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ABSTRACT

While policymakers often assume venture capital has a profound impact on innovation, that premise has not been evaluated systematically. We address this omission by examining 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 the amount of venture capital activity in an industry significantly increases its rate of patenting. While the ratio of venture capital to R&D has averaged less than 3% in recent years, our estimates suggest that venture capital accounts for about 15% of industrial innovations. We address concerns that these results are an artifact of our use of patent counts by demonstrating similar patterns when other measures of innovation are used in a sample of 530 venture-backed and non-venture-backed firms.

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1. Introduction

Governments around the globe have been eager to duplicate the success of the fast-growing U.S. venture capital industry.[1] These efforts share a common rationale: that venture capital has spurred innovation in the United States, and can do so elsewhere (see, for instance, the European Commission's *Green Paper on Innovation* [1995]).

Some anecdotal evidence appears to support the claim that venture capital spurs innovation. To cite one example, the Israeli government initiated two programs to encourage the formation of venture capital funds in 1991. Many analysts argue that the Yozma and Inbal initiatives led to not only an increase in venture capital under management (from $29 million in 1991 to over $550 million in 1997), but to a burst of investment by foreign high-technology companies in Israeli R&D and manufacturing facilities.

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, the amount of venture capital funding has an impact on the number of patented innovations. We find that venture disbursements are associated with a significant increase in patenting.

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1. Venture capital can be defined as equity or equity-linked investments in young, privately held companies, where the investor is a financial intermediary who is typically actively as a director, an advisor, or even a manager of the firm.

The results are robust to a variety of functional representations 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 that, while venture capital may indeed spur innovation, simple reduced-form regressions may overstate the effect. The model suggests that both venture capital investment and patenting could be correlated with a third unobserved variable, representing the arrival of entrepreneurial opportunities. Thus, the magnitude of the reduced-form results may be overstated.

We address this concern in two ways. First, we exploit the major discontinuity associated with the recent history of 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 the venture capital industry. 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 transform our basic equation. Using our model, we show that many of the causality problems should disappear 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 coefficients using different techniques suggest that a dollar of venture capital could be up to ten times more effective in stimulating patenting than a dollar of traditional corporate R&D. Our estimates suggest that venture capital, even though it has been less than 3% of corporate R&D in recent years, is responsible for a much greater share—perhaps 15%—of U.S. industrial innovations.

The final section of the paper 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. Venture-backed firms may simply patent more of their innovations because they either seek to impress potential investors or fear expropriation of their ideas by these investors.

To investigate this possibility, we construct a sample of 530 venture-backed and non-venture-backed companies based in Middlesex County, Massachusetts. We find that the venture-backed firms do patent more, but not so much as to dilute the economic importance of their patents: their patents are more frequently cited in other patent applications and more aggressively litigated. Finally, the venture-backed firms are also more frequent litigators of trade secrets, which suggests that they are not simply patenting more in lieu of relying on trade secret protection. The firm-level results suggest that the association of more patent filings with venture capital activity is not simply a consequence of venture-backed firms having a greater propensity to patent discoveries.

It is important to acknowledge that our analysis is limited in scope. In particular, we have estimated a simple stylized model of the relationship between venture capitalists, corporate researchers, and innovations. Due to the paucity of data and the lack of previous research in this arena, our paper can be seen as a first step in addressing the impact of venture capital 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 innovative activities.[2]

The plan of this paper is as follows. In Section 2, we provide an overview of the U.S. venture capital industry and its role in financing young, technology-intensive firms. Section 3 takes a first look at the data and estimates a set of reduced-form regressions. We illustrate the limitations of this approach through a simple model and explore alternative approaches in Section 4. We address the concerns about patenting as a measure of innovation in Section 5. The final section concludes the paper.

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2. Our work is, however, related to two bodies of empirical literature. First, an extensive body of research [reviewed in Cohen and Levin, 1989, and Cohen, 1995] has examined the determinants of R&D spending and innovative outputs. Frequently examined issues include the impact on innovation of industry structure, product market demand, scientific advance, and intellectual property protection. The relationship between cash flow and R&D expenditures has been studied at the firm level [e.g., Bernstein and Naidri, 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. A second area of related research is the examination of the impact of the financial system on economic growth [reviewed in Levine, 1997]. The focus of this literature, however, has typically been at a more aggregate level. Studies relate, for instance, the overall level of equity market capitalization and bank lending activity to the growth in gross domestic product and productivity. This study looks in depth at a particular financial institution that is potentially important in promoting technological change.

2. Venture Capital and the Financing of Young Firms[3]

The formal venture capital industry in the United States dates back to the formation of the first fund, American Research and Development, in 1946. A handful of other venture funds were established in the decade after that pioneering fund's formation. 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 accounting for the increase in money flowing into the venture capital sector 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. In 1978, when $424 million was invested in new venture capital funds, individuals accounted for the largest share (32 percent). Pension funds supplied just 15 percent. Eight years later, when more than $4 billion was invested, pension funds accounted for more than half of all contributions. In the years 1996 and 1997, there was another leap in venture capital activity.

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3. This section is based in part on Gompers and Lerner [1996, 1998]. The second paper provides a detailed examination of inflows into venture capital funds, and emphasizes the importance of exogenous events such as the 1979 policy shift discussed below in determining the magnitude of these inflows.

The fundraising patterns are mirrored in the investments by venture capitalists into young firms, also depicted in Figure 1. The mixture of projects financed by venture capitalists differs significantly from those undertaken by corporate research laboratories. Using a variety of mechanisms, venture capitalists are able to finance many risky early-stage projects with no tangible assets. First, business plans are intensively scrutinized: historically only 1% of those firms that submit business plans to venture organizations have been funded. The venture capitalist's decision to invest in a project is frequently made conditional on the identification of a syndication partner who agrees that the investment is attractive. Once the decision to invest is made, venture capitalists frequently disburse funds in stages. To ensure that the money is not squandered, managers of venture-backed firms are forced to return repeatedly to their financiers for additional capital. In addition, venture capitalists intensively monitor managers. These investors demand representation on the board of directors and preferred stock with numerous restrictive covenants. (The venture investment process is documented in Gompers and Lerner [1999].) Thus, it is not surprising that venture capital has emerged as the dominant form of equity financing in the U.S. for privately held high-technology businesses.[4]

3. Reduced-Form Regressions

Before turning to a detailed discussion of what drives venture capital and

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4. While evidence regarding the financing of private firms is imprecise, Freear and Wetzel's [1990] survey suggests that venture capital accounts for about two-thirds of the external equity financing raised by privately held technology-intensive businesses from private-sector sources.

corporate R&D, we provide an initial look at how they influence patenting.[5] Reduced-form regressions of patenting on R&D expenditures and on venture disbursements must be interpreted with caution due to concerns about causality. Nonetheless, it is natural to begin by investigating whether venture capital has a place in the patent production function.

The analyses in Sections 3 and 4 focus on twenty industries between 1965 and 1992. The level of industry detail is determined by the patents, whose industry must be inferred from their technological classification. These industries also correspond well with the industry scheme used by the U.S. National Science Foundation (NSF) in tabulating its survey of industrial R&D.[6] The time period is determined by the availability of data on venture capital investment (Venture Economics' records date back to the mid-1960s) and our inability to observe the detailed technological classifications of U.S. patent applications before they are issued (awards are held confidential until issue). The data sources are described in detail in the Appendix.

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5. Conceptually, we will distinguish between R&D financed by corporations and R&D financed by venture capital organizations. In actuality, the industrial R&D data that we use undoubtedly includes some research financed by venture capital organizations. We think that it would be unwise to subtract venture capital funding from measured R&D since some venture funding goes to non-R&D activities and because the R&D survey overlooks the activities of many smaller firms. 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 R&D.

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

Tables 1 through 3 summarize three of the data series that we analyze—patent applications by U.S.-resident inventors that eventually result in a U.S. patent, venture capital disbursements, and industrial R&D spending—for all manufacturing firms and at the industry level. The tables highlight the rapid growth of the venture capital industry and the concentration of disbursements in certain industries. The top three industries represent 54% of the venture disbursements; the comparable figure for R&D expenditures is 39%. 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.

3.A. The Patent Production Function

We estimate a constant elasticity of substitution (CES) patent production function. In particular, we assume that $P_{it} = (R_{it}{}^{r} + bV_{it}{}^{r})^{a/r} u_{it}$, where patenting (P) is a function of privately funded industrial R&D (R) and venture disbursements (V), as well as an error term (u) capturing shifts in the propensity to patent or technological opportunities. Each variable is indexed by industry (i) and year (t). The parameter α captures the returns to scale in R and V, *i.e.*, the percentage change in patenting brought about by a 1% increase in both R and V. The parameter b captures the role of venture capital in the patent production function. If b is greater than one, then venture capital is more effective than corporate R&D in spurring innovation. ρ measures the degree of substitutability between R and V as means of financing innovative effort. As ρ goes to zero, the patent production function approaches

of the rate of technological innovation here. A more detailed industry breakdown would lead to greater errors in assigning patents to industries.

the traditional Cobb-Douglas functional form, $P_{it} = R_{it}^{a/(1+b)} V_{it}^{ab/(1+b)} u_{it}$. When ρ equals one, the function reduces to $P_{it} = (R_{it} + bV_{it})^{a} u_{it}$.

We will begin by considering the case when ρ→0. Similar patent production functions (but with b=0) have been estimated at the industry level by Kortum [1992, 1993] and at the firm level by many others (see Griliches [1990] for an overview), with the consistent finding that a positive relationship between R&D and patenting exists. We will then highlight some problems with this functional form, and consider alternative specifications.

3.B. Estimating the Cobb-Douglas Specification

The first two columns of Panel A of Table 4 provide an initial look at the patent production function using the Cobb-Douglas specification. We regress the logarithm of the number of (ultimately successful) patent applications filed by U.S. inventors in each industry and year on the logarithm of privately financed R&D in that industry and either the logarithm of the number of firms receiving venture backing or the dollar volume of venture disbursements in the industry.[7] We use as a control the logarithm of the federally funded

7. One question is whether to use the number of companies funded each year by venture investors, or the dollar amount that these funds invested. The amount invested might be thought a more natural choice: after all, some firms receive only a seed financing of a few hundred thousand dollars, while others receive tens of millions of dollars. One of the crucial sources of value provided by venture investors, however, is their ability to certify companies to other investors: for instance, venture-backed firms are much more likely to be able to attract the interest of a reputable investment banker and complete an initial public offering. Similarly, corporate business development groups are much more likely to invest in new firms backed by venture investors. Thus, the financing contributed by the venture investor is often relatively modest compared to the total amount that the venture-backed firm raises. (To cite one example, Kleiner, Perkins, Caufield, and Byers

R&D in that industry, as well as dummy variables for each industry and year.[8] The venture capital measures are statistically significant and economically meaningful.[9] A doubling of venture capital activity is associated with between a 6% and 9% increase in patenting.

We explore the robustness of the results in Panel B of Table 4. One concern relates to the definition of venture capital activity. It might be thought that a measure of the venture capital activity more relevant to innovation would include only seed and early-stage financings. The financings of start-ups and very young companies are likely to pose the greatest information problems, and the contributions of the venture capital investors might be most valuable here. In the first two columns of Panel B, we repeat the regressions reported in columns three and four of Panel A, but use the logarithm of the count and dollar

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initiated a major effort in late 1980s to fund mobile communications firms. Between 1988 and 1993, the venture capital organization invested $39 million in these firms, a modest amount when compared to the approximately $250 million that these firms raised simultaneously from corporate partners.) Thus, we use both measures. Because some industries received no venture financing in given years, we take the logarithm of the number of venture capital financings (or the volume of venture disbursements, in millions of 1992 dollars) plus a nominal amount.

8. We include year dummy variables because the pattern of patenting has changed over time, at least partially due to policy changes. Kortum and Lerner [1998] describe how the creation of the Court of Appeals for the Federal Circuit apparently coincided with a shift to a more "pro-patent" legal environment. We include industry dummy variables because the propensity for firms in particular industries to file for patents on innovations may vary. This may reflect the nature of the competition in the industry and the degree of disclosure entailed by patent awards [e.g., Horstmann, MacDonald, and Slivinski, 1985] or the persistence of organizational norms within particular firms and industries [an argument advanced in Levin, *et al.*, 1987]. Even without these two sets of control variables, the regressions reported in the first two columns of Panel A of Table 4 show that both measures of venture financing are statistically and economically significant.

9. 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. This is computed as $(SSR_{\text{dummy only}} - SSR_{\text{new regression}})/SSR_{\text{dummy only}}$, where SSR refer to the sum of squared residuals of the various regressions.

volume of seed and early-stage financings only. The venture activity measures are slightly larger and more precisely estimated using this alternative definition. Another concern is that our analysis may be distorted by the inclusion of numerous industries with very little innovative activity, as measured by R&D spending. We repeat the analysis, only employing those industries whose R&D-to-sales ratio was above the median in 1964 (the year before the beginning of the analysis). Once again, there is a slight increase in the magnitude and significance of the venture activity measures.[10]

3.C. Alternative Functional Forms

One unappealing aspect of the Cobb-Douglas production function (*i.e.*, our initial assumption that ρ is close to zero) is that it assumes that a given percentage increase in venture capital disbursements has the same percentage impact on patenting across industries, whatever the initial level of venture activity. We might suspect that the impact of a doubling of venture capital on overall patenting would be much smaller in an industry where it initially was miniscule compared to corporate R&D (e.g., transportation equipment). In industries where it was significant relative to R&D (e.g., office and computing equipment), it might be thought that the impact of such an increase on patenting would be more dramatic.

This uneasiness is borne out by Figure 2, which graphically presents the results of a regression similar to that in the third column of Table 4, but in which the coefficient on the

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10. The results are little changed when we use those firms with above the median R&D-to-sales ratio in the year immediately before the observation, as well as when we omit the year and industry dummy variables.

venture capital measure is allowed to vary. In particular, the observations are divided into four equal-sized groups, based on the ratio of the number of venture-funded companies to R&D. A separate venture capital coefficient is calculated for each group. The figure depicts the level of and the 95% confidence interval around the coefficient for each quartile. For those observations where the ratio of venture capital to R&D is below the median, the coefficient is not significantly different from zero. (For the group with the least venture capital activity, the coefficient is even negative.) As the ratio increases, however, the coefficient becomes increasingly positive. This suggests that the functional representation of the relationship between patenting, R&D, and venture capital used in Table 4 is problematic.

A more formal way to illustrate this problem is to undertake a non-linear regression analysis. We estimate the equation $P_{it} = (R_{it}{}^{r} + bV_{it}{}^{r})^{a/r} u_{it}$, and seek to determine which value of ρ provides the best fit. The estimation is performed using non-linear least squares after taking logarithms of both sides of the equation. We use the same set of regressors as in the third and fourth regressions reported in Panel A of Table 4 (*i.e.*, we include industry and year dummies, as well as the logarithm of federally funded R&D). Both regressions, reported in the first and fifth columns of Table 5, produce estimates of ρ very close to one.

Table 5 also presents three sets of formal hypothesis tests. First, we examine the hypothesis that the coefficient on venture capital is zero. In the second and sixth columns, we repeat the non-linear estimation in columns one and five, now constraining b to be zero. A likelihood ratio test soundly rejects this null hypothesis. Second, we constrain ρ to be equal to zero. As the third and seventh columns report, we once again reject the null hypothesis that the function is Cobb-Douglas. Finally, we estimate the equations under the null hypothesis that ρ=1. Only in this case, reported in the fourth and eighth columns, can the null hypothesis not be rejected. The non-linear analysis thus suggests that the case of ρ=1 is an appropriate simplification: *i.e.*, where R and V are perfect substitutes, but with V allowed to be more or less potent (as determined by b). In this case, the elasticity of patenting with respect to venture capital will increase with the ratio of venture capital to R&D, as Figure 2 indicates is the case.

The non-linear equation, however, makes our subsequent instrumental variable estimation much more complicated. To avoid the technically difficult issues associated with the choice of instruments in a non-linear setting, we approximate our expression by a linear equation in the analyses below. We employ an approximation suggested by Griliches [1986] in his analysis of the impact of basic research on productivity growth. The basic research expenditures whose impact Griliches wishes to assess represent, like venture capital, only a small fraction of total R&D expenditures. Griliches argues that in this context, it is reasonable to approximate the production function through a Taylor expansion of the logarithm of the function. This approximation will be accurate when basic research is relatively small. Employing a similar strategy here, we linearize the logarithm of the patent production function equation (with ρ=1) around $V/R=0$, and obtain $\ln(P_{it}) = a\ln(R_{it}) + ab(V_{it}/R_{it}) + \ln(u_{it})$.

Table 6 presents four regressions employing this linearized specification. These are akin to those in third and fourth regressions in Panel A of Table 4 and the first and second columns in that table's Panel B. While the coefficients must be interpreted with a degree of caution, the regressions suggest that the increase in venture capital is substantially more effective than private R&D in stimulating patenting. Consider the second regression, which estimates the coefficient on venture capital as 1.73. Because this is an estimate for the product of α and b, we must divide by our estimate of α, 0.24, to obtain the implied value of b. The regression suggests that a dollar of venture capital is over seven times more powerful in stimulating patenting than a dollar of corporate R&D.[11]

3.D. Difference Analyses

A concern with the above analyses is autocorrelation in the residuals. Our error term is affected by shocks to the propensity to patent and technological opportunities, which are likely to persist for some time, if not forever. Our standard errors may be consequently artificially low and our t-statistics inflated. In correcting this problem, however, we want to avoid accentuating any downward bias in our coefficients that may be caused by an errors-in-variables problem. In particular, the venture disbursement series fluctuates dramatically from year to year. This variability partially reflects the fact that venture funds are provided to companies in periodic staged financings, rather than as a steady stream. A single financing round might provide funds that will be spent by the firm over a two-to-three year

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11. Note that in this linearized regression the units of venture financing matter. If we use the number of firms receiving venture capital backing, then the coefficient rises to 6.49, since the average financing is well over a million dollars in size (see Table 3). This issue has no implications, however, for the consistency of our estimates.

period [Gompers, 1995]. Thus, the venture funding measure is prone to an errors-in-variables problem that might lead to a downwardly biased coefficient.

To address the issue of persistent residuals, we employ a first-difference approach, which is appropriate if the original errors were random walks. In order 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. For example, our dependent variable is the average of the logarithm of patent applications filed in the years between 1973 and 1976 less the average of the logarithms over the 1965-1968 period, *etc*.

Table 7 presents four first-difference regressions. Two are for the case where $\rho \to 0$, while two employ the linear approximation to the $\rho=1$ case. In addition to the differences in privately and federally funded research and development and venture capital activity, we employ as independent variables (but do not report) dummies denoting the time period of the observation. The coefficients are very close to those in the Tables 4 and 6, helping address our concerns about accentuating the errors-in-variables problem. The standard errors rise by a factor of two to four, but the impact of venture capital remains significantly positive.

Another approach is to recalculate the standard errors in Tables 4 and 6 using the autocorrelation-consistent covariance estimator of Newey and West [1987]. Using a maximum lag of three years, we find that the standard errors on the R&D and venture capital coefficients each roughly double. In Table 8 and Panel A of Table 9 below, we report only the autocorrelation-consistent standard errors.

4. Addressing the Causality Problem

Section 3 suggests that there is a strong association between venture capital and patenting. The mechanisms behind this relationship and the extent to which our estimates may be inflated by unobserved factors, however, are not addressed by the reduced-form regressions that we employ. This section builds a model of venture capital, corporate research, and innovation. In the Section 4.B, we use the model to illustrate under what conditions the approach of Section 3 is appropriate and when it may be problematic. The final two sections present some refinements of our empirical approach.

4.A. Modeling 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 assumptions.

First, we assume that innovations are generated according to a production function similar to that we have settled upon empirically (*i.e.*, with ρ=1). In particular, we envision the innovation production function for each industry *i* and time period *t* as

$$I_{it} = (R_{it} + bV_{it})^{a} N_{it}^{(1-a)} l_{it}^{g} = H_{it}^{a} N_{it}^{(1-a)} l_{it}^{g} \qquad \textbf{(1)}$$

where R_{it} represents corporate R&D expenditures, $b \geq 0$ represents the effectiveness of venture capital funding relative to corporate R&D in creating innovations, and V_{it} is venture capital disbursements. The final two terms represent shocks to the invention production function: N_{it} represents the exogenous arrival of innovative opportunities, while λ_{it} represents how major the technological opportunities are (this term will also figure below in determining the extent of venture capital financing). For expositional ease, the total innovative effort is defined as $H_{it} \equiv R_{it}+bV_{it}$. It is worthwhile dwelling on the interpretation of each of these parameters. N has to do with the quantity of new opportunities that arrive.[12] Only some subset of these, however, will be financed. The term α, where $0<\alpha<1$, parameterizes the distribution of the quality of these opportunities. A low value of α signifies more heterogeneity, so that a project at the margin is of much lower quality (in terms of the number of innovations that it yields) than the average project undertaken. We assume that periods with more substantial (radical) technological change (a higher λ_{it}) are associated with greater innovative output (I_{it}), with γ calibrating of the extent to which such changes stimulate overall inventiveness.

Second, we assume that innovations are translated into patents in a proportional manner. The relationship may vary, however, across industries and time periods. We hypothesize a relationship of the form $P_{it} = I_{it}e_{it}$, where P_{it} is the number of patented innovations generated in a particular industry and year, and ε_{it} is a stochastic term representing the propensity to patent. Combining this expression with Equation (1), we obtain:

12. By taking N_{it} to be exogenous, we take a middle ground between Romer [1990], where past research exerts a positive influence on the arrival of subsequent technological opportunities because of knowledge spillovers, and Kortum [1997], where past research exerts a negative influence (due to the “fishing out” of opportunities).

$$P_{it} = (R_{it} + bV_{it})^{a} N_{it}^{(1-a)} l_{it}^{g} e_{it} \qquad \textbf{\textit{(2)}}$$

The unobserved factor driving patenting is thus $N_{it}^{(1-a)} l_{it}^{g} e_{it}$: the product of technological opportunities in general, the nature of these 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 Π_{it}. (Built into this value is the assumption that some, but not all, innovations will be worth patenting.) We take a simple partial equilibrium approach and do not model the determinants of Π_{it}, although we have in mind that it evolves with the size of the market, as in Schmookler [1966].

Finally, we make assumptions regarding 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: some projects will be very appropriate for a corporate research laboratory, while others will be more suited to be funded by a venture capitalist in an entrepreneurial setting.[13]

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13. For instance, in the face of the biotechnology revolution, pharmaceutical companies—whose research departments almost entirely consisted of chemists who had spent their careers in industrial research—found it difficult to recruit or retain academic molecular biologists. Many of these leading researchers were, nonetheless, willing to work for venture-backed start-ups. A number of years later, however, when biotechnology drugs were being submitted for clinical approval, the few venture-backed firms that sought to do

In order to capture this concept, we assume that the marginal cost of both venture capital and corporate R&D is increasing in the share of the activity that is taking place in that sector. The most promising opportunities will differ according to the relative ease with which they are managed either in the corporate setting or by venture capitalists. Corporate research expenditures are aimed at the opportunities most conducive to that setting and venture capital disbursements finance the more entrepreneurial ones. The initial projects that venture capitalists fund are likely to be well suited for that setting. As they fund a progressively larger share of the projects, however, they begin to back projects that might be better suited for a corporate setting. The same is true for projects funded by corporations. For instance, as venture activity rises as a fraction of total innovative effort, venture capitalists are pushed into areas farther from their comparative advantage and their costs rise, while corporate researchers are able to specialize in areas they have the greatest advantage in exploiting.

More specifically, we assume that given a total research effort H, and venture financing V, the venture capitalist's costs of managing the last venture-backed project is $n_t f_V(V_{it} / l_{it} H_{it})$, while the corporation's costs of managing the last corporate-backed project is $f_R(V_{it} / l_{it} H_{it})$. We assume that the venture capitalists' function is increasing ($f_V' > 0$), and the corporations' is decreasing ($f_R' < 0$). As the technological opportunities

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so found it exceedingly expensive. Venture capitalists soon concluded that this was a process that could be more efficiently pursued within pharmaceutical companies, who had many decades of experience with such filings. The number of new biotechnology firms funded by venture capitalists consequently fell dramatically.

available to an industry become more radical in nature (as λ_{it} increases), the management cost of pursuing the projects through venture capital falls and the cost to the corporation rises. The ν_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, which we will model as a fall in ν_t. Note that a shock to λ_{it} affects the relative costs of venture capital and corporate R&D, while an increase in N_{it} stimulates both forms of finance.

From this set of assumptions, we can 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 benefits (the product of the added probability of an invention and the value of an innovation). Assuming that we are not at a corner solution where V or R is equal to zero,[14] the conditions are:

$$\Pi_{it}\frac{\partial I_{it}}{\partial V_{it}} = a\Pi_{it}b\left(\frac{H_{it}}{N_{it}}\right)^{a-1} l_{it}^{\ g} = n_t f_V\left(\frac{V_{it}}{l_{it}H_{it}}\right) \qquad \textbf{\textit{(3)}}$$

$$\Pi_{it}\frac{\partial I_{it}}{\partial R_{it}} = a\Pi_{it}\left(\frac{H_{it}}{N_{it}}\right)^{a-1} l_{it}^{\ g} = f_R\left(\frac{V_{it}}{l_{it}H_{it}}\right) \qquad \textbf{\textit{(4)}}$$

Through a series of mathematical manipulations,[15] we obtain the expressions

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14. An attractive feature of the model is that it can also address the empirically relevant case of V=0. In that case, $a\Pi_{it}b\left(\frac{R_{it}}{N_{it}}\right)^{a-1} l^g \le n_t f_V(0),\quad \text{where } R_{it} = N_{it}\left[\frac{a\Pi_{it}\, l_{it}^{\ g}}{f_R(0)}\right]^{1/(1-a)}$.

15. Specific steps included *(i)* defining $x \equiv a\Pi_{it}\left(\frac{H_{it}}{N_{it}}\right)^{a-1} l^g$, *(ii)* combining the two equilibrium conditions (Equations (3) and (4)) to get $\frac{b}{n_t} = \left(\frac{1}{x}\right) f_V\left(f_R^{-1}(x)\right) \equiv h(x)$, where

$$\frac{V_{it}}{R_{it}} = l_{it}\left[\frac{g_2(n_t)}{1-b\,l_{it}\,g_2(n_t)}\right] \qquad \textbf{\textit{(5)}}$$

$$R_{it} = N_{it}\left[\frac{a\Pi_{it}\,l_{it}^{\;g}}{g_1(n_t)}\right]^{\frac{1}{1-a}}(1-b\,l_{it}\,g_2(n_t)), \qquad \textbf{\textit{(6)}}$$

where g_1 is an increasing function and g_2 a decreasing one. An important implication of Equation (5) is that V_{it}/R_{it}, the ratio of venture capital to corporate R&D, will be increasing in the degree to which the technological innovations are radical in nature (λ_{it}) and decreasing in the cost of venture funds, ν_t. Corporate research is increasing in overall opportunities, N_{it}, and in the value of inventions, Π_{it}.

4.B. Addressing Causality by Using an Instrument for Venture Capital

This set of equations allows us to illustrate the estimation challenge that we face. Equation (2) implies that the linear approximation to patent production function is $\ln(P_{it}) \approx a\ln(R_{it}) + ab(V_{it}/R_{it}) + (1-a)\ln(N_{it}) + g\ln(l_{it}) + \ln(e_{it})$. In Table 6, we estimated a similar equation, relying on industry and year dummy variables to proxy for the final three terms.

To understand why that approach may be problematic, consider the impact of a temporary increase to the nature of technological change in an industry (a transitory positive shock to our metric for radical innovation, λ_{it}). This will affect innovation in two

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h'(x)<0, *(iii)* solving for $x = h^{-1}(b/n_t) \equiv g_1(n_t)$, *(iv)* plugging into Equation (4) to get $\frac{V_{it}}{H_{it}} = l f_R^{\;-1}(g_1(n_t)) \equiv l g_2(n_t)$, *(v)* using $x \equiv g_1(n_t)$ to solve for H_{it}, and *(vi)*, recalling that $H_{it}=R_{it}+bV_{it}$, solving for V_{it}/R_{it} and R_{it}.

ways. First, there will be a direct impact, as the increased λ_{it} leads to a higher I_{it}. Second, the increase in λ_{it} will stimulate an increase in venture disbursements, which will also lead to more innovations. If we simply regress P_{it} on V_{it}/R_{it} without controlling for the (unobservable) shock to λ_{it}, we will overstate the impact of venture capital on innovation. In order to address this problem, we need to identify some variable that is correlated with the level of venture capital, but uncorrelated with shocks to λ_{it}. We can then employ this measure in an instrumental variable regression to determine the impact of venture capital on innovation.

Our model also allows us to specify the conditions when our earlier estimates are valid: those situations when we can obtain consistent estimates of the patent production function without employing instrumental variables. Two conditions must be satisfied: *(i)* $\gamma = 0$, so that shocks to the mix of opportunities have no direct effect on the rate of innovation, and *(ii)* the measure of the arrival of new ideas, N, has no variation that cannot be explained by aggregate time or industry effects. The second condition will be satisfied, if, for instance, the variation in innovative effort is driven only by demand-side factors such as changes in the value of inventions rather than by shifts in the supply of technological opportunities. (This is akin to Schmookler's [1966] view of demand-driven technological innovation.)

If these conditions are not satisfied, we will need an instrument for venture capital, *i.e.*, a variable that is correlated with the level of venture financing in each industry, but uncorrelated with the arrival of entrepreneurial opportunities.[16] In this section, we discuss how the changes associated with the 1979 Department of Labor policy shift provide an instrumental variable.[17]

As discussed in Section 2, the Department of Labor's clarification of the "prudent man" rule appears to have led to a surge in venture capital fundraising in the early 1980s. One might initially think of capturing this shift through a dummy variable, which could take on the value of zero prior to 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 patent-holder 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

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16. The attentive reader will note that the level of private R&D in Equation (6) is also affected by shifts in λ_{it}. In Section 4.B, we are essentially assuming that the parameter α, the impact of R&D on patenting, is known. In Section 4.C, we will relax this assumption.

17. We also undertake an unreported analysis in the spirit of Rajan and Zingales [1998], who examine the impact of various nations' stage of financial market development on industries that have greater and lesser needs for external financing. They show that sectors with a greater need for external financing develop disproportionately quickly in countries with well-developed capital markets. If, as discussed in Section 2, a key contribution of venture investors is to address informational asymmetries that surround young firms, then we may similarly find stronger effects in particular sectors. As a proxy for the degree of information problems, we employ the book-to-market ratio of large public companies in the industry. The gap between the book and market value will be greatest in those industries where intangible assets are important, growth prospects substantial, and traditional financial measures less reliable. These should be associated with settings in which both uncertainty and informational asymmetries are greater. The interaction between the number of venture-funded companies and the book-to-market ratio is significantly negative. These effects are not only statistically significant, but economically meaningful. For instance, a one standard deviation decrease in the industry book-to-market ratio leads to a 40% increase in the impact of venture financing. The results are robust to various definitions of the book-to-market ratio.

applications actually fell in the years after 1979. But this was also a period during which firms' ability to enforce intellectual property rights were under attack [Kortum and Lerner, 1998].

In the remainder of this section, we discuss why the 1979 policy shift should have had a predictably greater impact on patenting in some industries than others. Industries with a high level of venture capital prior to the policy change should have experienced a greater increase in funding, and thus a greater burst in patenting. This relationship suggests that we can use the level of venture financing prior to the shift as an instrumental variable.

Our approach is based on the observation that the increase in the ratio of venture capital activity to R&D in the years after the shift was positively correlated with this ratio prior to the shift. Figure 3 depicts for each industry the ratio of venture capital disbursements to R&D spending for the period 1965 through 1975, as well as the difference of the average ratio between 1985 and 1990 and that between 1965 and 1975. There is a strong positive relationship between the two variables. An ordinary least squares regression produces an adjusted R^2 of 0.42 and a t-statistic on the venture capital ratio between 1965 and 1975 of 3.85. The relationship continues to be statistically significant at the five-percent confidence level when we delete various extreme observations.[18]

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18. The observation in the upper right-hand corner is lumber and furniture. While the volume of venture disbursements is not large here, the amount of R&D is also very modest. When we delete this industry from the instrumental variable regressions below, the goodness-of-fit slightly improves. Other interesting outliers include office and

This empirical pattern is not surprising given two features of the venture industry. First, the supply of venture capitalists appears to be quite inelastic, at least in the short run. Gompers and Lerner [1996] document that during periods with increasing inflows into venture capital, both the amount raised in the average new venture fund and the dollars managed per partner increase. They point to practitioner discussions suggesting that the highly specialized skills of venture capitalists can only be developed through years of experience undertaking these investments. Second, individual venture capitalists tend to specialize in particular industries. Venture capitalists often have educational backgrounds that match the areas in which they invest: e.g., a Ph.D. in biochemistry or a master's degree in electrical engineering. Moreover, as they develop experience investing in a particular industry, they tend to receive more business plans from entrepreneurs specializing in that area.

These two factors suggest that during periods when the supply of venture capital increases sharply, much of the investment will be concentrated in industries with a high level of venture investment already, independent of the new opportunities facing the industry. Because of these structural reasons, we expect that the impact of the 1979 shock will vary across industries. We will exploit the predicted increase in venture capital disbursements to each industry associated with this policy shift as an instrumental variable.

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computing machines. Traditionally one of the mainstays of venture investing, this sector lost much of its luster after many computer hardware and peripheral manufacturers encountered difficulties in the mid-1980s. By way of contrast, drugs had very modest venture capital activity until the biotechnology revolution in the early 1980s.

We can motivate this suggestion more formally by returning to our model. If we examine Equation (5), we see that V_{it}/R_{it} in each industry is increasing in λ_{it}. The impact on V_{it}/R_{it} of a change in ν_t (which we argue underwent a single large decline in 1979) is also increasing in λ_{it}. Suppose that the arrival of entrepreneurial opportunities in each industry, λ_{it}, is somewhat predictable, depending on an industry-specific component λ_i, as well as a transitory shock ω_{it}. If we average the observations of V_{it}/R_{it} before 1979, we should get a number that is highly correlated with the level of λ_i in each industry, as long as the shocks are not too large relative to the variation across industries in λ_i. Thus, according to Equation (5), the average level of V_{it}/R_{it} before 1979 should be positively related to the industry-specific jump in venture financing associated with the 1979 policy shift (the fall in ν_t). In order to exploit this result, we define a variable that takes on the value of zero prior to 1979 (before the policy shift). In the years thereafter, it takes on the average level of V_{it}/R_{it} in the industry in the years before the policy shift. This variable should be a desirable instrument because it is correlated with the level of venture financing after 1978, but not correlated with transitory shocks that increased both venture disbursements and overall innovation in those years.[19]

19. Our instrumental variable approach is similar to the literature that uses policy changes as “natural experiments” to identify a key parameter [reviewed in Meyer, 1995]. In our context, the policy shift is the change in the prudent man rule, and we expect the impact of this change on patenting to be greatest in industries with a high V/R before the change. Consider an extreme example where V/R was zero in some industries and some positive number in the others. Then we would simply calculate the change in patenting before and after 1979 for each group of industries, and then compute the difference in the change between the two groups.

The results of this estimation are shown in the first two columns of Table 8. The table employs specifications identical to those in the leftmost regressions in Table 6. The instrumental variable, as discussed above, is the average ratio for each industry of either the number of companies receiving venture financing or the dollars of venture disbursements to private R&D expenditures during the period 1965 to 1978. In both cases, the measure of venture capital activity remains significantly positive at conventional confidence intervals. The implied value of b continues to be economically significant as well: the second regression, for instance, suggests that a dollar of venture capital is 14 times more effective than a dollar of corporate R&D spending in stimulating patenting.[20]

4.C. Refining the Instrumental Variable Approach

There remain, however, two lingering concerns about our approach. In Sections 4.C and 4.D, we attempt to address these concerns in two ways. We will refine our instrumental variable estimations, and examine the ratio of patenting to R&D.

The first of these concerns is that the shock in entrepreneurial opportunities, ω_{it}, may be serially correlated. If so, our instrumental variable estimates may also be biased. The reader will recall that our original concern about the reduced-form approach was that shocks to λ_{it} would affect both venture disbursements and innovation. Because of this, our estimates of the impact of venture capital on patenting in Tables 4 through 7 might be

20. We expected the magnitude of the coefficient on V/R to fall when we employed an instrumental variable approach, since in principle we are addressing an upward bias generated by endogeneity. In fact, the coefficient estimates rise, suggesting there may have been an even more serious downward bias due to errors-in-variables which our instrument also mitigates.

biased. If the transitory component of λ_{it} is serially correlated, we face a similar problem with our instrumental variable approach. Consider a case where there was a positive shock (an increase in the ω_{it} term) in the mid-1970s that persisted into the 1980s. In this case, the average of V_{it}/R_{it} in the industry prior to 1979 would be correlated with ω_{it} in the years after 1979. The instrumental variable would be correlated with the disturbance in patenting, and we would confront a problem very similar to that we faced in the reduced-form analysis. We address this concern by only using the period between 1965 and 1975 to compute the average of V_{it}/R_{it}. This approach limits this danger, as long as the serial correlation in the error terms does not persist for five years or more.

The second concern is that in our eagerness to develop an appropriate instrument for venture disbursements, we have ignored the fact that our model implies that the level of corporate R&D in each industry, R_{it}, will be correlated with shifts in entrepreneurial opportunities. If the coefficient of R_{it} is biased, it will distort the coefficient of venture capital as well.

We address the second concern in this section by employing an instrument for R&D in addition to our instrument for V_{it}/R_{it}. An ideal instrument will be one that is correlated with R&D but not correlated with the shift in technological opportunities. One candidate is the value of the gross industry product, Y_{it}. This is an attractive candidate for two reasons. First, it is hard not to believe that the amount of R&D in an industry will increase as the size of the industry does. Second, several models suggest that the value of industry output may not be correlated with technological opportunities. For instance, Shleifer [1986] and Grossman and Helpman [1991] derive general equilibrium models in which the price elasticity of demand is equal to one. In this case, a fall in prices associated with a process innovation will be just offset by the increase in demand, leaving the value of industry output unchanged.

The regressions reported in the third and fourth columns of Table 8 thus differ in two respects from those in the first two columns: the average levels of V_{it}/R_{it} are calculated over a more distant time period (1965 through 1975) and a second instrumental variable, gross industry product, is used. In both the reported and unreported regressions, the results are weaker, particularly when the ratio of venture disbursements to private R&D is used. This may reflect the fact that gross industry product is a very blunt instrument for corporate R&D. In Section 4.D, we address these problems in an alternative manner.

4.D. The Patent-R&D Ratio

The approach taken above is not entirely satisfying, since it depends on the assumption that the value of industry output is not correlated with technological opportunities. While this assumption may be valid in some cases, it is not likely to be a universal rule. Revisiting our model, however, suggests a second approach. If instead of estimating a patent production function, we instead consider the determinants of the patent-R&D ratio, we can eliminate some of our endogeneity problems.

Combining equations (2), (5), and (6), we get an expression for patenting, $P_{it} = N_{it}\left[\frac{a\Pi_{it}}{g_1(n_t)}\right]^{-1}\left[l_{it}^{\ g}\right]^{\frac{1}{1-a}} e_{it}$. Dividing by the expression for R&D in Equation (6), we get

$$\frac{P_{it}}{R_{it}} = \left[\frac{a\Pi_{it}}{g_1(n_t)}\right]^{-1}\left(1 + b\frac{V_{it}}{R_{it}}\right)e_{it}. \qquad \textbf{(7)}$$

The left-hand side of Equation (7) is the patent-R&D ratio. Note that changes in technological opportunities do not influence the patent-R&D ratio exception through changing either V_{it}/R_{it} or the value of an invention (Π_{it}). If changes in technological opportunities do not effect Π_{it} in a systematic way or if we can find a proxy for the value of an invention, then we will have gotten around our endogeneity problem. The potency of venture capital can thus be inferred from the coefficient b on the venture capital-R&D ratio.

In order to estimate this equation, we take logarithms of both sides. We ignore terms which would be absorbed by a constant term or time dummies and linearize around $V_{it}/R_{it}=0$, obtaining $\ln(P_{it}) - \ln(R_{it}) = -\ln(\Pi_{it}) + b(V_{it}/R_{it}) + \ln(e_{it})$. We then take the two approaches suggested above. First, we assume that the determinants of V_{it}/R_{it} (*i.e.*, λ_{it} and ν_t) have nothing to do with the value of inventions. We therefore subsume $\ln(\Pi_{it})$ in the error term and estimate $\ln(P_{it}) - \ln(R_{it}) = b(V_{it}/R_{it}) + controls + \ln(e_{it})$.

Second, we employ a proxy for $\ln(\Pi_{it})$. In the models of Shleifer [1986] and Grossman and Helpman [1991], the flow of profits to an invention is a fixed fraction of the value of market output. Contemporaneous industry output may thus be a reasonable proxy for the present value of an invention, or more formally, $\ln(\Pi_{it}) \approx a + \ln(Y_{it})$. Adopting this simplification, we add the logarithm of industry output to both sides of the equation. We thus estimate $\ln(P_{it}) - \ln(R_{it}) + \ln(Y_{it}) = -\ln(\Pi_{it}) + b(V_{it}/R_{it}) + controls + \ln(e_{it}) + \ln(Y_{it})$, the right-hand side of which reduces to $-a + b(V_{it}/R_{it}) + controls + \ln(e_{it})$.

The results from this estimation are presented in Table 9. In Panel A, we present four regressions (using respectively $\ln(P_{it}) - \ln(R_{it})$ and $\ln(P_{it}) - \ln(R_{it}) + \ln(Y_{it})$ as the dependent variables). Independent variables include the ratios of venture capital activity to private R&D and industry and time dummy variables (not reported). In Panel B we address concerns about persistent residuals by differencing the equation, following the procedure in Table 7. With the exception of first-difference equation using $\ln(P_{it}) - \ln(R_{it})$ as the dependent variable, the V_{it}/R_{it} term is strongly positive and significant throughout. It should be noted, however, that the estimates if b are more modest using this approach, suggesting that a dollar of venture capital is at most five times more effective than a dollar of corporate R&D.

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 Equation (2), there may be correlation between the ε_{it} and V_{it}/R_{it} terms.

Two reasons might lead venture-backed firms—or companies seeking venture financing—to seek to patent inventions that otherwise they would not. First, they may fear that the venture investors will exploit their ideas. Firms seeking external financing must make extensive disclosures of their technology. While potential investors may sign non-disclosure 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. In order 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 does not provide 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 alternative measures of the importance of the companies' intellectual property: the citations to their earlier patents, the extent of patent renewals, and the involvement of the firm in intellectual property litigation. The construction of this data set is described in detail in the Appendix.

We examine four measures of the innovative production by these firms. The first is very similar to the dependent variable in the industry-level analyses, and is simply intended as corroboration of the earlier analyses: the number of U.S. patent awards to the firm, its subsidiaries, and R&D limited partnerships between January 1990 and June 1994.[21] The other measures, however, deserve greater discussion:

- Trajtenberg [1990] has demonstrated a strong relationship between the number of patent citations received and the economic importance of a patent. Using only those firms that received any patent awards prior to 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. This provides a largely external measure of the importance of patent awards.

- The next measure is the percentage of U.S. patents awarded to these firms between 1981 and 1989 that had expired by their fourth, eighth, and twelfth year anniversaries. The U.S. Patent and Trademark Office (USPTO) has required owners of patents awarded since December 1980 to pay renewal fees prior to these anniversaries or else the patents expire at these points. Firms may let less important patents expire more often. But the interpretation of this variable is problematic: the same motivation that leads firms to file for awards on less important technologies may lead them to renew these patents.

- Our final measure of the intellectual property activity of firms is a less frequently encountered one: the frequency and extent of intellectual property litigation in which the firm has engaged. Models in the law-and-economics literature suggest 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. We present these tabulations not only for intellectual property litigation as a whole, but separately for patent and trade secret suits. These may provide rough measures of the importance of both patents and trade secrets to the firm.

21. Two differences with the above analysis should be noted. Because we are here examining a cross-section of firms rather than a panel data set, our concerns about using patent awards (instead of applications) are considerably less. For expositional ease, we report t-statistics rather than standard errors in Tables 11 and 12.

Table 10 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. (No differences are significant with respect to patent renewals.) All the tests of differences in means and medians in these three categories are significant at least at the five-percent confidence level. In unreported tabulations, we show that these differences are more pronounced among the privately held firms.

While these univariate comparisons are suggestive, these differences could be an artifact of the greater scale of the venture-backed firms, or else their differing industry composition. We consequently examine these patterns in a regression framework, which allows us to control (at least partially) for these differences.

Once again, we use each of the 530 firms as observations. Reflecting the ordinal, non-negative nature of the dependent variables in most regressions (counts of patent awards, patent citations, litigation, or docket filings), we employ a Poisson regression specification.[22] In the analysis of patent renewals, we employ a double-censored Tobit regression (as the probability of renewal cannot be less than zero or greater than one). As independent variables, we employ firm sales and employment in 1990, the year that the firm was founded, and dummy variables denoting whether the firm was publicly traded and venture backed in 1990 (and, in some regressions, interactions between these dummy variables).

22. While in the industry-level analysis, each industry had a sufficient number of patents that the discreteness of the patent counts was largely irrelevant, the same is not true for the firm-level patenting.

We also employ dummy variables for each two-digit Standard Industrial Classification (SIC) code, which are not reported in the tables.

The regression results are reported in Tables 11 and 12. In all cases except for the patent renewals,[23] the dummy variable indicating that the firm was venture-backed in 1990 is significantly positive. These results are economically significant in magnitude as well. In the left-most regression in Panel A of Table 11, the coefficient of 0.77 implies that, controlling for sales, status as a publicly traded firm, year of formation, and industry, a venture-backed firm was awarded an additional 2.2 patent awards between January 1990 and June 1994. This is significant relative to the sample mean of 4.8.[24]

Perhaps most striking is the finding in Tables 10 and 12 that venture-backed firms are not just more frequent litigators of patents, but also of trade secrets. The results in Sections 3 and 4 do not seem to be driven simply by a greater propensity to patent discoveries. Rather, the results suggest that there is a real difference in the extent of innovation in venture-backed and non-venture-backed firms.

23. We only report the regressions employing patent expirations at the fourth anniversary. The other results are similar.

24. When we interact the dummy variables denoting whether the firm was publicly traded and venture-backed at the end of 1989, we note that the differential impact in terms of patent filings and citations is the greatest for private venture-backed firms. It is the public venture-backed firms, however, that are the most active litigators of patent awards. In unreported regressions, we examine the sensitivity of the results to a variety of alternative specifications. These include using the number of intellectual property suits (rather than docket filings) as the dependent variable, and employing ratings of the importance of patent and trade secret protection in each industry and industry R&D-to-sales ratios instead of the industry dummy variables. These alterations have only a modest impact on the results.

6. Conclusions

This paper examines the impact of venture capital on technological innovation using both industry- and firm-level data. Patenting patterns across industries over a three-decade period suggest that there is a significant effect. The results are robust to different measures of venture activity, sub-samples of industries, and representations of the relationship between patenting, R&D, and venture capital.

Our estimates of b (the impact of a dollar of venture capital relative to a dollar of R&D) are almost always positive and significant, but do vary depending on the equation estimated. Averaging across the different regressions, we come up with an estimate for b of 6.2. In the last decade in our sample, the mean ratio of venture capital disbursements to R&D was 2.92%. Using these two averages, we calculate that venture capital accounts for 15% of industrial innovations in the past decade.[25] Thus, the results suggest that the venture capital has had a substantial impact on innovation in the U.S. economy. Taken at face value, the results also suggest that the jump in venture disbursements since 1995 may trigger an additional wave of innovative activity.

This paper leaves some critical questions unanswered. One set relates to the

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25. We average the values of b implied by the coefficients from the five linearized regressions with $\rho=1$ and with venture capital measured by disbursements (Table 6, Regressions 2 and 4; Table 7, Regression 4; Table 8, Regressions 2 and 4) as well as from the four regressions with venture capital measured by disbursements in Table 9. The ratio of venture capital disbursements to R&D (V/R) is an average over the years 1983 to 1992 (see Table 1). Our calculation of the share of innovations due to venture capital is $b(V/R)/(1+b(V/R))$.

effectiveness of public efforts to transfer the venture capital model to other regions. Even if venture capital organizations spur technological innovation in the United States, it is not evident that the model can be seamlessly transferred abroad. Different employment practices, regulatory policies, or public market conditions might limit the formation of these funds (see Black and Gilson [1998] for a discussion). Even if it were feasible to transfer this model, public economic development programs can be subject to political manipulation: e.g., pressures to award funds to politically connected businesses. In contrast to many forms of government intervention to boost economic growth, the implementation of such programs has received little scrutiny by economists.

A second broad issue relates to the governance of industrial R&D in the United States. The apparently greater efficiency of venture funding in spurring innovation raises questions about whether industrial R&D spending has been optimally directed or exploited. Jensen [1993], for one, has argued that agency problems have hampered the effective management of major corporate industrial research facilities. Indeed, it appears that many major corporate research facilities are today in the process of being restructured. One striking change is an emphasis by many corporations on adopting programs, such as joint ventures with smaller firms and strategic investment programs, whose structures resemble that of venture capital investment [for an overview, see Rosenbloom and Spencer, 1996]. A deeper exploration of the implications of organizing R&D in these alternative manners is an important area for future research.

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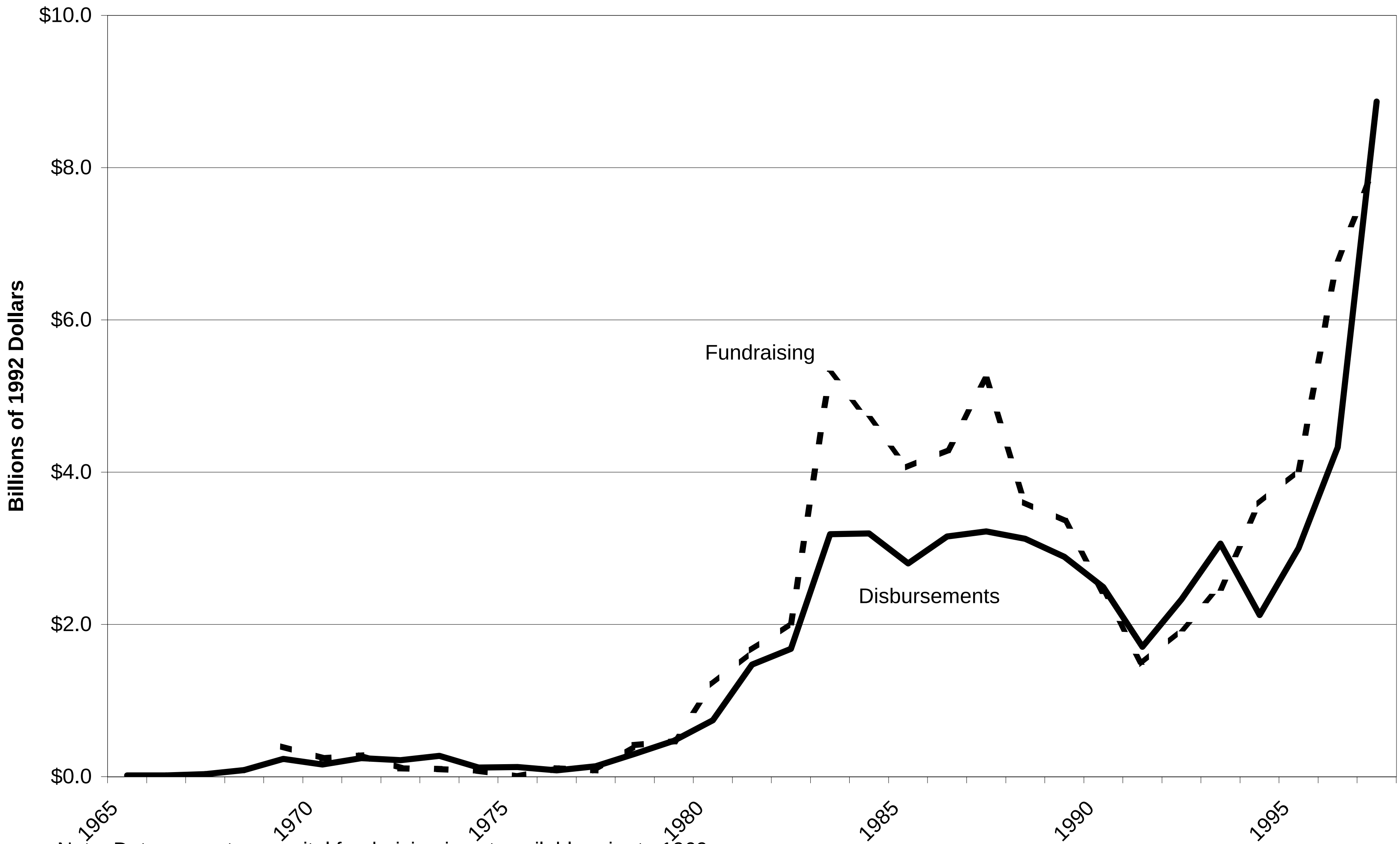
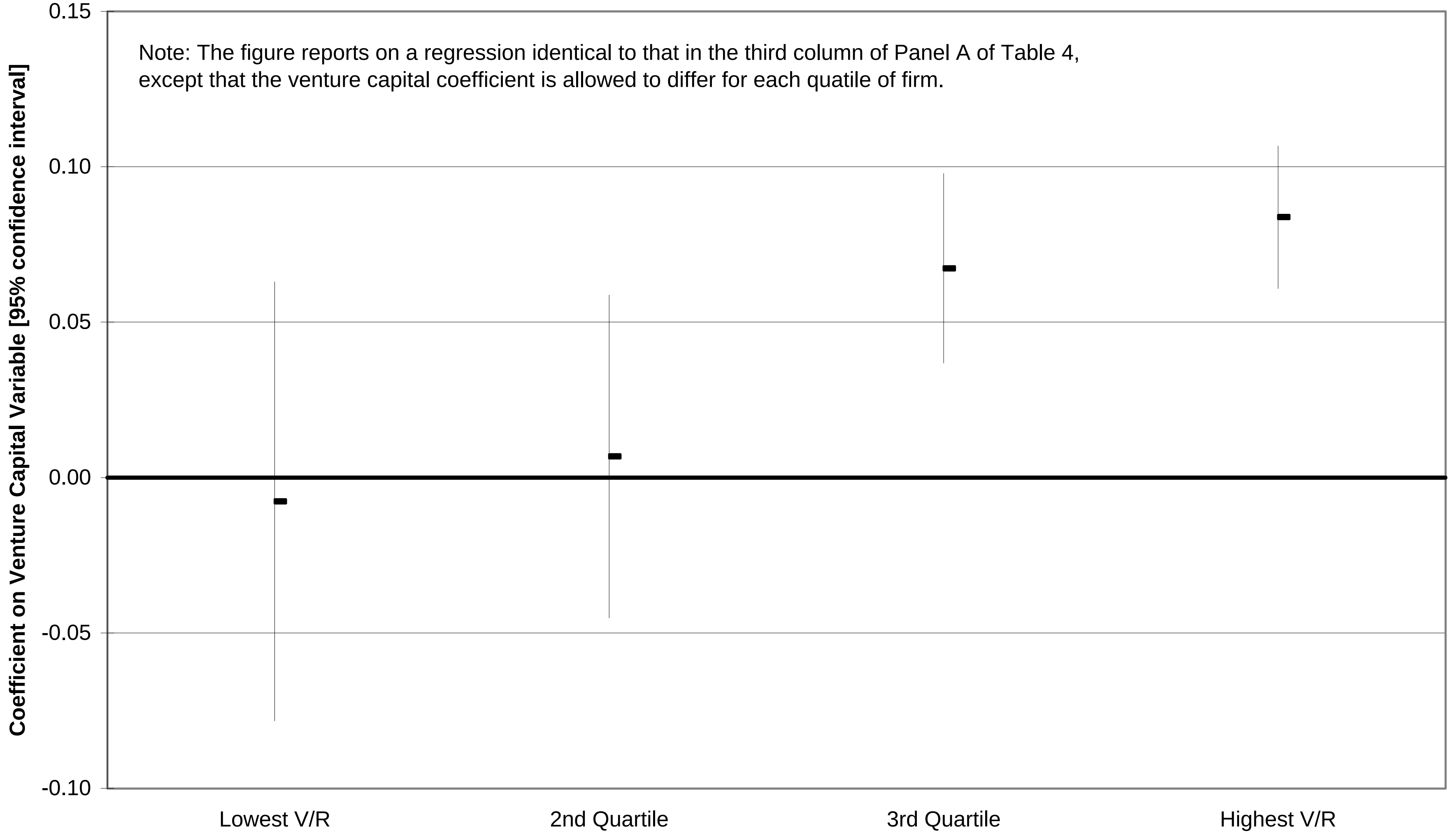
Figure 1: Venture Capital Fundraising and Disbursements, 1965-1997



Note: Data on venture capital fundraising is not available prior to 1969.

Figure 2: Coefficient on the Venture Capital Independent Variable for Sub-Samples with Different Ratios of Venture Capital to Private R&D



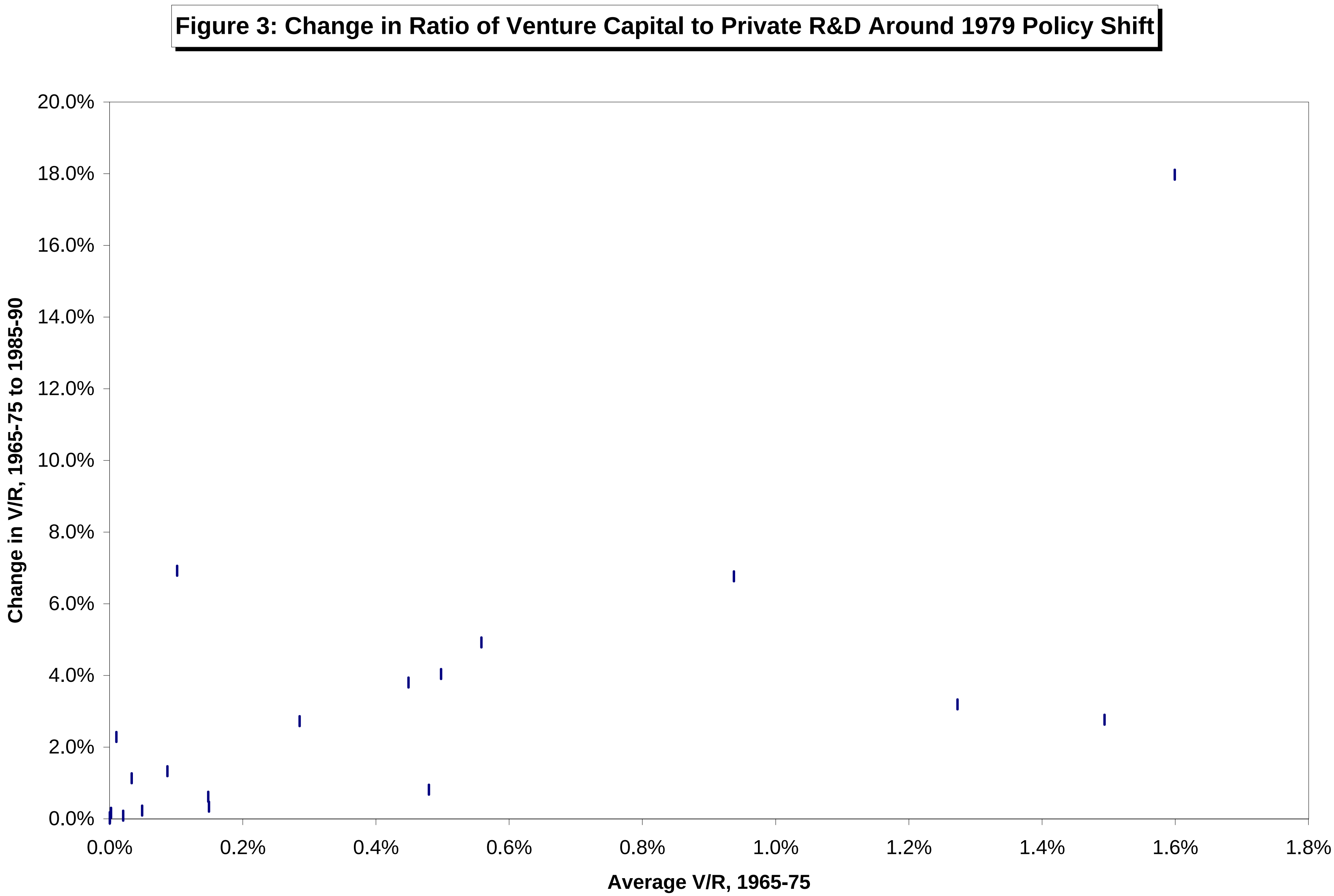


Figure 3: Change in Ratio of Venture Capital to Private R&D Around 1979 Policy Shift
20.0%
18.0%
16.0%
14.0%
12.0%
10.0%
8.0%
6.0%
4.0%
2.0%
0.0%
Change in V/R, 1965-75 to 1985-90
0.0%
0.2%
0.4%
0.6%
0.8%
1.0%
1.2%
1.4%
1.6%
1.8%
Average V/R, 1965-75

Table 1

Patenting activity of, R&D expenditures by, and venture capital disbursements for U.S. manufacturing industries, by year. All tabulations refer to Standard Industrial Classification codes 13 and 20 through 39. 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.

	# of Patent	*R&D*	Venture Capital Disbursements		Ratio of Venture Capital to R&D	
Year	*Applications*	*Expenditures ($M)*	*# of Firms*	*Amount ($Ms)*	*All VC*	*Early-Stage Only*
1965	50,278	25,313	8	13	0.05%	0.02%
1966	48,740	27,573	3	2	0.01%	0.00%
1967	48,900	29,515	9	24	0.08%	0.07%
1968	49,980	31,387	25	37	0.12%	0.08%
1969	51,614	33,244	66	149	0.45%	0.38%
1970	53,950	32,883	63	126	0.38%	0.24%
1971	54,776	32,360	57	224	0.69%	0.41%
1972	49,777	33,593	52	209	0.62%	0.44%
1973	45,807	36,169	74	235	0.65%	0.30%
1974	44,465	37,323	42	81	0.22%	0.13%
1975	44,082	35,935	41	118	0.33%	0.24%
1976	44,026	38,056	47	83	0.22%	0.10%
1977	41,550	39,605	57	138	0.35%	0.21%
1978	42,648	42,373	116	255	0.60%	0.37%
1979	44,941	45,318	152	301	0.66%	0.28%
1980	41,726	48,700	231	635	1.30%	0.80%
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%	0.71%
1992	60,771	70,825	469	1,571	2.22%	1.05%

Table 2

Patenting activity of U.S. manufacturing industries, by industry and five-year period. Patent applications refer to the number of ultimately successful patent applications filed in each year.

#	*Industry*	*SIC Codes*	*1965-69*	*1970-74*	*1975-79*	*1980-84*	*1985-89*	*1990-92*
1	Food and kindred	20	1,790	1,957	1,365	1,201	1,555	1,138
2	Textile and apparel	22,23	3,246	3,004	2,639	2,339	3,787	2,923
3	Lumber and furniture	24,25	3,028	3,052	2,877	2,160	3,149	2,539
4	Paper	26	2,738	2,312	1,924	1,626	2,493	1,859
5	Industrial chemicals	281,282,286	22,124	22,353	18,507	15,612	15,882	11,673
6	Drugs	283	2,099	2,873	3,561	4,399	8,262	6,281
7	Other chemicals	284,285,287-289	14,559	14,403	11,760	10,461	11,283	8,405
8	Petroleum refining and extraction	13,29	892	794	850	827	744	450
9	Rubber products	30	8,504	8,169	6,726	5,823	9,028	6,641
10	Stone, clay and glass products	32	2,677	2,671	2,366	2,062	2,790	2,147
11	Primary metals	33	2,245	2,183	1,689	1,340	1,710	1,156
12	Fabricated metal products	34	19,805	19,484	18,479	14,894	18,359	13,211
13	Office and computing machines	357	5,487	5,752	4,931	4,922	6,638	5,905
14	Other non-electrical machinery	351-356,358-359	60,790	61,139	52,426	42,634	48,135	35,534
15	Communication and electronic	366,367	30,838	28,380	24,679	24,302	30,417	25,793
16	Other electrical equipment	361-365,369	23,768	22,403	19,213	16,995	19,736	14,197
17	Transportation equipment	371,373-375,379	10,829	12,119	9,715	7,096	8,579	6,610
18	Aircraft and missiles	372,376	1,634	1,434	1,200	905	1,113	835
19	Professional and scientific instruments	38	18,690	19,244	17,287	15,683	21,026	17,235
20	Other machinery	21,27,31,39	13,769	15,050	15,054	12,237	16,582	13,521
	Total		249,512	248,775	217,247	187,518	231,268	178,053

Table 3

Number and dollar amount of venture capital disbursements for U.S. manufacturing industries, by industry and five-year period. The count of venture capital investments in each five-year period is the sum of the number of firms receiving investments in each year. All dollar figures are in millions of 1992 dollars.

		Panel A: Venture Capital Investments (#s)					
#	*Industry*	*1965-69*	*1970-74*	*1975-79*	*1980-84*	*1985-89*	*1990-92*
1	Food and kindred	1	9	6	23	80	41
2	Textile and apparel	4	12	9	19	27	33
3	Lumber and furniture	2	8	6	24	62	16
4	Paper	2	2	2	2	12	4
5	Industrial chemicals	1	1	1	6	18	10
6	Drugs	1	12	34	245	554	337
7	Other chemicals	1	7	8	10	52	25
8	Petroleum refining and extraction	3	3	26	92	27	8
9	Rubber products	1	5	6	19	11	3
10	Stone, clay and glass products	0	1	3	14	48	23
11	Primary metals	0	3	5	20	44	15
12	Fabricated metal products	0	0	0	2	1	1
13	Office and computing machines	39	84	108	744	641	205
14	Other non-electrical machinery	12	12	32	254	280	98
15	Communication and electronic	23	65	60	497	736	298
16	Other electrical equipment	0	6	16	36	52	28
17	Transportation equipment	1	7	5	6	24	10
18	Aircraft and missiles	0	0	0	12	20	2
19	Professional and scientific instruments	13	37	70	383	549	252
20	Other machinery	7	14	16	62	89	39
	Total	111	288	413	2,470	3,327	1,448
		Panel B: Venture Capital Disbursements (millions of 1992 $s)					
#	*Industry*	*1965-69*	*1970-74*	*1975-79*	*1980-84*	*1985-89*	*1990-92*
1	Food and kindred	4	19	7	25	212	128
2	Textile and apparel	6	15	14	27	45	83
3	Lumber and furniture	4	17	9	26	200	30
4	Paper	1	8	3	3	22	1
5	Industrial chemicals	0	1	1	41	34	16
6	Drugs	0	15	136	623	1,869	1,317
7	Other chemicals	1	40	4	9	155	27
8	Petroleum refining and extraction	12	6	92	359	110	12
9	Rubber products	1	3	15	28	8	8
10	Stone, clay and glass products	0	1	5	34	99	40
11	Primary metals	0	8	11	25	67	19
12	Fabricated metal products	0	0	0	1	0	1
13	Office and computing machines	67	404	288	3,253	2,491	613
14	Other non-electrical machinery	64	17	37	677	669	140
15	Communication and electronic	44	189	82	1,746	2,646	1,042
16	Other electrical equipment	0	8	53	78	107	41
17	Transportation equipment	0	10	4	9	47	42
18	Aircraft and missiles	0	0	0	19	19	7
19	Professional and scientific instruments	13	86	114	811	1,449	606
20	Other machinery	7	28	22	113	176	102
	Total	$225	$874	$895	$7,907	$10,423	$4,273

Table 4

Ordinary least squares regression analysis of the patent production function (ρ→0 case). The sample consists of annual observations between 1965 and 1992 of 20 National Science Foundation industries. The dependent variable is the logarithm of the number of (ultimately successful) U.S. patent applications filed by U.S. inventors in that year and industry. The independent variables are in each case the logarithms of federally and privately funded industrial R&D expenditures (in millions of 1992 dollars) and the logarithm of either the number of companies receiving venture capital financing in that year or the dollar volume of such financings (in millions of 1992 dollars). In the third and fourth regressions of Panel A and all regressions in Panel B, we employ dummy variables for each year and industry (the dummy coefficients are not reported). In the first and second regressions in Panel B, we employ the amount of seed and early-stage venture financings rather than the total amount of venture financings. In the third and fourth regressions in Panel B, we employ annual observations only of those ten industries with a R&D-to-sales ratio above the median in 1964. Standard errors are in brackets.

Panel A: Basic Regressions				
	No Dummy Variables		*Year and Industry Dummies*	
Privately funded industrial R&D (α/(1+b))	0.01	0.05	0.16	0.18
	[0.07]	[0.07]	[0.03]	[0.03]
Venture capital (αb/(1+b)):				
Firms receiving funding	0.18		0.09	
	[0.04]		[0.01]	
Venture disbursements		0.11		0.06
		[0.03]		[0.01]
Federally funded industrial R&D	0.11	0.10	0.01	0.01
	[0.03]	[0.03]	[0.01]	[0.01]
Constant	6.34	6.15		
	[0.41]	[0.41]		
Sum of squared residuals	675.16	685.49	10.78	10.94
R^2	0.12	0.11	0.99	0.99
R^2 relative to dummy variable only case			0.24	0.23
Number of observations	560	560	560	560
Panel B: Sensitivity of Results to Venture Capital Measures and Sample Definition				
	Using Early-Stage Financings		*Using High R&D Industries Only*	
Privately funded industrial R&D (α/(1+b))	0.15	0.18	0.31	0.37
	[0.03]	[0.03]	[0.05]	[0.05]
Venture capital (αb/(1+b)):				
Firms receiving funding	0.10		0.15	
	[0.01]		[0.02]	
Venture disbursements		0.06		0.09
		[0.01]		[0.01]
Federally funded industrial R&D	0.01	0.01	-0.09	-0.08
	[0.01]	[0.01]	[0.02]	[0.02]
Sum of squared residuals	10.62	10.90	5.84	6.20
R^2	0.99	0.99	0.99	0.99
R^2 relative to dummy variable only case	0.25	0.23	0.48	0.45
Number of observations	560	560	280	280

Table 5

Non-linear least squares regression analysis of the patent production function. The sample consists of annual observations between 1965 and 1992 of 20 National Science Foundation industries. The dependent variable is the logarithm of the number of (ultimately successful) U.S. patent applications filed by U.S. inventors in that year and industry. The specification that we estimate in the first and fifth regressions is $\ln(P_{it}) = (a / r)\ln(R_{it}^{\ r} + bV_{it}^{\ r}) + \text{control variables} + e_{it}$, where R_{it} denotes privately funded industrial R&D expenditures (in millions of 1992 dollars) and V_{it} the number of companies receiving venture capital financing in that year (in the first through fourth regressions) or the dollar volume of such financings (in millions of 1992 dollars) (in the fifth through eighth regressions). The control variables in each case are the logarithm of federally funded industrial R&D expenditures (in millions of 1992 dollars) and dummy variables for each year and industry (the dummy coefficients are not reported). In the second and sixth regressions, we use the same specification, but constrain the venture capital parameter to be zero. In the third and seventh regressions, ρ is constrained to be zero, so the specification is $\ln(P_{it}) = (a/(1+b))\ln(R_{it}) + (ab/(1+b))\ln(V_{it}) + \text{control variables} + e_{it}$. In the fourth and eighth regressions, ρ is constrained to be equal to one. For the second through fourth and sixth through eighth regressions, the table also reports the test statistic and p-value from a likelihood ratio test of the null hypothesis that the restricted model is valid, versus the unconstrained model. Standard errors are in brackets.

	Using Firms Receiving Venture Backing				Using Venture Disbursements			
	Unconstrained	*Constrained*			*Unconstrained*	*Constrained*		
		b=0	*r=0*	*r=1*		*b=0*	*r=0*	*r=1*
Returns to scale parameter (α)	0.25	0.25	0.26	0.25	0.22	0.25	0.24	0.22
	[0.02]	[0.03]	[0.02]	[0.02]	[0.02]	[0.03]	[0.03]	[0.02]
Venture capital parameter (b):								
Firms receiving funding	87.59	0.00	0.57	156.30				
	[121.01]	----	[0.13]	[43.06]				
Venture disbursements					29.44	0.00	0.32	51.74
					[34.46]	----	[0.03]	[14.84]
Substitution parameter (ρ)	0.90	----	0.00	1.00	0.89	----	0.00	1.00
	[0.24]	----	----	----	[0.24]	----	----	----
Federally funded industrial R&D	0.01	0.02	0.01	0.01	0.01	0.02	0.01	0.01
	[0.01]	[0.01]	[0.01]	[0.01]	[0.01]	[0.01]	[0.01]	[0.01]
Sum of squared residuals	10.17	12.23	10.78	10.18	10.21	12.23	10.94	10.21
R^2	0.99	0.98	0.98	0.99	0.99	0.98	0.98	0.99
R^2 relative to dummy variable only case	0.28	0.14	0.24	0.28	0.28	0.14	0.23	0.28
Likelihood ratio statistic		103.3	32.6	0.6		101.1	36.7	0.2
p-Value, Likelihood ratio test		0.000	0.000	0.439		0.000	0.000	0.655
Number of observations	560	560	560	560	560	560	560	560

Table 6

Ordinary least squares regression analysis of the patent production function (linear approximation to ρ=1 case). The sample consists of annual observations of 20 National Science Foundation industries. The dependent variable is the logarithm of the number of (ultimately successful) U.S. patent applications filed by U.S. inventors in that year and industry. The independent variables are in each case the logarithms of federally and privately funded industrial R&D expenditures (in millions of 1992 dollars) and the logarithm of the ratio of either the number of companies receiving venture capital financing in that year or the dollar volume of such financings (in millions of 1992 dollars) to privately funded R&D. In the third and fourth regressions, we employ annual observations only of those ten industries with a R&D-to-sales ratio above the median in 1964. Standard errors are in brackets.

	Year and Industry Dummies		*Using High R&D Industries Only*	
Privately funded industrial R&D (α)	0.25	0.24	0.38	0.37
	[0.03]	[0.03]	[0.04]	[0.05]
Venture capital / Privately funded R&D (αb):				
Firms receiving funding	6.49		21.30	
	[0.94]		[2.80]	
Venture disbursements		1.73		5.14
		[0.26]		[0.75]
Federally funded industrial R&D	0.01	0.01	-0.07	-0.07
	[0.01]	[0.01]	[0.02]	[0.02]
Sum of squared residuals	11.18	11.26	6.21	6.45
R^2	0.99	0.99	0.99	0.99
R^2 relative to dummy variable only case	0.21	0.20	0.45	0.43
Number of observations	560	560	280	280

Table 7

Difference regression analysis of the patent production function (ρ→0 and linear approximation to ρ=1 cases). The sample consists of differenced observations of 20 National Science Foundation industries at four intervals covering 1965 to 1992. The dependent variable is the difference between the four-year average (e.g., between 1973 and 1976) of the logarithm of the number of (ultimately successful) U.S. patent applications filed by U.S. inventors in that year and industry and the four-year average eight years earlier (e.g., that in the 1965 to 1968 period). In the first and second regressions, we employ the specification used in Table 4 (the ρ→0 case); in the third and fourth regressions, we employ the linear approximation to the non-linear regression estimated in Table 6 (the ρ=1 approximation). The independent variables are in each case the differences between the four-year averages of the logarithms of federally and privately funded industrial R&D expenditures (in millions of 1992 dollars) and either the number of companies receiving venture capital financing in that year or the dollar volume of such financings (in the first two regressions, the logarithm of the venture capital measures is used; in the third and fourth, the ratio of the venture measures to privately funded R&D) and the values eight years earlier, as well as dummy variables for the time periods (the dummy coefficients are not reported). Standard errors are in brackets.

	r ®0 case		*Approximation to r=1 case*	
Difference in Privately funded industrial R&D	0.17 [0.08]	0.17 [0.08]	0.24 [0.07]	0.22 [0.07]
Difference in Venture capital:				
Firms receiving funding	0.08 [0.03]			
Venture disbursements		0.06 [0.02]		
Difference in Venture capital / Privately funded R&D:				
Firms receiving funding			7.40 [3.70]	
Venture disbursements				2.29 [1.04]
Difference in Federally funded industrial R&D	0.02 [0.02]	0.02 [0.02]	0.03 [0.02]	0.02 [0.02]
Sum of squared residuals	1.31	1.29	1.38	1.36
R^2	0.82	0.83	0.81	0.82
R^2 relative to dummy variable only case	0.28	0.29	0.24	0.25
Number of observations	60	60	60	60

Table 8

Instrumental variable (IV) regression analysis of the patent production function (linear approximation to ρ=1 case). The sample consists of annual observations between 1965 and 1992 of 20 National Science Foundation industries. The dependent variable is the logarithm of the number of (ultimately successful) U.S. patent applications filed by U.S. inventors in that year and industry. The specification that we estimate is the linear approximation to non-linear estimation employed in Table 6, with privately funded industrial R&D expenditures (in millions of 1992 dollars) and the ratio of the number of companies receiving venture capital financing in that year or the dollar volume of such financings (in millions of 1992 dollars) to privately funded R&D as independent variables. The control variables in each case are the logarithm of federally funded industrial R&D expenditures (in millions of 1992 dollars) and dummy variables for each year and industry (the dummy coefficients are not reported). In the first and second regressions, we employ as an instrument a variable that equals zero if the observation is from before 1979, and otherwise equals the average value between 1965 and 1978 of the ratio of either the number of companies receiving venture capital financing or the dollar volume of such financings (in millions of 1992 dollars) divided by the privately funded R&D spending. In the third and fourth regressions, we employ a similar dummy variable, but only use observations between 1965 and 1975 to compute the ratio. We also use the gross industry product (in millions of 1992 dollars) as an instrumental variable for privately funded R&D. Standard errors (in brackets) are based on the Newey-West autocorrelation-consistent covariance estimator (with a maximum of three lags).

	IV Computed Using 1965 to 1978 Period		*1965-1975 IV; Also GDP as IV*	
Privately funded industrial R&D (α)	0.25	0.23	0.52	0.55
	[0.06]	[0.06]	[0.10]	[0.14]
Venture capital / Privately funded R&D (αb):				
Firms receiving funding	8.69		5.74	
	[2.89]		[3.77]	
Venture disbursements		3.19		-0.36
		[1.19]		[2.04]
Federally funded industrial R&D	0.01	0.01	0.02	0.02
	[0.01]	[0.01]	[0.01]	[0.02]
Sum of squared residuals	11.30	11.96	13.47	14.59
R^2	0.99	0.98	0.98	0.98
R^2 relative to dummy variable only OLS case	0.20	0.16	0.05	-0.03
Number of observations	560	560	560	560

Table 9

Ordinary least squares levels and difference regression analyses of the patent-R&D ratio. The sample in Panel A consists of annual observations between 1965 and 1992 of 20 National Science Foundation industries; in Panel B, the sample consists of differenced observations of the 20 industries at four intervals. The dependent variable in the first two regressions of Panel A is the logarithm of the number of (ultimately successful) U.S. patent applications filed by U.S. inventors in that year and industry minus the logarithm of privately funded industrial R&D spending (in millions of 1992 dollars). The dependent variable in the third and fourth regressions of Panel A is the logarithm of the number of (ultimately successful) U.S. patent applications filed by U.S. inventors in that year and industry minus the logarithm of privately funded industrial R&D spending plus the logarithm of gross industry product (both in millions of 1992 dollars). In Panel B, the dependent variables are the differences between the four-year average (e.g., between 1973 and 1976) of the dependent variables in Panel A and the four-year average eight years earlier (e.g., that in the 1965 to 1968 period). The independent variable in Panel A is the ratio of number of companies receiving venture capital financing in that year or the dollar volume of such financings (in millions of 1992 dollars) to privately funded R&D. In Panel B, this variable is differenced in the same manner as the dependent variable. In Panel A, we employ dummy variables for each year and industry; in Panel B, dummy variables for the time periods. (The dummy coefficients are not reported.) Standard errors are in brackets. In Panel A, they are based on the Newey-West autocorrelation-consistent covariance estimator (with a maximum of three lags).

Panel A: Levels Regressions

	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	7.31		9.03	
	[2.50]		[2.67]	
Venture disbursements		1.45		2.70
		[0.55]		[0.85]
Sum of squared residuals	28.91	29.56	34.32	33.97
R^2	0.97	0.97	0.97	0.97
R^2 relative to dummy variable only case	0.04	0.02	0.06	0.07
Number of observations	560	560	560	560

Panel B: Difference Regressions

	Dependent Variable			
	Difference in $ln(P_{it})-ln(R_{it})$		Difference in $ln(P_{it})-ln(R_{it})+ln(Y_{it})$	
Difference in Venture capital / Privately funded R&D (b):				
Firms receiving funding	7.76		15.15	
	[6.21]		[6.96]	
Venture disbursements		0.89		5.08
		[1.77]		[1.92]
Sum of squared residuals	4.04	4.14	5.07	4.89
R^2	0.71	0.70	0.65	0.64
R^2 relative to dummy variable only case	0.03	0.01	0.08	0.11
Number of observations	60	60	60	60

Table 10

Comparisons of intellectual property activities of venture-backed and non-venture-backed firms. The sample consists of 530 firms based in Middlesex County, Massachusetts. The second and third columns present the means for 122 venture-backed and 408 non-venture-backed firms on several measures of intellectual property activities. "Patents" is the number of patent filings by the firm and its subsidiaries between January 1990 and June 1994. "Citations/patent" is the ratio of citations in patents awarded between January 1990 and June 1994 to patents awarded to the firm and its subsidiaries between 1969 and 1989, divided by the number of patents awarded to the firm and its subsidiaries between 1969 and 1989. (This ratio is only calculated for firms that were awarded patents during the 1969-1989 period.) "Patent expiration" indicates the fraction of patents awarded each firm between 1981 and 1989 that had expired by their fourth, eighth and twelfth anniversaries. (This ratio is only calculated for firms that were awarded patents during the 1981-1989 period.) The final rows indicate the number of intellectual property suits (both in aggregate and for patents and trade secrets only) that were open in Middlesex County Superior Court or the Federal District for Massachusetts between January 1990 and June 1994, and the number of docket filings in these cases in this period. The fourth and fifth columns present p-values from t-tests of the equality of means and Wilcoxon tests of the equality of medians.

	Mean for Firms that are…		p-Value, Comparison of …	
	Venture-Backed	*Non-Venture*	*Means*	*Medians*
Patents, 1990 to mid-1994	12.74	2.40	0.029	0.000
Citations/patent	6.44	4.06	0.016	0.004
Patent expiration:				
At 4 years	0.15	0.18	0.619	0.660
At 8 years	0.42	0.29	0.141	0.165
At 12 years	0.39	0.30	0.320	0.281
Intellectual property suits:				
Number of suits	0.79	0.18	0.000	0.000
Number of docket filings	30.29	4.21	0.000	0.000
Patent suits only:				
Number of suits	0.36	0.08	0.000	0.000
Number of docket filings	15.35	2.04	0.000	0.000
Trade secret suits only:				
Number of suits	0.34	0.08	0.000	0.000
Number of docket filings	6.43	1.86	0.007	0.000

Table 11

Regression analyses of patenting, patent citation, and patent expiration patterns of venture-backed and non-venture-backed firms. The sample consists of 530 firms based in Middlesex County, Massachusetts. (The analysis in Panel B only includes firms that were awarded patents during the 1969-1989 period; in Panel C, those awarded patents between 1981 and 1989.) In the first panel, the dependent variable is the number of patent filings by the firm and its subsidiaries between January 1990 and June 1994. In the second panel, the dependent variable is the number of citations in patents awarded between January 1990 and June 1994 to patents awarded to the firm and its subsidiaries between 1969 and 1989. In the third panel, the dependent variable is fraction of patents awarded the firm between 1981 and 1989 that had expired by the fourth anniversary. The independent variables include the employment and sales of the firm in January 1990, the year the firm was founded, dummy variables denoting whether the firm was publicly traded and venture backed in January 1990 (as well as interactions between these terms), (in all regressions other than the renewal analysis) dummy variables for the two-digit Standard Industrial Classification code of the firm (not reported), and (in the citation and renewal analyses only) the number of patents awarded to the firm and its subsidiaries between 1969 and 1989. In each case, the dummies are coded as 1.0 if the answer to the posed question is in the affirmative. The patent award and renewal analyses employ a Poisson regression specification; the expiration analysis, a double-censored Tobit regression. Absolute t-statistics in brackets.

Panel A: Dependent Variable is Patent Awards Between 1990 and 1994				
	With No Interaction Terms		*With Interaction Terms*	
Firm Sales in 1990 ($ billions)	0.33 [64.26]		0.33 [64.04]	
Firm Employment in 1990 (000s)		0.18 [29.65]		0.18 [30.22]
Year Firm was Founded	-0.01 [5.78]	-0.003 [1.64]	-0.01 [4.71]	-0.001 [0.89]
Publicly Traded at End of 1989?	1.91 [29.23]	1.60 [22.14]	2.23 [25.12]	2.13 [22.43]
Venture Backed at End of 1989?	0.77 [11.56]	0.49 [6.74]		
Venture Backed and Public?			0.56 [7.46]	0.05 [0.53]
Venture Backed and Private?			1.24 [11.68]	1.29 [11.83]
Log likelihood	-1572.3	-1286.9	-1556.7	-1242.1
χ^2-Statistic	13589.0	3204.9	13620.2	3294.4
p-Value	0.000	0.000	0.000	0.000
Number of observations	428	419	428	419
Panel B: Dependent Variable is Citations to Earlier Patent Awards Between 1990 and 1994				
	With No Interaction Terms		*With Interaction Terms*	
Firm Sales in 1990 ($ billions)	0.15 [77.91]		0.15 [77.68]	
Firm Employment in 1990 (000s)		0.12 [55.07]		0.13 [55.31]
Year Firm was Founded	-0.01 [24.27]	-0.01 [22.84]	-0.01 [24.03]	-0.01 [22.26]
Publicly Traded at End of 1989?	1.82 [60.09]	1.53 [48.12]	1.85 [45.70]	1.78 [43.79]
Venture Backed at End of 1989?	0.47 [17.81]	0.18 [6.07]		
Venture Backed and Public?			0.46 [16.05]	0.02 [0.71]
Venture Backed and Private?			0.52 [10.00]	0.66 [12.45]
Patent Awards, 1969-89 (000s)	1.03 [85.46]	0.62 [41.25]	1.03 [83.98]	0.57 [36.53]
Log likelihood	-4746.2	-3701.3	-4745.5	-3644.8
χ^2-Statistic	48942.6	30509.2	48943.8	30622.1
p-Value	0.000	0.000	0.000	0.000
Number of observations	142	140	142	140
Panel C: Dependent Variable is Probability of Patent Expiration by Fourth Anniversary				
	With No Interaction Terms		*With Interaction Terms*	
Firm Sales in 1990 ($ billions)	-0.08 [1.00]		-0.09 [1.07]	
Firm Employment in 1990 (000s)		-0.08 [1.19]		-0.07 [1.23]
Year Firm was Founded	-0.01 [2.63]	-0.01 [2.69]	-0.01 [2.66]	-0.01 [2.72]
Publicly Traded at End of 1989?	-0.05 [0.29]	0.01 [0.06]	-0.19 [0.86]	-0.14 [0.62]
Venture Backed at End of 1989?	0.07 [0.38]	0.09 [0.48]		
Venture Backed and Public?			0.25 [0.98]	0.29 [1.11]
Venture Backed and Private?			-0.09 [0.37]	-0.08 [0.33]
Patent Awards, 1969-89 (000s)	0.29 [0.31]	0.87 [0.74]	0.41 [0.44]	0.96 [0.83]
Log likelihood	-100.86	-99.33	-100.34	-98.74
χ^2-Statistic	9.03	9.63	10.06	10.81
p-Value	0.108	0.086	0.122	0.094
Number of observations	124	122	124	122

Table 12

Poisson regression analyses of intellectual property litigation patterns of venture-backed and non-venture-backed firms. The sample consists of 530 firms based in Middlesex County, Massachusetts. In the first panel, the dependent variable is the number of docket filings in all intellectual property suits involving the firm and its subsidiaries that were open in Middlesex County Superior Court or the Federal District for Massachusetts between January 1990 and June 1994. In the second panel, the dependent variable is the number of docket filings in patent cases only; in the third, the number in trade secret cases. The independent variables include the employment and sales of the firm in January 1990, the year the firm was founded, dummy variables denoting whether the firm was publicly traded and venture backed in January 1990 (as well as interactions between these terms), and dummy variables for the two-digit Standard Industrial Classification code of the firm (not reported). In each case, the dummies are coded as 1.0 if the answer to the posed question is in the affirmative. Absolute t-statistics in brackets.

Panel A: Dependent Variable is Filings in Intellectual Property Suits Between 1990 and 1994				
	With No Interaction Terms		*With Interaction Terms*	
Firm Sales in 1990 ($ billions)	0.14 [34.47]		0.14 [34.50]	
Firm Employment in 1990 (000s)		0.14 [44.47]		0.14 [44.06]
Year Firm was Founded	-0.002 [2.30]	0.01 [4.65]	-0.003 [3.32]	0.005 [4.19]
Publicly Traded at End of 1989?	2.50 [68.10]	2.31 [60.11]	2.09 [39.23]	2.08 [38.76]
Venture Backed at End of 1989?	1.15 [32.14]	0.89 [24.39]		
Venture Backed and Public?			1.36 [32.14]	1.02 [23.67]
Venture Backed and Private?			0.59 [9.13]	0.58 [8.86]
Log likelihood	-7391.3	-6501.7	-7336.3	-6484.6
χ^2-Statistic	14825.8	14080.5	14935.9	14114.7
p-Value	0.000	0.000	0.000	0.000
Number of observations	428	419	428	419
Panel B: Dependent Variable is Filings in Patent Suits Between 1990 and 1994				
	With No Interaction Terms		*With Interaction Terms*	
Firm Sales in 1990 ($ billions)	0.12 [19.88]		0.13 [20.33]	
Firm Employment in 1990 (000s)		0.21 [40.75]		0.21 [40.28]
Year Firm was Founded	-0.01 [7.94]	0.01 [3.66]	-0.01 [8.58]	0.01 [3.38]
Publicly Traded at End of 1989?	2.36 [46.26]	1.95 [35.15]	1.89 [25.08]	1.63 [20.28]
Venture Backed at End of 1989?	1.52 [29.80]	1.24 [23.34]		
Venture Backed and Public?			1.75 [28.98]	1.40 [22.53]
Venture Backed and Private?			0.92 [10.04]	0.82 [8.83]
Log likelihood	-4324.8	-3253.1	-4291.8	-3237.9
χ^2-Statistic	9237.7	10610.4	9303.8	10640.6
p-Value	0.000	0.000	0.000	0.000
Number of observations	428	419	428	419
Panel C: Dependent Variable is Filings in Trade Secret Suits Between 1990 and 1994				
	With No Interaction Terms		*With Interaction Terms*	
Firm Sales in 1990 ($ billions)	0.01 [0.89]		0.01 [0.89]	
Firm Employment in 1990 (000s)		0.04 [4.70]		0.04 [4.70]
Year Firm was Founded	0.01 [8.32]	0.02 [8.49]	0.01 [8.32]	0.02 [8.49]
Publicly Traded at End of 1989?	2.30 [38.08]	2.23 [36.61]	2.29 [29.02]	2.24 [28.36]
Venture Backed at End of 1989?	0.43 [7.21]	0.38 [6.31]		
Venture Backed and Public?			0.44 [6.19]	0.37 [5.24]
Venture Backed and Private?			0.42 [4.12]	0.39 [3.88]
Log likelihood	-2970.6	-2925.5	-2970.6	-2925.5
χ^2-Statistic	3154.4	3119.7	3154.4	3119.8
p-Value	0.000	0.000	0.000	0.000
Number of observations	428	419	428	419

Appendix: Data Sources

1. The Industry Data Set

Patent applications. The patent data by industry are from Kortum [1992], updated using information on U.S. patent awards by technology class in a variety of databases prepared by the U.S. Patent and Trademark Office (USPTO). We compile from these databases the number of successful patents applied for by U.S. inventors in each year. Because of variations in the speed with which the USPTO handles patent applications (in particular, the periodic slow-downs associated with budget crises [Griliches, 1989]), it is preferable to compile the number of successful applications filed each year, rather than the awards granted annually. This information is not known until all patents filed in a given year are issued. Thus, while we can be confident about essentially how many successful patent applications were filed in 1980, the number of successful applications filed in 1995 is still quite uncertain.

Concerns about data incompleteness determined the last year of the analysis. While we can project from preliminary data (e.g., the number of patent applications filed in 1992 that were awarded through 1996) how many applications filed in each year will ultimately be granted, we do not wish to have to make large imputations. Consequently, we only extend the analysis through 1992.

In addition to defining the time frame of the analysis, we have to consider which patents to include in the analysis. USPTO databases compile not only awards to U.S. inventors, but also those to foreign firms and individuals seeking protection in the U.S. market. Because we seek a proxy for the innovative output of the United States, we drop patents that were not originally filed in the United States.

The USPTO does not compile total patent applicants by industry. Even though we know the names of the applicants, many of these firms have multiple lines-of-business. Thus, we rely instead on a concordance that relates the primary classification to the most likely industry of the inventing firm in which the patent is classified. This concordance, based on a study of Canadian patenting behavior, employs the International Patent Classification to which the patent is assigned to determine the industry where it is likely to be used.

One challenge with both compilations of patent awards is the need to adjust the number of recent patent awards. While we exclude from the sample (as discussed above) patent applications from recent years, a few patents applied for in the early 1990s will not be awarded until the first decade of the 21st century. We adjust the observed counts of patent awards between 1987 and 1992 upward to reflect the number of patents that can expected to be awarded based on historical patterns.

Venture capital disbursements. The consulting firm Venture Economics compiles investments by venture capital funds (also known as disbursements). Venture capital organizations and major institutional investors provide quarterly reports to Venture Economics on their portfolio holdings, in exchange for summary data on investments and returns. This data have been collected since the formation of Venture Economics' predecessor entity, S.M. Rubel and Co., in 1961. While Venture Economics does not obtain reports on all funds, because multiple venture groups invest in a typical venture-backed firm, the database identifies at least 85% of all venture capital transactions [Lerner, 1995].

We obtain Venture Economics tabulations that list total disbursements by the industry of the firm receiving the financing. The industry codes are classified according to a proprietary scheme developed by Venture Economics. We map these into our industry classification scheme, with the help of a concordance between the Venture Economics and the Standard Industrial Classification (SIC) codes.

One complex question is what constitutes a venture capital investment. Until the late 1970s, there were not distinct funds set up to make investments in leveraged buyout transactions. Rather, venture capital groups would invest into a wide variety of transactions: seed and early-stage financings, expansion rounds of rapidly-growing entrepreneurial firms, and buyouts and other special situations (e.g., purchases of blocks of publicly traded securities). Since the 1970s, most buyout investing by private equity funds has been done through specialized funds dedicated to these transactions (e.g., Kohlberg, Kravis, and Roberts). Some venture capital funds, however, have continued to invest in buyouts (this was a particularly common phenomenon in the mid-1980s) and other special situations. Meanwhile, some groups frequently classified as buyout specialists (such as Welch, Carson, Anderson, and Stowe) also make a considerable number of venture capital investments.

We wish to focus our analysis on the relationship between innovation and investments in growing firms where the types of information problems that venture capitalists address are most critical. While many buyouts create value by eliminating inefficiencies and improving cash flows, these types of transactions are outside the focus of this paper. The standard tabulation of venture capital investments prepared by Venture Economics includes investments by venture capital funds into both venture transactions and buyouts, as well as venture investments by groups classified as buyout funds. We undertake a special tabulation of the venture capital investments only, whether made by groups classified as venture capital or buyout funds. To insure compatibility with the other data series, we include only investments into firms based in the United States (whether the venture fund was based domestically or not). In order to test the robustness of our results, we also compile the seed and early-stage investments by these funds using a similar approach. We collect both the dollar amount invested and the number of companies funded in each year.

R&D expenditures. We compile information on privately and federally funded R&D performed by industry from the U.S. National Science Foundation (NSF). Both data series have been compiled since 1957 as part of the "Survey of Research and Development in Industry," using an industry scheme unique to NSF. Occasionally, data series for smaller industries are suppressed in particular years. In these cases, it is necessary to extrapolate based on the relative level of R&D spending in previous years.[26] We slightly collapse this scheme to insure

26. The NSF will not report data when one or two firms account for the majority of the R&D in an industry or when firms representing more than one-half the R&D spending do not respond to the survey. Ideally, we would also have compiled expenditures by universities relevant to each

comparability with the patent classification discussed above, for a total of twenty industries. The R&D data are summarized in Tables A-1 and A-2.

Gross industry product. The Department of Commerce's Bureau of Economic Analysis has estimated gross product by industry for the two-digit SIC classes, as well as some important three-digit classes, using the current definitions of these industries. Not all three-digit SIC codes necessary for this analysis are compiled in their database. For the missing industries, we collect this information from the printed volumes of the *Annual Survey of Manufacturers*. While this does not report gross product by industry, it does compile a related measure, value added. In each case, we examine the distribution of value added across the three-digit industry classes, and then assign the two-digit industry's gross product in a proportionate manner. Where necessary, we adjust the categories reported in these volumes to reflect today's classification structures. (For instance, prior to 1972, guided missiles were included in SIC 19, "ordnance and accessories." When that category was disbanded, they were moved to SIC 37, "transportation equipment").

Book and market equity values. A frequently employed proxy for the extent of information problems is the ratio of a firm's market and book values of equity. In an ideal setting, we might have calculated such ratios for the privately held firms in the industry, or those contemporaneously receiving venture financing, but accounting and valuation data are difficult to obtain for privately held firms. Thus, following the lead of Gompers [1995], we compute the ratio of these measures for the firms in the industry that are publicly traded.

Because of concerns about back-filling in the Compustat data [discussed in Chan, Jegadeesh, and Lakonishok, 1995], we compute these ratios only using firms traded on the New York and American Stock Exchanges. We compute the ratio of the book-to-market equity (rather market-to-book) values because for some firms, the book value can be zero or negative. We calculate three measures at the beginning of the year of the observation: the average ratio across all firms in the industry, the average when weighted by the market value of each firm, and the median ratio.[27] We examine all quarterly observations of publicly traded firms in the same industry. Using data from Compustat and the Center for Research into Security Prices (CRSP), we compute the book value of common equity as well as the market value of the common stock. We define the book value as the par value of the common shares, plus retained earnings and paid-in capital, less the par value of any common stock held as treasury stock.

2. The Firms Data Set

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industry. Associating the classes of academic research with particular industries, however, proved problematic.

27. Because the average ratio can be affected by extreme outliers (some distressed firms may have substantial liabilities and negative book values; some inactive firms have very low market capitalizations while retaining substantial assets), it has a much greater variance than the other measures. All three measures, however, are highly correlated. When no quarterly observations are available, we use annual data.

In order to assess the behavior of firms at a more disaggregated level, we examine firms whose headquarters are in a single county, Middlesex County, Massachusetts. We include in the sample all 130 manufacturing firms based here that were publicly traded between January 1990 and June 1994, as well as a random sample of 400 such firms that were privately held. By using a sample of firms in one region, rather than a diverse array of locations, we can examine their innovative activities in more depth.[28]

Middlesex County includes much of the "Route 128" high-technology complex, as well as concentrations of more traditional manufacturers. The first four columns of Table A-3 contrast the mix of industrial establishments and employment in the U.S. and Middlesex County in 1990. The comparison indicates that the mixture of traditional industry in the county is fairly representative of the nation as a whole. Technology-intensive sectors, however, are disproportionately represented.

We include all firms in Compustat with headquarters in Middlesex County that file financial data with the U.S. Securities and Exchange Commission for any quarter between the first quarter of 1990 and the second quarter of 1994. Following the analysis above, we confine our analysis to manufacturing firms (Standard Industrial Codes 20-39), but also include firms in SIC codes 7372 and 7373, who make packaged software and operating systems for mainframe computers.[29] We exclude shell companies that are established merely to make an acquisition and "SWORDs," publicly traded subsidiaries that finance R&D. After these deletions, the sample consists of 130 firms.

Publicly traded firms are likely to have different characteristics than other companies. Thus, we seek to include a representative sample of private firms as well. There is no single directory that lists all the firms in the county. Conversations with economic development officials, however, indicate that two directories taken together provide quite comprehensive coverage of manufacturing firms. *George D. Hall's Directory of Massachusetts Manufacturers*, which is prepared with the cooperation of the Associated Industries of Massachusetts, provides the most detailed listing of traditional manufacturers, while the *Corporate Technology Directory* specializes in high-technology firms. We draw 200 firms based in Middlesex County each from these directories. In both cases, the information is collected via a survey (and, in the case of *Hall's*, through consultation with the records of the Associated Industries of Massachusetts). All firms were required to have been in

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28. In particular, we can examine not only patent filings but also intellectual property litigation. In both the federal and state court systems, intellectual property cases are often not identified as such by the courts' internal tracking systems. They are often recorded simply as "miscellaneous tort" or "contract" disputes, depending upon the circumstances of the case. We do not use the firms' 10-K filings with the U.S. Securities and Exchange Commission to identify litigation for two reasons. First, we wish to include in our sample privately held firms, which need not make such filings. Second, while firms are required to report any material litigation in these filings, they are often highly selective in the suits that they actually disclose.

29. Our rationale is that while software manufacturers are classified as service providers, their relationship with customers is more akin to that of manufacturers. The analyses below are robust to the deletion of these observations.

business by the end of 1989, though some exit (e.g., through bankruptcy or liquidation) during the sample period.

The fifth and sixth columns of Table A-3 compare the firms in the sample with those in the nation and county. We classify the public firms in our sample into industries using the primary SIC provided by Compustat; for the other firms, we employ the SIC code of the first-listed line-of-business in the *Hall's* and *Corporate Technology* directories. (Both directories list lines-of-business in order of importance, as reported by the firm.)[30]

We obtain a variety of information about these firms. From Compustat or the two business directories, we determine the sales and employment in 1990, as well as the year in which the firm was founded. From CRSP, we determine if and when the firm went public. We determine whether the firm was venture-backed from Venture Economics. We also use the number of patents that the firm has been awarded in the period 1969 through 1994 (as well as citations to these awards), which we identify using Mead's LEXIS/PATENT/ALL file and the USPTO's CASSIS CD-ROM database. (We include awards to subsidiaries, R&D limited partnerships, and earlier names, which we identify through the data sources cited below.) We determine whether patents have been renewed using a database of all patent expirations between the inception of the patent renewal system in December 1980 and December 1997.

We finally identify all litigation involving these firms in the federal and state judicial districts that include their headquarters: the Federal District for Massachusetts and the Commonwealth of Massachusetts' Middlesex Superior Court. Both systems include every lawsuit that was open during the sample period, even if the suit was settled almost immediately after the initial complaint was filed. We identify 1144 cases that were open on January 1, 1990 or were filed between January 1, 1990 and June 30, 1994. After eliminating those cases that are very unlikely to involve intellectual property issues, we examined the remaining case files.[31] The docket records also allow us to compute the total number of docket filings by the plaintiffs, defendants, and other parties in the dispute between January 1, 1990 and June 30, 1994. (This approach to characterizing

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30. The comparison of the sample with the federal and county data is not precise for three reasons. First, the tabulation of the sample firms shows the distribution of firms; the U.S. and county columns present the pattern of establishments. (Many firms will have multiple establishments.) Second, firms with less than twenty employees are only sampled in *County Business Patterns*, and thus are underrepresented. The two directories appear to have quite comprehensive coverage of smaller firms, who generally welcome the visibility that a listing provides. Consequently, industries with many small firms may have greater representation in the sample. Finally, the tabulation of employment in the sample firms includes employees that work in Middlesex County and elsewhere. The county tabulation presents the distribution of employees working in Middlesex County, regardless of where the parent firm has its headquarters.

31. In addition, we could not examine nine dockets that may or may not have involved intellectual property issues. These cases had been either lost or sealed. (While most of the case files were accessible at the clerk of the court's offices at the two courthouses, we found many case files in off-site storage archives, in courthouses elsewhere in the county or state, or in the possession of judges' docket clerks.)

disputes was also used in the Georgetown antitrust study [White, 1988].) The records do not provide information on the extent of activity at the appellate level. Thus, they may tend to understate the magnitude of litigation in cases that are appealed.

Table A-4 characterizes the venture-backed and non-venture-backed firms in the sample. The 122 venture-backed firms are significantly larger in sales and employment than the 408 non-venture-backed firms, and are more likely to be publicly traded. They tend to have been founded later, and (as a result) have accumulated a smaller stock of patents. The venture-backed firms are concentrated in high-technology industries, as the final three lines of each panel in Table A-4 illustrate. First, the average ratio of R&D-to-sales of all public firms that reported R&D data in 1990 with a primary assignment in Compustat to the same four-digit SIC code as the venture-backed firms is higher than the ratios of the companies matched to the non-venture-backed firms. Similar patterns emerge from two responses to the Yale survey on intellectual property [described in Levin, *et al.*, 1987]. The "Yale Rating" refers to the average rating of the importance of patents and trade secrecy (on a 1 to 6 scale, with larger numbers indicating greater importance) of firms in the same three-digit SIC code. Respondents in the same industry as the venture-backed firms tended to give higher ratings to the importance of both forms of protection.

3. Data Sources

Patent Applications:

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Table A-1

R&D expenditures by U.S. manufacturing industries, by industry and five-year period. All figures are in millions of 1992 dollars.

#	*Industry*	*1965-69*	*1970-74*	*1975-79*	*1980-84*	*1985-89*	*1990-92*
1	Food and kindred	3,271	3,741	4,333	5,643	7,231	4,032
2	Textile and apparel	962	909	869	1,002	1,376	781
3	Lumber and furniture	269	945	1,204	1,111	936	670
4	Paper	2,419	2,871	3,554	4,019	3,980	3,520
5	Industrial chemicals	14,780	13,582	14,376	18,587	22,023	15,518
6	Drugs	6,384	9,033	12,365	17,870	25,730	21,395
7	Other chemicals	3,191	4,105	4,504	6,776	10,826	7,086
8	Petroleum refining and extraction	7,135	7,423	8,784	13,657	12,207	7,270
9	Rubber products	3,089	3,738	3,559	4,330	4,054	3,572
10	Stone, clay and glass products	2,430	2,535	2,734	3,625	4,898	1,521
11	Primary metals	4,293	4,231	5,070	4,916	4,222	2,006
12	Fabricated metal products	2,812	3,664	3,578	4,343	4,390	2,278
13	Office and computing machines	10,802	17,045	23,398	35,485	53,779	33,061
14	Other non-electrical machinery	8,455	10,226	12,543	15,849	14,596	9,445
15	Communication and electronic	16,902	20,262	22,106	37,661	50,187	20,711
16	Other electrical equipment	12,483	13,903	13,764	13,597	8,560	7,722
17	Transportation equipment	19,713	25,133	30,340	34,324	46,152	28,489
18	Aircraft and missiles	19,104	16,631	17,043	27,177	34,692	18,113
19	Professional and scientific instruments	6,958	10,259	14,748	24,186	30,321	21,101
20	Other machinery	1,580	2,094	2,417	3,094	2,342	1,763
	Total	$147,032	$172,328	$201,288	$277,251	$342,501	$210,055

Table A-2

Ratio of venture capital disbursements to R&D expenditures for U.S. manufacturing industries, by industry and five-year period. 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.

Panel A: All Venture Capital Disbursements/R&D Spending							
#	*Industry*	*1965-69*	*1970-74*	*1975-79*	*1980-84*	*1985-89*	*1990-92*
1	Food and kindred	0.14%	0.50%	0.16%	0.44%	2.93%	3.18%
2	Textile and apparel	0.57%	1.68%	1.59%	2.72%	3.24%	10.59%
3	Lumber and furniture	1.44%	1.77%	0.72%	2.32%	21.39%	4.40%
4	Paper	0.06%	0.28%	0.10%	0.08%	0.56%	0.03%
5	Industrial chemicals	0.00%	0.00%	0.01%	0.22%	0.15%	0.10%
6	Drugs	0.01%	0.17%	1.10%	3.49%	7.26%	6.16%
7	Other chemicals	0.03%	0.98%	0.09%	0.13%	1.43%	0.38%
8	Petroleum refining and extraction	0.16%	0.08%	1.04%	2.63%	0.90%	0.17%
9	Rubber products	0.04%	0.07%	0.42%	0.64%	0.20%	0.21%
10	Stone, clay and glass products	0.00%	0.02%	0.19%	0.93%	2.01%	2.62%
11	Primary metals	0.00%	0.19%	0.21%	0.51%	1.59%	0.94%
12	Fabricated metal products	0.00%	0.00%	0.00%	0.03%	0.01%	0.03%
13	Office and computing machines	0.62%	2.37%	1.23%	9.17%	4.63%	1.85%
14	Other non-electrical machinery	0.75%	0.16%	0.30%	4.27%	4.58%	1.48%
15	Communication and electronic	0.26%	0.93%	0.37%	4.64%	5.27%	5.03%
16	Other electrical equipment	0.00%	0.06%	0.38%	0.57%	1.25%	0.53%
17	Transportation equipment	0.00%	0.04%	0.01%	0.03%	0.10%	0.15%
18	Aircraft and missiles	0.00%	0.00%	0.00%	0.07%	0.05%	0.04%
19	Professional and scientific instruments	0.19%	0.84%	0.77%	3.35%	4.78%	2.87%
20	Other machinery	0.46%	1.34%	0.90%	3.65%	7.51%	5.81%
Panel B: Early-Stage Venture Capital Disbursements/R&D Spending							
#	*Industry*	*1965-69*	*1970-74*	*1975-79*	*1980-84*	*1985-89*	*1990-92*
1	Food and kindred	0.14%	0.22%	0.05%	0.14%	1.69%	2.17%
2	Textile and apparel	0.36%	0.90%	0.79%	0.67%	1.46%	3.05%
3	Lumber and furniture	0.00%	0.74%	0.51%	1.19%	11.23%	2.07%
4	Paper	0.00%	0.28%	0.00%	0.08%	0.21%	0.01%
5	Industrial chemicals	0.00%	0.00%	0.00%	0.21%	0.04%	0.07%
6	Drugs	0.01%	0.14%	0.92%	2.53%	4.40%	3.39%
7	Other chemicals	0.00%	0.62%	0.03%	0.10%	0.55%	0.21%
8	Petroleum refining and extraction	0.13%	0.08%	0.56%	1.40%	0.59%	0.11%
9	Rubber products	0.00%	0.05%	0.32%	0.41%	0.17%	0.00%
10	Stone, clay and glass products	0.00%	0.02%	0.00%	0.50%	1.37%	1.46%
11	Primary metals	0.00%	0.15%	0.12%	0.46%	1.35%	0.17%
12	Fabricated metal products	0.00%	0.00%	0.00%	0.00%	0.01%	0.00%
13	Office and computing machines	0.55%	1.32%	0.73%	4.21%	1.74%	0.87%
14	Other non-electrical machinery	0.68%	0.08%	0.12%	2.08%	2.11%	0.49%
15	Communication and electronic	0.19%	0.46%	0.16%	2.68%	2.69%	1.97%
16	Other electrical equipment	0.00%	0.04%	0.20%	0.33%	0.69%	0.27%
17	Transportation equipment	0.00%	0.03%	0.00%	0.00%	0.04%	0.01%
18	Aircraft and missiles	0.00%	0.00%	0.00%	0.02%	0.01%	0.04%
19	Professional and scientific instruments	0.10%	0.65%	0.26%	1.95%	2.86%	1.39%
20	Other machinery	0.31%	1.12%	0.36%	2.34%	3.54%	1.84%

Table A-3

The distribution of firms in the analysis of venture-backed and non-venture-backed firms. We compare the number of firms and employees across manufacturing industries (two-digit Standard Industrial Code classes). We compare all firms in the United States, all those in Middlesex County, Massachusetts, and the 530 in the sample. The U.S. and Middlesex County figures are based on U.S. Department of Commerce [1991]. These present the number of establishments (one firm may have multiple establishments). Not all firms with fewer than twenty employees are included. The county figures are only for those employees actually working in the county. The sample columns present the number of firms, and include all employees of these firms, whether or not they work in Middlesex County.

	United States		Middlesex County		Sample	
SIC Class	*Percent of Establishments*	*Percent of Employees*	*Percent of Establishments*	*Percent of Employees*	*Percent of Firms*	*Percent of Employees*
20: Food & kindred products	5.5%	8.0%	3.7%	4.3%	2.6%	8.3%
21: Tobacco products	0.0	0.2	0.0	0.0	0.0	0.0
22: Textile mill products	1.7	3.6	1.1	1.7	0.6	0.1
23: Apparel & other textiles	6.4	5.7	2.9	1.6	1.5	0.3
24: Lumber & wood products	9.3	3.9	2.2	0.7	1.3	0.1
25: Furniture & fixtures	3.2	2.8	1.7	0.5	0.8	0.0
26: Paper & allied products	1.7	3.5	1.9	3.7	0.6	0.1
27: Printing & publishing	16.8	8.6	17.7	9.4	3.2	2.8
28: Chemicals & allied products	3.3	4.8	3.8	3.3	9.1	3.2
29: Petroleum & coal products	0.6	0.6	0.5	0.1	0.2	0.0
30: Rubber & misc. plastics	4.1	4.9	3.5	3.5	2.5	0.7
31: Leather & leather products	0.5	0.7	0.4	0.1	0.2	2.7
32: Stone, clay & glass	4.3	2.9	2.1	1.0	0.8	0.1
33: Primary metal industries	1.8	4.0	1.0	1.4	1.3	0.5
34: Fabricated metal products	10.1	8.2	9.3	4.8	5.1	1.3
35: Industrial machinery	13.8	10.6	14.8	14.5	19.1	24.8
36: Electronic equipment	4.6	8.6	11.1	16.8	14.7	12.3
37: Transportation equipment	2.9	9.9	1.4	5.1	0.8	0.3
38: Instruments	2.7	5.3	9.7	19.4	16.4	24.9
39: Miscellaneous	4.8	2.2	4.3	1.8	2.3	1.9
7372 & 7373: Software	1.9	0.9	7.0	6.4	17.2	15.4

Table A-4

Characteristics of venture-backed and non-venture-backed firms. The sample consists of 530 firms based in Middlesex County, Massachusetts. The tabulation presents the summary statistics for the 122 firms that had received venture capital financing prior to January 1990, and the 408 that did not. The "Publicly Traded at End of 1989?" variable is a dummy that takes on the value 1.0 if the firm was publicly traded. The final three items in each panel describe the industry of the respondents. The first is the average ratio of R&D-to-sales of all publicly traded firms that reported R&D data in 1990 with a primary assignment in Compustat to the same four-digit SIC code as the firm. The "Yale Rating" refers to the average rating of the importance of patents and trade secrecy (on a 1 to 6 scale, with larger numbers indicating greater importance) of firms in that three-digit Standard Industrial Classification code industry [from the survey described in Levin, *et al.*, 1987].

Panel A: 122 Venture-Backed Firms					
	Mean	*Median*	*Stan. Dev.*	*Minimum*	*Maximum*
Firm Sales in 1990 ($ millions)	173	11	1199	0	12942
Firm Employment in 1990	526	106	2103	8	20184
Year Firm was Founded	1977	1981	15	1880	1989
Publicly Traded at End of 1989?	0.30			0	1
Patent Awards, 1969-1989	10	0	41	0	375
Characteristics of Industry:					
R&D/Sales Ratio in 1990	0.11	0.10	0.08	0.00	0.38
Yale Rating of Patents	4.1	3.7	1.0	2.5	6.0
Yale Rating of Trade Secrecy	4.4	4.4	0.5	3.0	6.0
Panel B: 408 Non-venture-backed Firms					
	Mean	*Median*	*Stan. Dev.*	*Minimum*	*Maximum*
Firm Sales in 1990 ($ millions)	44	2	477	0	9268
Firm Employment in 1990	184	19	940	2	11768
Year Firm was Founded	1967	1974	25	1842	1989
Publicly Traded at End of 1989?	0.11			0	1
Patent Awards, 1969-1989	13	0	149	0	2644
Characteristics of Industry:					
R&D/Sales Ratio in 1990	0.06	0.04	0.06	0.00	0.38
Yale Rating of Patents	3.6	3.7	0.7	2.0	5.8
Yale Rating of Trade Secrecy	4.2	4.2	0.6	2.0	6.0