in Table 4, but these estimates were not robust to dropping or adding powers of the underlying instruments. Since a comparison of Table 2 and Table 3 suggests that the linear specification is more conservative in its implications about the potency of venture funding, we decided to focus on that specification.

[22] Such a feedback will not exist if the price elasticity of industry demand is equal to one. In this case, a fall in quality-adjusted prices associated with a process or product innovation will be just offset by the increase in demand, leaving the value of industry output unchanged.

[23] If we accept $\alpha = .5$, we can resolve the puzzle of the high estimates of venture-capital potency shown in Table 2. Redoing those nonlinear regressions under the restriction that $\alpha = .5$ (and $\rho = 1$) yields much lower estimates of the potency of venture capital, in the range of four to five.

value of inventions in the disturbance. This approach implicitly assumes, however, that shocks to venture funding relative to R&D are uncorrelated with shocks to the expected value of an invention.

Our other approach begins with (9) but uses industry output as a proxy for the expected value of an invention, $\ln \Pi_{it} = a_0 + a_1 \ln Y_{it}$. Assuming $a_1 = 1$ (footnote 24 relaxes this assumption), we obtain the equation

$$\ln P_{it} - (\ln R_{it} - \ln Y_{it}) = b(V_{it}/R_{it}) + \ln \epsilon_{it}. \tag{10}$$

The dependent variable is simply the logarithm of the ratio of patents $P$ to R&D intensity, $R/Y$. Note that our use of the value of industry output as a proxy for the expected value of an invention does not require the value of industry output to be independent of technological opportunities. Thus, we are able to avoid the most problematic assumption that was required in our IV approach.

The results from estimating (9) and (10), shown in Table 5, are largely consistent with our findings in Tables 3 and 4. In all cases, venture funding is significantly more potent than corporate R&D. The estimates of $b$ are more modest, suggesting that venture funding is between 1.5 and 3 times as potent as corporate R&D.[24]

## 5. Patenting or innovation?

▩ While the analyses above suggest a strong relationship between venture capital and patenting on an industry level, one major concern remains. In particular, it might be thought that the relationship between venture capital disbursements and patent applications is not indicative of a relationship between venture disbursements and innovative output. It may be that the increase in patenting is a consequence of a shift in the propensity to patent innovations stimulated by the venture financing process itself. In the terms of (7), there may be a positive correlation between the $\epsilon_{it}$ and $V_{it}/R_{it}$ terms.

Two reasons might lead venture-backed firms—or companies seeking venture financing—to patent inventions that other firms would not. First, they may fear that the venture investors will exploit their ideas. Firms seeking external financing must make extensive disclosure of their technology. While potential investors may sign nondisclosure agreements (and may be restrained by reputational concerns), there is still a real possibility that entrepreneurs' ideas will be directly or indirectly transferred to other companies. Alternatively, venture or other investors may find it difficult to discern the quality of firms' patent holdings. To enhance their attractiveness (and consequently increase the probability of obtaining financing or the valuation assigned in that financing), firms may apply for patents on technologies of marginal worth.

The industry-level data do not give us much guidance here, but we can explore these possibilities by examining a broader array of behavior by venture-backed and non-venture-backed firms. Using a sample of 530 Middlesex County firms, we examine three measures of innovative activity.

Trajtenberg (1990) has demonstrated a strong relationship between the number of patent citations received and the economic importance of a patent. Using only those

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[24] We can generalize by including $-a \ln Y_{it}$ on the right-hand side of (9). Restricting $a_1 = 0$, we get back the specification shown in the first two columns of Table 5, while restricting it to be one yields the specification in the last two columns. If we estimate $a_1$, we get a value of about .4 while the corresponding estimate of $b$ remains statistically significant and within the range reported in Table 5. We have also run regressions corresponding to the nonlinear versions of equations (9) and (10). The estimates of $b$ are somewhat larger than those reported in Table 5: 3.23 [.74], 1.86 [.58], 4.55 [.91], and 4.81 [.84].

**TABLE 5** **Ordinary Least-squares Regression Analyses of the Patent-R&D Ratio**

| | Dependent Variable | | | |
|---|---|---|---|---|
| | $\ln P_{it} - \ln R_{it}$ | | $\ln P_{it} - (\ln R_{it} - \ln Y_{it})$ | |
| Venture capital/privately funded R&D ($b$): | | | | |
| Firms receiving funding | 2.39<br>(.82) | | 2.96<br>(.87) | |
| Venture disbursements | | 1.45<br>(.55) | | 2.70<br>(.85) |
| $R^2$ | .97 | .97 | .97 | .97 |
| $R^2$ relative to dummy variable only case | .04 | .02 | .06 | .07 |
| Number of observations | 560 | 560 | 560 | 560 |

Notes Standard errors (in parentheses) are based on the Newey-West autocorrelation-consistent covariance estimator (with a maximum of three lags) Year and industry dummy variables are included in each regression

firms that received any patent awards before 1990, we compute the ratio of the number of U.S. patent citations during the period between 1990 and June 1994 to U.S. patents awarded between 1969 and 1989. Citations per patent provides a largely external measure of the average importance of the firms' patent awards.

The second and third measures of the intellectual-property activity of firms are the frequency and extent of patent and trade-secret litigation in which the firm has engaged. Models in the law-and-economics literature suggest that parties are more likely to file suits and pursue these cases to trial when (i) the stakes of the dispute are high relative to the costs of the litigation or (ii) the outcome of the case is unclear (Cooter and Rubinfeld, 1989). Thus, litigation may serve as a rough proxy for economic importance, a suggestion verified empirically by Lanjouw and Schankerman (1997). We present

**TABLE 6** **Comparisons of Intellectual Property Activities of Venture-Backed and Non-Venture-Backed Firms**

| | Mean for Firms | | $p$-Value, Comparison | |
|---|---|---|---|---|
| | Venture-Backed | Non-Venture | Means | Medians |
| Patents, 1990 to mid-1994 | 12.74 | 2.40 | .029 | .000 |
| Citations/patent | 6.44 | 4.06 | .016 | .004 |
| Intellectual property suits: | | | | |
| Number of suits | .79 | .18 | .000 | .000 |
| Number of docket filings | 30.29 | 4.21 | .000 | .000 |
| Patent suits only | | | | |
| Number of suits | .36 | .08 | .000 | .000 |
| Number of docket filings | 15.35 | 2.04 | .000 | .000 |
| Trade-secret suits only | | | | |
| Number of suits | .34 | .08 | .000 | .000 |
| Number of docket filings | 6.43 | 1.86 | .007 | .000 |

Notes The sample consists of 530 firms based in Middlesex County, Massachusetts, of which 122 are venture-backed these tabulations separately for patent and trade-secret suits. These measures may provide a rough indication of the importance of both patents and trade secrets to the firm.

Table 6 presents univariate comparisons. There are substantial differences between the 122 venture-backed and 408 non-venture-backed firms: the venture firms are more likely to patent, have previous patents cited, and engage in frequent and protracted litigation of both patents and trade secrets. All the tests of differences in means and medians in these three categories are significant at least at the 5% confidence level, as well as when we employ regression specifications. These findings help allay fears that differences in the propensity to patent drove our findings in Sections 3 and 4. At the same time, it is important to acknowledge that while the firm-level analysis allows us to examine whether the innovative behavior of venture-backed and non-venture-backed firms differs on measures other than patent counts, it does not allow us to address endogeneity issues as in the industry-level analysis.

## 6. Conclusions

■ This article examines the impact of venture capital on technological innovation. Patenting patterns across industries over a three-decade period suggest that the effect is positive and significant. The results are robust to different measures of venture activity, subsamples of industries, and representations of the relationship between patenting, R&D, and venture capital. Averaging across our preferred regressions, we come up with an estimate for $b$ (the impact on patenting of a dollar of venture capital relative to a dollar of R&D) of 3.1. This estimate suggests that venture capital accounted for 8% of industrial innovations in the decade ending in 1992.[25] Given the rapid increase in venture funding since 1992, and assuming that the potency of venture funding has remained constant, the results imply that by 1998, venture funding accounted for about 14% of U.S. innovative activity.[26]

In our earlier work (1998), we argued that the recent surge in patenting in the United States was most likely explained by changes in the management of innovative activities. Interpreted broadly, the growth of venture capital is one such management change. While our results help answer some questions, they pose in turn additional questions:

First, what are the sources of the venture capitalists' advantage in funding innovation? Is the key source of advantage the process by which projects are chosen *ex ante,* or is it the monitoring and control after the investment is made?

Second, the finding of the apparently greater efficiency of venture funding in spurring innovation raises the question of why industrial R&D managers have not adopted some of the same approaches to financing innovation. Jensen (1993), for one, has argued that agency problems have hampered the effectiveness of major corporate industrial research facilities over the past several decades. What barriers have limited the diffusion of the venture capitalists' approaches?

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[25] We get the estimate of $b = 3.1$ by averaging the estimates in the regressions reported in Panel B of Table 4, Table 5, and footnote 24. The ratio of venture capital disbursements to R&D ($V/R$) averaged over the years 1983 to 1992 is 2.9% (see Table 1). Our calculation of the share of innovations due to venture capital is $b(V/R)/(1 + b(V/R))$.

[26] Based on estimates of venture capital disbursements to all industries in 1998 (from Venture Economics) and preliminary estimates of R&D performed and funded by industry (from the National Science Foundation), we calculate that $V/R$ increased at a 14% annual rate from 1992 to 1998. Given that $V/R$ was 2.22% in 1992, we project that it had risen to 5.1% by 1998. Applying the same venture funding potency $b$ of 3.1, we get the 14% number noted in the text.

Finally, other innovations in organizing research occurred contemporaneously. For example, central R&D facilities of large corporations have been redirected toward more applied problems (for an overview, see Rosenbloom and Spencer (1996). Is it possible to disentangle the distinct effects of the rise of venture capital from other R&D management innovations?

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