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Venture capital as a catalyst to commercialization☆

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ABSTRACT

We find that the public funding of academic research and venture capital have a complementary relationship in fostering innovation and the creation of new firms. Using panel data on metropolitan areas in the United States, from 1993 to 2002, our analyses reveal that the positive relationships between government research grants to universities and research institutes and the rates of patenting and firm formation in a region become more pronounced as the supply of venture capital in that region increases. Our results remain robust to estimation with an instrumental variable to address potential endogeneity in the provision of venture capital. Consistent with perspectives that emphasize the importance of an innovation ecosystem, our findings point to a strong interaction between private financial intermediation and public research funding in promoting entrepreneurship and innovation.

1. Introduction

Governments around the world devote vast sums to the support of research and development (R&D). In 2008 alone, for example, OECD nations spent roughly $253 billion on these activities (OECD, 2009). But large though it is, even that number understates the true level of public support because it includes neither the budgets of developing nations nor the implicit subsidies imparted through the favorable tax treatment of research expenditures and of non-profit institutes and universities. The justification for allocating such extensive public resources to laboratories and universities, and to the support of research and development elsewhere, stems largely from a belief that the ideas and inventions emerging from this research lead to new and improved products and to more efficient and higher quality manufacturing, and thus to an acceleration in economic growth (Bush, 1945; Malakoff, 2000).

Even casual observation, however, suggests that the ease with which these ideas and inventions flow from laboratories and universities into companies and society varies widely across regions. Some places, such as Boston and Silicon Valley, seem to enjoy a steady stream of innovations moving from research centers, such as MIT and Stanford, into both startups and existing companies. But other areas, such as Atlanta, appear far less successful (Powell et al., 2002). Despite being home to Emory, the Georgia Institute of Technology and the Centers for Disease Control and Prevention, few would consider the Southern city a hotbed of entrepreneurial activity or of biotechnology.

What accounts for these differences? Entire research programs have tried to answer this question (e.g., Etzkowitz and Leydesdorff, 2000; Furman et al., 2002). Our approach here attempts not to provide a complete answer, but rather to investigate one piece of the puzzle. In particular, we explore the extent to which the local availability of venture capital might act as a catalyst to commercialization.

A number of factors might lead one to question the importance of venture capital. Startups could obtain funding from elsewhere. Capital is mobile and can, in principle, flow into and out of regions in search of profitable opportunities. Public research funding could also presumably substitute for venture capital, to the extent that it

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too can support product development (Kortum and Lerner, 2000; Wallsten, 2000). Established firms, moreover, might absorb the knowledge produced by academic research, precluding any need to involve startups in the commercialization process (e.g., Cohen et al., 2002).

But there are also several reasons to believe that a local venture capital community might serve as a critical catalyst to moving innovations from the laboratory into the factory and on to consumers. While the public funding of research at universities and research institutes has generally been targeted toward the support of basic research, venture capital and other forms of early stage investing finance the applied research necessary to move those innovations out of the lab (Bygrave and Timmons, 1992). Even once a technology has been proven, commercialization often requires the development of a means of manufacturing it efficiently and of deploying it safely. And, though in principle capital flows readily from one place to another, identifying emerging technologies and verifying their value often demands that early-stage investors play an active role, building relationships with universities, research institutions, and the scientists and engineers employed by them (Sorenson and Stuart, 2001).

To determine whether venture capital plays a critical role in commercialization, we estimated the effects of venture capital and federal research grants to universities and non-profit research institutes on innovation and entrepreneurship – measured through patents and business starts – using a panel data set of metropolitan areas in the United States from 1993 to 2002. Our models controlled for stable regional differences and for variation over time at the national level. To address the fact that venture capital firms might actively allocate resources to regions rich in promising technologies, we also estimated the effects using an instrumental variable (IV). Institutional investors adjust their commitments to venture capital on a regular basis to maintain optimal asset allocation ratios, and they tend to invest these funds locally. Hence, the returns to local institutional investors on their investment portfolios provide a valid instrument for the local supply of venture capital (Samila and Sorenson, 2011).

Our results reveal an interplay between the public funding of academic research and venture capital in innovation and entrepreneurship. Though the local provision of venture capital has direct effects on the number of patents awarded to inventors in a region and to the number of new business establishments, its effectiveness in producing both outcomes increases with the local supply of public research funding to universities and research institutes. By contrast, in the absence of a local venture capital community, the government funding of academic research appears to have little, if any, effect on either patenting or firm founding. Further exploration of these relationships moreover revealed that the efficacy of public funding in producing patents and firms depends on its source, with funding from the National Science Foundation (NSF) and the Department of Defense (DoD) having the largest effects. We discuss some of the possible factors that may account for these differences in Section 4.

In essence, our findings reveal a strong complementarity between venture capital and the public funding of research and development. Most directly, our results suggest that regions, such as Atlanta, rich in academic research but poor in entrepreneurial capital could benefit from policies to promote the development of a local venture capital community. More broadly, we lend quantitative empirical support to the growing literature suggesting that innovation requires an entire ecosystem to support it. Though the various perspectives, such as the triple helix (Etzkowitz and Leydesdorff, 2000), national innovation systems (Lundvall, 1992; Freeman, 1995), regional innovation systems (Cooke et al., 1997), and regional institutions and networks (e.g. Powell et al., 2002) differ in their details, all of them forward a notion that government,

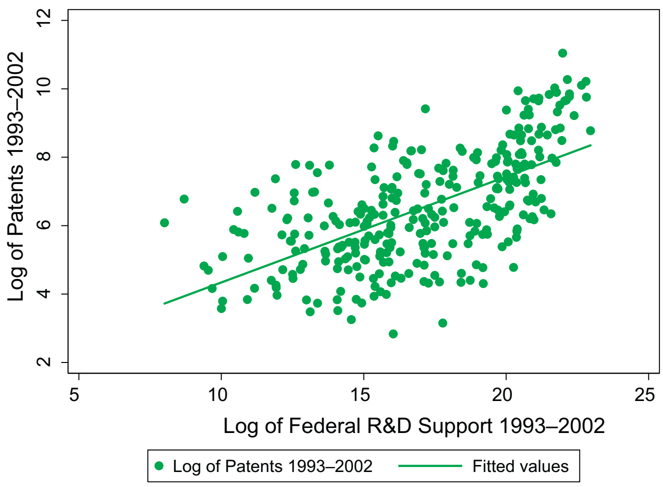

Fig. 1. Patenting by federal research support for MSAs.

educational institutions, and industry play complementary roles. Comparing and quantifying the importance of the relationships proposed by these perspectives has nevertheless been difficult because no two systems are quite alike in all of their elements. Our approach offers a middle ground. By investigating pairs of relationships – in this case, between the public support for research and the private provision of financial capital – one can consider seriously the complementarity between pieces of these systems while still maintaining the analysis at a level amenable to quantification and statistical analysis.

2. Technology commercialization

An important – if not the – justification for the public support of research has been the belief that the fruits of such research result in inventions and innovations that accelerate economic growth. Consistent with that belief, research has generally found positive relationships between research expenditures within a region and economic activity. For example, Adams (1990) found that the number of academic publications predicted future growth in the productivity of the manufacturing sector in the United States. Or, at a more micro level, Bottazzi and Perl (2003) estimated that a doubling in R&D expenditures in a region in Europe resulted in an 80–90% increase in patenting in that region.

But these estimates represent only averages. Behind them lies a great deal of variation in the effectiveness with which regions convert these research inputs into economic outputs. Consider regions within the United States. Figs. 1 and 2 plot the number of patents and firm starts in each Metropolitan Statistical Area (MSA) over the decade from 1993 to 2002 as a function of the amount of federal support universities and research institutes in those same regions received over the period. The graphs reveal clear and strong positive relationships between public research funding and innovation and entrepreneurship. But as one can tell from the dispersion around the regression lines, regions also vary considerably in the effectiveness with which they translate research dollars into patents and firms – in other words, in their ability to commercialize technologies.

What accounts for these differences? As with any complex phenomenon, a whole host of factors undoubtedly contributes to this variation in the ability of regions to move technologies out of the lab and into products and services. Here, we examine one potentially important factor – the local availability of venture capital – in detail and estimate the extent to which it might account for these differences.

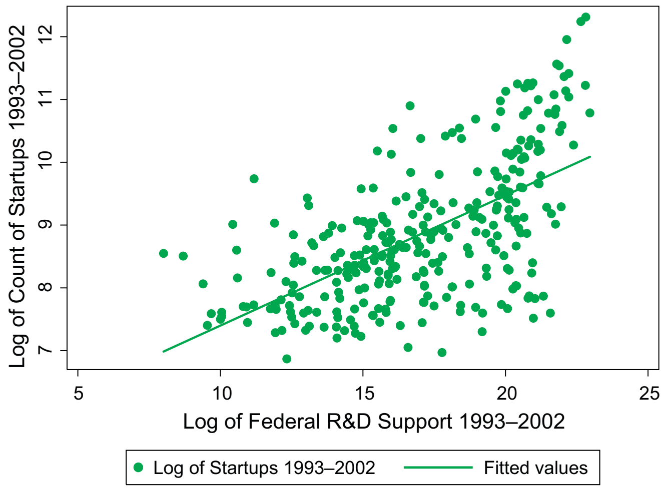

Fig. 2. Startups by federal research support for MSAs.

2.1. Academic research and venture capital

In general, the literature has largely thought of public and private funds as substitutes in the production of innovative ideas and products (Kortum and Lerner, 2000; Wallsten, 2000). Though governments hope to increase the overall level of innovation by subsidizing research and development, firms may well use these public funds as a cheap source of capital and then re-allocate the funds that they otherwise would have spent on research to other activities (Wallsten, 2000). Hence, one might expect a negative relationship between public and private spending on research and development.[1]

This literature to date, however, has primarily been focused on government grants to firms and the (private) research spending of those same firms. But the public funding of academic research and the private provision of venture capital seem qualitatively different for a number of reasons. On the one hand, academic institutions would probably not engage in the same levels of research in the absence of government funding. Individual researchers usually do not have the financial resources to pursue their own research and academic institutions primarily depend on revenues from educating students not from commercializing the innovations that they incubate. On the other hand, venture capitalists provide more than mere funding for innovation. These active professionals screen ideas and inventions to determine which have the greatest market potential, help to connect inventors to more business-minded individuals, and advise the companies in which they invest. We therefore see several reasons that one might instead expect these public and private actors to act as complements, rather than substitutes, in the production of ideas and businesses.

Complementary focus. The potential for academic research and venture capital to act as complements begins with their distinct focuses in terms of stages of development. Whereas venture capital and the research expenditures of incumbent firms often fund similar activities (Kortum and Lerner, 2000), the academic research supported by public funds generally has a somewhat different character. Most notably, public grants to universities and research institutes have been targeted to "basic" research – research that does not have an immediate apparent application but that forwards our understanding of the world.

That focus does not imply that such research does not produce economically valuable products and services. Inventions as diverse and as important as penicillin, lasers, functional MRI and computers emerged out of academic research (Cole, 2009). But it does mean that the ideas that arise from these activities generally require additional development before they can realize their commercial potential. The invention only represents a first step. Commercialization further requires the matching of the idea to a need, the refinement of the invention to allow for wide usage, the development of an efficient process for manufacturing products or providing services, the education of the consumer to the value of the innovation, and the distribution of the good.

Schumpeter (1947, p. 152) conceptualized this distinction as the difference between the inventor, who comes up with the idea, and the entrepreneur, who engages in all of the subsequent activities necessary to bring that idea to fruition. Such a distinction maps well onto the difference between the roles played by academic institutions and by venture capital. Whereas the public funding of universities and research institutes trains inventors and supports their research, venture capital develops entrepreneurs. In this sense, the fact that venture capitalists are not simply passive investors is important. Venture capitalists provide legal, financial, and strategic advice, and help to connect entrepreneurs to talent, buyers and suppliers (Florida and Kenney, 1988; von Burg and Kenney, 2000). They often do so even for entrepreneurs in whom they choose not to invest.[2] As a result, they help to improve the entrepreneurial abilities not only of the few that they fund but also of the larger community in which they reside.

To the extent that invention and entrepreneurship represent distinct, yet jointly necessary, components of the commercialization process, one would expect them to act as complements. Michelacci (2003) builds an analytical model on this intuition and demonstrates that, under these conditions, regions with an inadequate supply of entrepreneurial talent experience lower returns to investments in research and development. Hence, one would expect regions with an insufficient supply of venture capital – and consequently of entrepreneurs – to produce fewer patents and firms for each dollar of public funding.

Compatible incentives. But why could not established firms serve as substitutes for entrepreneurs in the commercialization of academic research? Indeed, to the extent that these firms already have established routines and complementary resources, they may prove even more adept than entrepreneurs at bringing this research to market. So, perhaps the entrepreneur, and hence also venture capital, should not play such an important role.

In some cases, established firms undoubtedly do serve as an alternate route to commercialization, but in many cases, they cannot. They cannot, in large part, because these incumbent firms have different incentives from entrepreneurs that preclude them from pursuing many of the ideas emerging from academic research. For example, incumbents usually wish to maintain at least some part of the status quo, either in terms of a particular product or service or in the method for pricing or distributing those goods. Because many of the ideas emerging from universities and research institutes would either cannibalize these products or lead to a devaluation of incumbents' prior investments in physical assets and routines, existing firms find it economically unattractive to pursue them (Dewar and Dutton, 1986; Henderson and Clark, 1990). Entrepreneurs, however, do not need to factor these externalities – these effects on other products and services – into their decisions and hence often pursue ideas that incumbents would not.

[1] Empirical estimates, however, have been mixed. Though some, such as Wallsten (2000) in his study of the SBIR program, find that government grants to firms crowd out private investment, others have found that government subsidies to firms lead to net gains in the level of research (e.g., Lach, 2002; González and Pazó, 2008).

[2] Venture capitalists provide such free advice in the hope of placing themselves first in line in the consideration of potential future investments, either from that entrepreneur or from his or her friends.

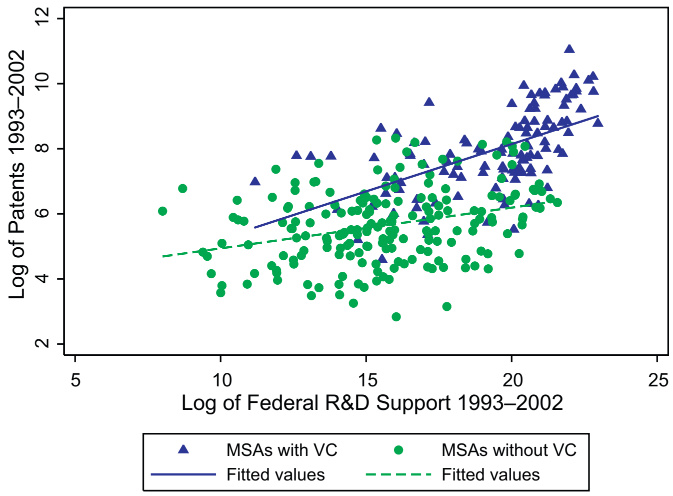

Fig. 3. Patenting by federal research support for MSAs, for regions with and without venture capital.

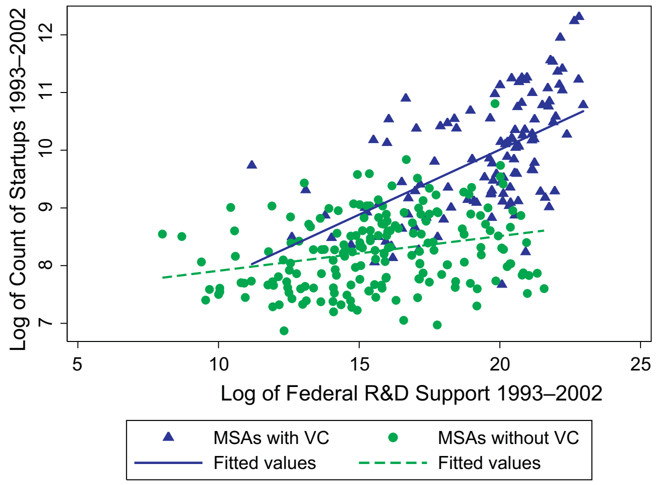

Fig. 4. Startups by federal research support for MSAs, for regions with and without venture capital.

Incompatible incentives could similarly prevent existing firms from pursuing the development of early stage products and services more generally. Shareholders and stakeholders demand reliability and accountability from established organizations (Hannan and Freeman, 1984). As a result, the managers of these firms have a bias in favor of incrementally improving the tried-and-true over investing in ideas with great potential but a long time horizon (March, 1991). But basic research tends to produce precisely the sorts of ideas that the managers of incumbent firms find difficult to pursue, those with substantial promise but also facing an extended and uncertain development process. Entrepreneurs, on the other hand, backed by investors comfortable with such high levels of risk, may nonetheless pursue these early stage goods and services.

To the extent that the supply of entrepreneurial talent enables the pursuit of ideas that incumbent firms have incentives to avoid, their presence increases the "absorptive capacity" of a region (Romain and van Pottelsberghe, 2004b) – the region's ability to commercialize innovations. This increase in absorptive capacity should in turn lead to a complementarity between research expenditures and venture capital in a region.

Local investing. But even if entrepreneurs, and hence venture capitalists, do play an important role in the commercialization of academic research, one might still question the necessity of having a *local* venture capital community. Most economic models assume that capital flows freely to the best available opportunities and even casual observation suggests that capital markets operate on a national, if not global, scale.

Venture capital, however, operates on a local level because it confronts difficulties that investors in more mature companies do not. Before investing, venture capitalists must not only assess the quality of an idea but also of the team of people pursuing it. Since little public information exists on these fledgling ventures, the ability of venture capitalists to assess these qualities depends in large part on their access to private information, on the ideas and the entrepreneurs, traveling through interpersonal connections (Florida and Kenney, 1988). These connections are densest, and hence the ability of venture capitalists to assess opportunities are strongest, in their immediate geographic and social circles (Sorenson and Stuart, 2001).

Once an investment has been made, the active role that venture capitalists play in monitoring the use of the funds that they provide, in advising the entrepreneurs, and in connecting the company to talent and strategic partners requires them to interact regularly with the company. Studies have found that, on average, lead investors might visit a company 19 times a year and that venture capitalists allocate more than half of their time to monitoring and advising portfolio companies (Gorman and Sahlman, 1989). Proximity therefore also facilitates this post-investment role in two ways: (i) by reducing the time and cost of traveling to and from the companies, and (ii) by allowing them to monitor more efficiently and to provide more valuable introductions, because venture capitalists have more contacts and connections in the regions in which they reside (Sorenson and Stuart, 2001).

Together, these factors suggest that the supply of venture capital in a region should increase the effectiveness with which that region converts academic research into innovations and organizations. Certainly, such a relationship appears apparent in the cross-section. Figs. 3 and 4 redraw the graphs above, but with regions segmented according to whether or not they have a local venture capital community. Regions with venture capital are depicted with blue triangles while those without are represented by green circles. The solid and dashed lines reflect the best fitting regression slopes for those communities with and without venture capital, respectively. Consistent with our expectations, regions with a local venture capital community appear to have steeper slopes (i.e. to convert research dollars into patents and firms more effectively). A number of confounding factors may nonetheless plague this cross-sectional relationship, so we turn to a more precisely identified longitudinal analysis.

3. Data sources

For these analyses, we built an unbalanced panel data set of all 328 Metropolitan Statistical Areas in the contiguous United States from 1993 to 2002.[3] Because the effects of investments may spill beyond the firms receiving those investments and because the geographic extent of such spillovers remains uncertain, the choice of an areal unit involves a balancing act. Choosing a large unit – at the extreme, the country level – would allow us to capture fully the effects of any investments. But it would leave us without sufficient statistical power to test those effects. Choosing a small unit, meanwhile, gains power at the expense of potentially underestimating

[3] The Office of Management and Budget redefines MSAs roughly three years after each decennial census. The revised definitions from the 1990 census came into use in 1993 and remained in effect until 2002. Since our statistical analysis requires consistent definitions of the regions over time, we limited our analysis to the ten-year window from 1993 to 2002.

Table 1
Summary statistics.

Variable	Mean	Std. Dev.	*N*
Population (thousands)	659.4	1104.9	3270
Patents	246.8	583.0	3270
Patent Citations (5 years)	1228.2	3671.0	2614
Births of Establishments, 0–19	1415.2	2523.6	3270
R&D Support (millions)	49.6	122.6	3270
VC Investment Count	15.9	106.4	3270
VC Investment Amount (millions)	39.8	340.1	3270

the effects. Here, we opted for an intermediate level, the MSA. Each MSA consists of an urban core and an economically-integrated surrounding area, determined by commuting patterns. MSAs include any adjacent county, or township in the case of New England, in which more than 25% of the labor force commutes to the urban core. MSAs therefore form the smallest geographic regions that one could consider independent in economic activity (and therefore large enough to capture a substantial share of the spillovers).

For each MSA, we gathered data from multiple sources, both public and private. The patent data came from the Patent Network Dataverse (Lai et al., 2009) and the entrepreneurship data from the Small Business Administration, which collects it annually from the Census Bureau.[4] We derived our measures of venture capital from the VentureXpert database of Thomson-Reuters and our measures of federal research support from the National Science Foundation's WebCASPAR database. Our endowment returns data, meanwhile, came from *The Chronicle of Higher Education*. Summary statistics for all of the variables used in the models appear in Table 1.

3.1. Variables

Patents. We measured innovation as a (logged) count of utility patents in an MSA-year. Patents have at least two weaknesses as a measure of innovation. On the one hand, they do not capture a wide range of process innovations, such as learning-by-doing, that would fail the patent criteria of being a novel step. On the other hand, even as a measure of invention, individuals and firms frequently prefer to protect their ideas through secrecy rather than through the patent system. Using survey data, for example, Arundel and Kabla (1998) estimated that companies only patent about one-third of their product innovations and one-quarter of their process innovations.

Despite these limitations, patents nevertheless provide one of the few means of measuring innovation across a broad spectrum of industries and over time. Indeed, studies with information on other innovation metrics have found that, because patent counts correlate highly with other measures of innovation, one can usually generalize from them to the effects on innovation more broadly defined (Hagedoorn and Cloodt, 2003). Ample existing research, moreover, has connected patent counts to various measures of economic performance, such as stock prices and GDP growth (for a review, see Griliches, 1990).

To create our measure, we assigned each patent to an MSA-year based on the address of the inventor and the date of application.[5] If a patent had multiple inventors, we assumed that they all participated equally in the invention and hence divided the patent across the inventors' addresses. Assigning the patent instead only to the first inventor or randomly to one of the listed inventors yielded qualitatively equivalent results.

Establishment births. We assessed the level of entrepreneurship by counting the (logged) number of new business establishments with fewer than 20 employees in an MSA-year. The Census Bureau defines business establishments as single physical locations in which business occurs and for which employment records are maintained. It records an establishment birth when a location that had no employees in the pay period covering March 12 in one calendar year has employees at the same time the following year. Though this definition also captures relocations and expansions of existing firms, our measure focuses on entrepreneurship by using information on the size of the firm creating the new establishment. The Census Bureau reports establishment births by three categories of overall firm size: 0–19 employees, 20–499 employees, and over 500 employees. It allocates new firms to these categories according to their sizes at the end of the year. Since few startups have more than 19 employees by the end of their first year, our measure considers only births in the 0–19 employees category.

R&D Support. We used the lagged aggregate annual flows of federal funds to colleges, universities and research institutes in a region, in (logged) millions of dollars, as our main measure of research support.[6] In total, 2537 institutions received research grants from the federal government between 1971 and 2005. Two issues arose in apportioning these grants to regions for our analyses. First, the NSF data included only the name and state of the institution but not its MSA. We therefore gathered addresses for these institutions from a variety of sources, including the *US News & World Report* rankings of schools, the Carnegie Endowment's list of institutions of higher education, and online searches. We located addresses for 2526 of the 2537 institutions. Second, though the funding data identified specific locations for most universities with multiple campuses, prior to 2001, the database did not distinguish between campuses for some of these universities. To allocate these funds to regions, we therefore assumed that each federal agency awarded funds to campuses in the same proportions before 2001 as it did, on average, from 2001 to 2005. For example, we assumed that the support from the Department of Health and Human Services for Cornell, which has a main campus in Ithaca (NY) and a medical campus in New York City had the same proportions for these two campuses from 1993 to 2000 as it did from 2001 to 2005.

VC count/amount. We measured venture capital activity in two ways. First, we counted the (logged) number of investments made by venture capital funds in an MSA in a year (plus one to avoid zeros in the logarithm). Second, we summed the (logged) amount of these investments in dollars.

Because the VentureXpert database includes leveraged buyouts, public equity purchases, and fund-of-funds investments, we focused on venture capital activity by limiting the investments included to those for seed stage, early stage, later stage, expansion, or development, and to those from funds with limited partners. These criteria exclude LBO funds and funds-of-funds, as well as angel investors, corporate venture capital, and direct investments by university endowments. Though these investors probably also affect the regional economy, the logic of our instrumental variable constrains us to assessing the importance of entrepreneurial capital raised through limited partnerships. We assigned each investment to an MSA based on the location of the investing venture capital fund, even if the target company resided in a different region.[7] Thus,

[4] The Census Bureau collects data each year from the Business Register in March and hence we shifted our other measures to correspond to an April–March calendar.

[5] Actual grant dates by comparison would introduce some lag in the relationship between investments and invention related to the processing time for the application at the patent office.

[6] Our measure does not include research grants to for-profit firms. The effects of those subsidies have been studied extensively elsewhere (e.g., Wallsten, 2000; Lach, 2002; González and Pazó, 2008).

[7] Because venture capital firms generally invest locally (Sorenson and Stuart, 2001), this assumption has little bearing on our results.

if a venture capital firm based in New York City invested in a company in Boston, we incremented the count for New York City by one. For syndicated investments, we counted each investing firm as having made an investment. Table 1 reports descriptive statistics for the variables used in our analysis.

4. Results

Our models estimated a logged form of a standard production function:

$$\ln Y_{i,t} = \alpha + \beta_1 \ln P_{i,t} + \beta_2 \ln RD_{i,t} + \beta_3 \ln VC_{i,t} + \beta_4 \ln RD_{i,t} \ln VC_{i,t} + \phi_t + \eta_i + \varepsilon_{i,t}, \quad (1)$$

where i and t index the MSA and year, respectively, $Y_{i,t}$ denotes the dependent variable (i.e. patents or firm births), $P_{i,t}$ controls for regional growth in the population, $RD_{i,t}$ measures government support for academic research, $VC_{i,t}$ measures VC activity, ϕ_t represents a vector of indicator variables for each year, η_i denotes the MSA fixed effect (partialed out), and $\varepsilon_{i,t}$ represents an error term. To form the interaction term, which tests for the complementarity of academic research and venture capital, we mean-centered the variables before multiplying them. Because of the repeated observations of regions over time, the error term (ε) could remain correlated across cases, even with region-specific fixed effects.[8] We therefore estimated standard errors robust to repeated observations of the same regions.

All of our models included two kinds of fixed effects to control for a variety of unobserved factors: Region-specific fixed effects (η_i) absorbed all time-invariant regional attributes, such as local laws and tax rates, the presence and quality of colleges and universities in the region, geographic factors, and the composition of the local labor force. Year-specific fixed effects, implemented as a series of dummy variables (ϕ_t), meanwhile accounted for all factors that vary over time at the national-level, such as investment performance, interest rates, and other macroeconomic conditions.

The only remaining factors that could confound our results would therefore be region-specific factors that vary over time and that might influence both venture capital activity and either patenting or firm founding. Our models explicitly control for one such factor: population. Although we experimented with several other potential control variables, such as the unemployment rate, none of them had significant effects. In the interest of simplicity, we have therefore not reported them. We further discuss this issue below when introducing our IV analysis.

4.1. Fixed-effects estimates

Table 2 reports the results from estimating equation (1) for patents using linear regression. Columns 1 through 3 detail models predicting the number of patents using the counts of venture capital investments while columns 4 through 6 report models using the amounts of venture capital. Somewhat surprisingly, on average, federal research grants appear to have no effect on the number of patents in a region. (Note that the cross-sectional figures above did not control for region-specific factors such as population and the presence of universities.) This non-effect may reflect the fact that, absent a route for commercialization, academic researchers have little interest in patenting their inventions (Stuart and Ding, 2006).

By contrast, consistent with past studies (Kortum and Lerner, 2000), venture capital, at least when measured in terms of counts, does have a direct effect on patenting. Though the log–log format means that one can interpret this coefficient directly as an elasticity, few areas have more than 100 venture capital investments in a year, so a 1% increase in venture capital does not seem particularly meaningful. Instead, we calculated the marginal effect of a doubling in venture capital activity in the average region (roughly 16 additional venture capital investments). In the average region, a doubling in the supply of venture capital for a year would correspond to roughly four more patents in the subsequent year ($.0231 \times \ln 2 \times 246.8 = 3.95$).

The interaction term tests the complementarity of research support and venture capital. As one can see, consistent with the idea that venture capital serves as a critical catalyst to commercialization, the effect is both positive and significant. It is also economically meaningful. Whereas a doubling in the supply of venture capital would correspond to roughly four more patents in the average region, that same doubling would predict more than ten additional patents in a region one standard deviation above the mean in research funding, more than a doubling in the magnitude of the effect. Venture capital measured in amounts exhibits similar effects, though ones smaller in magnitude. The smaller size of the effect of amounts relative to counts suggests a declining marginal pay-off with investment size – in other words, smaller investments appear more effective than larger ones in stimulating innovation and entrepreneurship (though this difference could also stem from attenuation bias associated with the greater measurement error surrounding the investment amounts).

One might nonetheless worry that these differences in patenting reflect not an increase in innovation but rather an increased interest in protecting property rights.[9] The availability of a route for commercialization, for example, might encourage academic inventors to split their inventions into "smaller" patents to create more effective intellectual property protection for their ideas. Kortum and Lerner (2000) addressed this same issue by examining cumulative citations. Numerous studies have revealed that patent citation counts correlate highly with the underlying economic value of the inventions covered by the patents (Trajtenberg, 1990; Harhoff et al., 2003). If companies simply split the same inventions into "smaller" overlapping patents, then one would see an increase in patenting but not necessarily in cumulative citations. If, however, the combination of public research funding and private venture capital stimulate innovation, one would expect to see an increase in cumulative citations as well.

In models 3 and 6, we therefore substituted cumulative citations for cumulative patent counts as the dependent variable. In particular, we counted the citations that each patent from a region received in the subsequent five years after being filed. We then totaled those citations across all patents and logged the resulting sum. Because of the lag between patent filings and citations, however, we could only calculate these counts accurately for patents filed prior to 2001; we therefore estimated these models using eight – rather than ten – years of data. Not only are these coefficients significant and positive but also they are statistically equivalent in magnitude to the models using patent counts. These estimates suggest that our results capture actual increases in innovation and not simply changes in patenting practices. Because the cumulative citations yield equivalent results to patent counts but require us to use a shorter panel, in the remaining models, we report only patent counts.

[8] These correlated error terms will not bias the estimates from linear regression but they could lead to over- or under-estimation of the standard errors.

[9] Given that our results cover the Internet boom, one might also worry that Silicon Valley or Boston unduly influences our estimates. To examine this possibility, we estimated the results removing the MSAs covering Boston and the San Francisco Bay Area from the analysis. The results remained robust to the removal of either of these regions.

Table 2
Effects on innovation.

	(1) Patents	(2) Patents	(3) Citations	(4) Patents	(5) Patents	(6) Citations
Population ($t-1$)	1.427***	1.405***	1.721***	1.453***	1.444***	1.719***
	(4.81)	(4.71)	(3.45)	(4.90)	(4.87)	(3.46)
R&D Support ($t-1$)	−0.000460	0.0202**	0.0207**	−0.000410	0.00720	0.0145**
	(−0.19)	(2.19)	(2.00)	(−0.17)	(1.53)	(2.00)
VC Count (t)	0.0231*	0.0261**	−0.00568			
	(1.83)	(2.05)	(−0.37)			
VC Count (t) × R&D ($t-1$)		0.00764**	0.00636*			
		(2.27)	(1.78)			
VC Amount (t)				0.000643	0.00143	0.000229
				(0.42)	(0.89)	(0.11)
VC Amount (t) × R&D ($t-1$)					0.000452*	0.000654*
					(1.71)	(1.73)
Time period	1993–2002	1993–2002	1993–2000	1993–2002	1993–2002	1993–2000
Year Dummies	Yes	Yes	Yes	Yes	Yes	Yes
MSA Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.16	0.16	0.15	0.15	0.15	0.15
Clusters	328	328	328	328	328	328
Observations	3270	3270	2624	3270	3270	2624

Notes: OLS regression results; $^*p<0.10$, $^{**}p<0.05$, $^{***}p<0.01$. Robust t-statistics in parentheses; disturbances clustered by MSA.

A similar pattern emerges from the estimates of the effects on establishment starts (Table 3). Once again, research funding has no direct effect on entrepreneurship while venture capital does. And, as in the patent models, government grants and venture capital exhibit complementarity in the production of firms. While a doubling in the supply of venture capital would predict about eight additional startups in the average MSA, it predicts nearly eleven in a region one standard deviation above the mean in research funding.

Agency differences. Although our main models pool research funds from all federal sources, some grant agencies might prove more productive than others in generating ideas amenable to commercialization. To explore this possibility, Tables 4 and 5 report estimates of the effects individually for each of the five largest granting agencies: the Department of Health and Human Services (HHS, including the NIH), the National Science Foundation, the Department of Defense (DoD), the Department of Agriculture (DoA), and the National Aeronautics and Space Administration (NASA).

In terms of patenting, positive main effects appear to exist for three of the five agencies, the exceptions being Health and Human Services and the Department of Agriculture. However, with the exception of the Department of Agriculture, funding for which has no apparent effect on innovation, we cannot reject the possibility that all have equivalent coefficients (i.e. equal efficiency in terms of research dollars per patent). We nevertheless do see differences across the agencies in their complementarity with venture capital. NSF and Department of Defense funding appear to benefit most from the availability of venture capital in their ability to produce patents. Much larger differences arise in the effects on firm founding. Only funding from the National Science Foundation has either a positive and significant main effect or a positive and significant complementarity with venture capital.

At least three factors might account for these differences. On the one hand, the ideas produced by the various agencies probably have different commercialization paths. For example, because of the long time horizons involved in moving through clinical trials, much of the funding for the commercialization of biotechnology products in recent years has come from pharmaceutical companies rather than from venture capital firms (Pisano, 2006). Similarly, more of the inventions generated by research for the Department

Table 3
Effects on entrepreneurship.

	(7) Births	(8) Births	(9) Births	(10) Births
Population ($t-1$)	0.820***	0.815***	0.825***	0.821***
	(10.43)	(10.25)	(10.55)	(10.45)
R&D Support ($t-1$)	−0.000679	0.00413	−0.000658	0.00319
	(−1.04)	(1.54)	(−1.01)	(1.34)
VC Count (t)	0.0100***	0.0107***		
	(2.97)	(3.12)		
VC Count (t) × R&D ($t-1$)		0.00178*		
		(1.89)		
VC Amount (t)			0.00101**	0.00141***
			(2.57)	(3.21)
VC Amount (t) × R&D ($t-1$)				0.000229*
				(1.73)
Year Dummies	Yes	Yes	Yes	Yes
MSA Fixed Effects	Yes	Yes	Yes	Yes
R^2	0.22	0.22	0.22	0.22
Clusters	328	328	328	328
Observations	3270	3270	3270	3270

Notes: OLS regression results; $^*p<0.10$, $^{**}p<0.05$, $^{***}p<0.01$. Robust t-statistics in parentheses; disturbances clustered by MSA.

Table 4
Innovation by agencies.

Source of R&D Support	HHS (11) Patents	NSF (12) Patents	DoD (13) Patents	DoA (14) Patents	NASA (15) Patents
Population ($t-1$)	1.411***	1.403***	1.397***	1.441***	1.425***
	(4.77)	(4.71)	(4.71)	(4.85)	(4.77)
R&D Support ($t-1$)	0.00997	0.0135**	0.0119**	−0.00108	0.00888*
	(1.57)	(2.30)	(2.25)	(−0.52)	(1.85)
VC Count (t)	0.0272**	0.0267**	0.0308**	0.0250*	0.0258*
	(2.09)	(2.08)	(2.28)	(1.75)	(1.94)
VC Count (t) × R&D ($t-1$)	0.00245	0.00543**	0.00348*	0.000502	0.00142
	(1.09)	(2.41)	(1.82)	(0.51)	(0.74)
Year Dummies	Yes	Yes	Yes	Yes	Yes
MSA Fixed Effects	Yes	Yes	Yes	Yes	Yes
R^2	0.16	0.16	0.16	0.16	0.16
Clusters	328	328	328	328	328
Observations	3270	3270	3270	3270	3270

Notes: OLS regression results; $^{*}p<0.10$, $^{**}p<0.05$, $^{***}p<0.01$. Robust t-statistics in parentheses; disturbances clustered by MSA.

Table 5
Entrepreneurship by agencies.

Source of R&D Support	HHS (16) Births	NSF (17) Births	DoD (18) Births	DoA (19) Births	NASA (20) Births
Population ($t-1$)	0.817***	0.812***	0.814***	0.822***	0.820***
	(10.33)	(10.23)	(10.32)	(10.34)	(10.41)
R&D Support ($t-1$)	0.00146	0.00426***	0.00211	0.000191	−0.000157
	(1.07)	(2.76)	(1.42)	(0.31)	(−0.10)
VC Count (t)	0.0104***	0.0111***	0.0113***	0.0113***	0.00967***
	(2.94)	(3.23)	(3.07)	(3.11)	(2.67)
VC Count (t) × R&D ($t-1$)	0.000295	0.00161***	0.000614	0.000312	−0.000138
	(0.64)	(2.77)	(1.19)	(1.24)	(−0.25)
Year Dummies	Yes	Yes	Yes	Yes	Yes
MSA Fixed Effects	Yes	Yes	Yes	Yes	Yes
R^2	0.22	0.22	0.22	0.22	0.22
Clusters	328	328	328	328	328
Observations	3270	3270	3270	3270	3270

Notes: OLS regression results; $^{*}p<0.10$, $^{**}p<0.05$, $^{***}p<0.01$. Robust t-statistics in parentheses; disturbances clustered by MSA.

of Defense and NASA may interest established firms (cf. Cohen et al., 2002), perhaps because of the possibility of winning government contracts.

Agencies may also differ in the degree to which they consider the commercial potential of research in evaluating grants. Though academic researchers generally focus in their applications on the importance of the research to our understanding of the world, grants may mention potential applications and, even if they do not, the evaluation committees may bring them into the selection process. Hence, the differences across agencies might stem from the grant selection process.

On the other hand, the yield, in terms of commercial ideas per dollar of funding, might also vary across areas of research. The development of drugs, for example, is notoriously expensive. One might therefore expect fewer innovations per dollar from HHS/NIH funding. Our results, however, appear inconsistent with this possibility. If differences in yield accounted for the heterogeneity across agencies, then one would expect these differences to influence not just the complementarity between research funding and venture capital but also the "main" effects of research funding. But R&D dollars appear to have roughly equivalent effects, across agencies, on patenting.

Lag structure. We also explored the timing of these commercialization effects. Prior research has suggested that the spillovers from academic research to patenting might peak as long as twenty years after the publication of the basic research (Adams, 1990). Though our data do not allow the exploration of such long lags, we did consider the lag structure within our time window. Tables 6 and 7 detail the results of estimates using different lags for research funding, from zero to five years. In terms of patenting, the models suggest that research funding and its complementarity with venture capital begin to influence patenting only one year after the awarding of the funds and continue to influence it for at least five years. In terms of firm formation, the lags appear even longer. Although significant effects appear for the interaction term with one-year lags, both the main effects of research funding on entrepreneurship and its complementarity with venture capital peak at least four to five years out.

Table 8 then explores the effects of lagging venture capital, as well as research funding. The results are interesting. In terms of innovation, the positive effects of venture capital on the productivity of research funding appear to grow over time. Regarding establishment starts, the effect of venture capital seems to decrease over time with the interaction with research funding dropping below significance quite quickly.

4.2. IV estimates

Though the fixed effects in the models above should capture a wide variety of potential confounds, two remain. First, one might worry about endogeneity in the supply of venture capital. For example, the availability of attractive ideas and high-calibre

Table 6
Lag structure of R&D effects on innovation.

	(21) Patents	(22) Patents	(23) Patents	(24) Patents	(25) Patents	(26) Patents
Population ($t-1$)	1.418***	1.405***	1.405***	1.398***	1.415***	1.418***
	(4.77)	(4.71)	(4.71)	(4.71)	(4.77)	(4.75)
VC Count (t)	0.0239*	0.0261**	0.0263**	0.0270**	0.0261**	0.0253**
	(1.88)	(2.05)	(2.06)	(2.11)	(2.05)	(2.00)
R&D Support (t)	0.00803					
	(0.85)					
VC Count (t) × R&D (t)	0.00246					
	(0.71)					
R&D Support ($t-1$)		0.0202**				
		(2.19)				
VC Count (t) × R&D ($t-1$)		0.00764**				
		(2.27)				
R&D Support ($t-2$)			0.0190**			
			(2.23)			
VC Count (t) × R&D ($t-2$)			0.00689**			
			(2.20)			
R&D Support ($t-3$)				0.0221**		
				(2.41)		
VC Count (t) × R&D ($t-3$)				0.00809**		
				(2.38)		
R&D Support ($t-4$)					0.0174*	
					(1.81)	
VC Count (t) × R&D ($t-4$)					0.00733**	
					(2.11)	
R&D Support ($t-5$)						0.0157
						(1.60)
VC Count (t) × R&D ($t-5$)						0.00761**
						(2.13)
Year Dummies	Yes	Yes	Yes	Yes	Yes	Yes
MSA Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.16	0.16	0.16	0.16	0.16	0.16
Clusters	328	328	328	328	328	328
Observations	3270	3270	3270	3270	3270	3270

Notes: OLS regression results; $^*p<0.10$, $^{**}p<0.05$, $^{***}p<0.01$. Robust t-statistics in parentheses; disturbances clustered by MSA.

entrepreneurs in a region might attract venture capitalists to it. Consistent with this notion, Romain and van Pottelsberghe (2004a) found a positive relationship between the supply of venture capital and patenting and R&D spending across 16 OECD countries. Our results, therefore, could stem from reverse causality (though the lag structure would suggest otherwise). Second, one might worry about unobserved heterogeneity. Despite the fixed effects, our models may miss some relevant time-varying, region-specific factor. Such an omission could bias our results.

The use of an instrumental variable allows us to address both potential endogeneity in the supply of venture capital and any bias due to unobserved heterogeneity (Wooldridge, 2002). One can think of instrumental variable estimation as akin to looking for a natural experiment. Experiments serve as a gold standard in research because they randomly assign the variable of interest to cases. Since the assignment is random, any effect of the variable on an outcome must stem from that assignment rather than from some other confounding factor. In instrumental variable estimation, one looks for some process that would lead to a change in the variable of interest – in this case, the supply of venture capital – for reasons unrelated to the outcomes.

LP returns. We used the instrument proposed by Samila and Sorenson (2011), which exploits the fact that institutional investors generally use a fixed asset allocation ratio to determine the distribution of their investments over asset classes – that is, they cut their investment pie in slices, such as half for equity, four-tenths for debt and one-tenth for alternative assets (i.e., private equity, hedge funds and venture capital). In principle then, if the total pie grows or shrinks as returns fluctuate from year to year, then the slice of the pie devoted to venture capital should also grow and shrink by a roughly equal proportion. Thus, limited partner (portfolio) returns should partially determine the supply of venture capital in a region.

We can readily justify this assumption by decomposing it into three parts:

1. LP returns are positively related to future investments in venture capital.
2. Institutional investors exhibit a "home bias" when investing in venture capital funds.
3. Venture capital funds exhibit a "home bias" when investing in target companies.

Beginning with the first part, most institutional investors diversify their investments using a (relatively) fixed proportional allocation across different asset classes – for example, 40% equities, 40% bonds, and 20% alternative assets – adjusting their investments towards this target allocation at regular intervals. Given the limited maturity of venture capital investments, rebalancing requires that an increase in returns to the total portfolio results in a greater flow of funds into venture capital.

When they invest these funds, institutional investors exhibit a "home bias" – that is, they tend to invest in funds headquartered close to them. This home bias probably stems from the constraints facing first-time funds. Because the partners starting these funds do not have proven track records, they find it very difficult to raise funds and generally only receive investments from those with whom they have prior business dealings or personal relationships. Even when raising second and subsequent funds, this local bias often persists because partnerships rarely move their headquarters. As a consequence, limited partners invest in funds in the same MSA at twice the rate at which they invest in funds in adjacent

Table 7
Lag structure of R&D effects on entrepreneurship.

	(27) Births	(28) Births	(29) Births	(30) Births	(31) Births	(32) Births
Population ($t-1$)	0.821***	0.815***	0.815***	0.813***	0.811***	0.812***
	(10.49)	(10.25)	(10.23)	(10.18)	(10.11)	(10.15)
VC Count (t)	0.0101***	0.0107***	0.0105***	0.0107***	0.0108***	0.0107***
	(2.97)	(3.12)	(3.07)	(3.12)	(3.15)	(3.13)
R&D Support (t)	−0.000782					
	(−0.34)					
VC Count (t) × R&D (t)	0.000329					
	(0.40)					
R&D Support ($t-1$)		0.00413				
		(1.54)				
VC Count (t) × R&D ($t-1$)		0.00178*				
		(1.89)				
R&D Support ($t-2$)			0.00382*			
			(1.67)			
VC Count (t) × R&D ($t-2$)			0.00128			
			(1.56)			
R&D Support ($t-3$)				0.00444*		
				(1.81)		
VC Count (t) × R&D ($t-3$)				0.00154*		
				(1.78)		
R&D Support ($t-4$)					0.00588**	
					(2.20)	
VC Count (t) × R&D ($t-4$)					0.00188*	
					(1.95)	
R&D Support ($t-5$)						0.00602*
						(1.94)
VC Count (t) × R&D ($t-5$)						0.00193*
						(1.74)
Year Dummies	Yes	Yes	Yes	Yes	Yes	Yes
MSA Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.22	0.22	0.22	0.22	0.22	0.22
Clusters	328	328	328	328	328	328
Observations	3270	3270	3270	3270	3270	3270

Notes: OLS regression results; *$p < 0.10$, **$p < 0.05$, ***$p < 0.01$. Robust t-statistics in parentheses; disturbances clustered by MSA.

Table 8
Lag structure of venture capital effects on innovation and entrepreneurship.

	(33) Patents	(34) Patents	(35) Patents	(36) Births	(37) Births	(38) Births
Population ($t-1$)	1.405***	1.414***	1.420***	0.815***	0.815***	0.818***
	(4.71)	(4.73)	(4.77)	(10.25)	(10.15)	(10.17)
R&D Support ($t-1$)	0.0202**			0.00413		
	(2.19)			(1.54)		
VC Count (t)	0.0261**			0.0107***		
	(2.05)			(3.12)		
VC Count (t) × R&D ($t-1$)	0.00764**			0.00178*		
	(2.27)			(1.89)		
R&D Support ($t-2$)		0.0247***			0.00177	
		(2.80)			(0.49)	
VC Count ($t-1$)		0.0195			0.0108***	
		(1.60)			(2.59)	
VC Count ($t-1$) × R&D ($t-2$)		0.00894***			0.000520	
		(2.83)			(0.40)	
R&D Support ($t-3$)			0.0298***			0.00239
			(3.67)			(0.70)
VC Count ($t-2$)			0.0145			0.00837*
			(1.22)			(1.92)
VC Count ($t-2$) × R&D ($t-3$)			0.0109***			0.000782
			(3.73)			(0.63)
Year Dummies	Yes	Yes	Yes	Yes	Yes	Yes
MSA Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.16	0.16	0.16	0.22	0.22	0.22
Clusters	328	328	328	328	328	328
Observations	3270	3270	3270	3270	3270	3270

Notes: OLS regression results; *$p < 0.10$, **$p < 0.05$, ***$p < 0.01$. Robust t-statistics in parentheses; disturbances clustered by MSA.

regions and at six times the rate of those further away (Samila and Sorenson, 2011).

Finally, it has been well documented that venture capital funds have a strong tendency to invest locally (Sorenson and Stuart, 2001). Venture capitalists rely on local social networks to find investments and then must travel to their portfolio companies regularly to monitor and advise them; they therefore prefer to invest locally. Together, these facts imply that high returns among institutional investors' portfolios in one year lead to more venture capital investments in the next few years in the same regions and in neighboring regions to those institutional investors.

Following Samila and Sorenson (2011), we constructed our measure of LP Returns by multiplying the national average percentage returns to college and university endowments by the number of limited partners – not just colleges and universities but all institutional investors – in each region that had invested in any private equity fund at least ten years earlier (i.e. before our estimation window). For MSA i in year t:

$$LP\quad returns_{it} = \sum_{s=t-1}^{t-3} ER_s \ln(1 + LP_{is}), \tag{2}$$

where ER_s denotes the returns to college endowments in year s and $\ln(1+LP_{is})$ represents the logged count of limited partners located in MSA i who had invested in any private equity fund in the past ten years (plus 1 to avoid zeros). This product provides an estimate of the investment gains that institutional investors in the region experienced and hence of the amount of funds available for allocation to venture capital.

We summed three years of inflows to create our instrument because venture capital firms typically invest the funds that they raise over the first several years of the partnership. Samila and Sorenson (2011) reported that venture capitalists disperse these funds most rapidly over the first three years of the their funds' lives.

Exogeneity. Recall that the validity of the instrument also depends on a second assumption, that the path described – that is, an increase in the local supply of venture capital – forms the only connection between institutional investor returns and the economic health of the region. We made several choices in the construction of the instrument to ensure that this assumption holds. First, instead of using the actual returns of limited partners in a region, we used the national average returns for a year as a proxy for these returns. If we instead used the actual returns of each institutional investor, one might worry about reverse causality or mutual dependence on an unobserved factor – that the institutional investors in the region did well because of the strength of the local economy or that the better universities, with more interesting inventions, systematically invested in funds with higher returns. By using national average returns, we eliminated these potential threats to the validity of our instrument.

Second, instead of using a contemporaneous count of limited partners in the region, we lagged this count by ten years, to a period prior to our observation window. If instead we had used a contemporaneous count of institutional investors, one might worry that institutional investors enter endogenously as a result of the strength of the local economy. But by using the count from before the beginning of our observation window, we removed this potential threat to the validity of our instrument.

We believe that these precautions eliminated nearly all potential threats to the validity of our instrument. Note that, because of the region and year fixed effects, any threat would need to involve a within-region, region-specific, time-varying relationship between the returns of institutional investors and regional innovation or entrepreneurship. One final concern is that the instrument might directly influence patenting and/or entrepreneurship. To address that concern, we estimated the models while restricting the LPs used in the construction of the instrument to insurance companies and pension plans. Direct flows of funds from these investors to the regions in which they reside are either random (insurance claims) or largely pre-determined (pension payments) and therefore exogenous to the supply of venture capital. We nevertheless found qualitatively equivalent results with this more conservative version of the instrumental variable.

To incorporate the interaction terms, we estimated the IV results in two stages. We first regressed venture capital activity on the instrument (*LP returns*), population, year and region fixed effects, exactly as in the first stage of a standard 2SLS estimation. We then predicted the value of the venture capital measure using the estimated coefficients and used that prediction and its interaction with government research funding (*R&D Support*) in the second-stage regressions. Because OLS does not properly estimate the standard errors of the coefficients for predicted values, we obtained the standard errors through bootstrapping the regression 10,000 times. The first column of Table 9 reports the first-stage estimates for the instrumental variable and our measure of venture capital activity. Not only is the instrument valid, but also it appears strong, with a t-statistic of more than ten.

The second-stage results appear in the next four columns, the first two with patents as the dependent variable and the next two with establishment starts as the dependent variable. Not only are the estimates from the IV estimation consistent with those of the earlier models, but they appear roughly equivalent in the implied magnitude of the interaction effects. The estimates also mirror the OLS results in terms of statistical significance.

5. Discussion

Some regions have been far more successful than others in terms of converting basic research into economic growth. Here, we demonstrate one factor that appears to account for a significant portion of these differences: the local availability of venture capital. Examining a panel data set of metropolitan statistical areas in the United States from 1993 to 2002, we find evidence of complementarity between public research funding and the private provision of venture capital in the within-region variation over time in patenting and establishment starts. In other words, public research funding generates more patents and startups in regions rich in venture capital.

Venture capital most likely serves as a catalyst for commercialization because it helps to develop the pool of entrepreneurial talent in an area. Whereas federal research grants generally fund academic research – the creation of ideas – venture capital supports the development of these ideas and helps to train and encourage a community of entrepreneurs capable of bringing those ideas to market. Since high technology businesses often require both inventors and entrepreneurs, venture capital allows regions to exploit a larger share of the ideas that emerge from the region and consequently to grow more rapidly (Michelacci, 2003; Romain and van Pottelsberghe, 2004b). The availability of venture capital may even encourage researchers to explore more radical innovation paths, with the knowledge that an ecosystem exists to nurture the fruits of those investigations.

Although our results suggest that venture capital complements public research funding, the extent of this complementarity varies across agencies. Funding from the NSF and the Department of Defense appear to benefit the most from the presence of a venture capital community. Two factors might account for this variance. On the one hand, some agencies may sponsor technologies that fit better with established firms than with startups. On the other hand, agencies may vary in the efficiency with which their research dollars produce innovations. Our results suggest that the former

Table 9
Instrumental variables estimation for innovation and entrepreneurship.

	Fist stage	(39) Patents	(40) Patents	(41) Births	(42) Births
Population ($t-1$)	1.116**	1.330***	1.368***	0.803***	0.813***
	(2.45)	(4.71)	(4.85)	(9.32)	(9.13)
LP Returns	0.0112***				
	(10.49)				
R&D Support ($t-1$)	0.000791	−0.000617	0.0265*	−0.000706	0.00664
	(0.60)	(−0.22)	(1.89)	(−0.98)	(1.60)
VC Count (t)		0.0957***	0.0814**	0.0227**	0.0189*
		(3.23)	(2.57)	(2.35)	(1.95)
VC Count (t) × R&D ($t-1$)			0.00974**		0.00264*
			(1.98)		(1.83)
Year Dummies	Yes	Yes	Yes	Yes	Yes
MSA Fixed Effects	Yes	Yes	Yes	Yes	Yes
R^2	0.27				
Clusters	328	328	328	328	328
Observations	3270	3270	3270	3270	3270

Notes: 2SLS regression results; $^*p<0.10$, $^{**}p<0.05$, $^{***}p<0.01$. Bootstrapped t-statistics in parentheses.

matters more to this heterogeneity than the latter, since it appears only in the interactions between funding and venture capital and not in the main effects of research funding on patenting and entrepreneurship.

Most immediately, our results suggest that many regions in the United States would benefit from an influx of venture capital. In particular, regions receiving high levels of funding from the Department of Defense and the NSF stand to gain the most from such influxes. To return to our opening example, though, in part, the paucity of entrepreneurial activity in Atlanta may reflect the kind of research that occurs at its institutions – Emory and the Centers for Disease Control and Prevention primarily produce medical research – in part, this paucity also probably stems from Atlanta's relative lack of local venture capital. Atlanta therefore appears to have much to gain from developing a venture capital community.

Our results might also help to explain some of the cross-national variation in the returns to research and development. Cross-national comparisons of the effects of public research on growth, for example, have often found negative relationships, particularly among developing nations (Shenhav and Kamens, 1991; Schofer et al., 2000). Notably, these countries almost uniformly do not have local venture capital communities (and more generally may not have the institutional infrastructure necessary to support high tech entrepreneurship). This absence may therefore account for this otherwise puzzling result.

The question of how to stimulate the development of local venture capital communities nevertheless remains an open one. Numerous countries and states have attempted to enact policies to encourage venture capital but few of these policies have been successful (Lerner, 2009). Their failure has undoubtedly resulted both from the unintended incentives created by these policies and from the incompatibility of the venture capital model with some of the institutional attributes of the jurisdictions that have implemented these policies. But our knowledge of the precise reasons for these failures and potential solutions to them remains incomplete. The importance of this issue nonetheless argues for additional research.

More generally, our findings point to the importance of ecosystems for supporting innovation and entrepreneurship. Though prior research on government grants to firms have sometimes found a crowding out effect (e.g., Wallsten, 2000), government grants to universities and private venture capital appear to be complements in the production function. Though only one of the many potential interactions, in this sense, we see our results as quite consistent with the ideas forwarded by a number of scholars that government, institutions, and industry all play complementary roles in producing an environment conducive to innovation and economic growth (e.g., Freeman, 1995; Cooke et al., 1997; Etzkowitz and Leydesdorff, 2000; Powell et al., 2002).

With respect to this literature, our approach may also offer something of a methodological innovation. The empirical literature on regional ecosystems has found it difficult to progress beyond case studies. Though these case studies offer rich insight into the processes that unfold in regions, they find it difficult to isolate the most important factors – the potential levers for policymakers – and to quantify the magnitude of these effects. By investigating pairs of relationships, our approach offers a middle ground, one that allows statistical analysis and quantification while still recognizing the importance of the interactions between the elements of the regional ecosystem.

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