Venture Capital and Industrial Innovation: Evidence from Europe*

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Abstract

We provide the first cross-country evidence of the effect of venture capital investment on industrial innovation. Using a panel of 21 European countries and 10 manufacturing industries covering the period 1991-2005, we study the effect of venture capital, relative to R&D, on the number of granted patents. We address concerns about causality by exploiting variations across countries and over time in private equity fundraising and in the structure of private equity funds. Our estimates imply that while the ratio of venture capital to R&D has averaged around 6% between 1991 and 2005, VC has accounted for 9.7% of industrial innovation during that period. We also find that VC is relatively more successful in fostering innovation in countries with less stringent labour regulations and with higher human capital.

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1 Introduction

Innovation is at the heart of today's policy debate with President Obama's Innovation Agenda and President Barosso's Innovation Union. A potential problem to achieve these innovation agendas is that innovation is difficult to finance privately (Hall and Lerner, 2010) and that the economy's openness to innovation depends in part on its innate financial system (Czarnitzki and Hottenrott, 2009). In particular, bank-based systems in Continental Europe are viewed as less capable of financing innovation and of facilitating path-breaking innovations than the market-driven systems in the US and the UK (e.g., Boot and Thakor, 1997; Rajan and Zingales, 2001; Carlin and Mayer, 2002; Herrera and Minetti, 2007).

Policymakers often perceive venture capital as being better able to finance innovation than banks (e.g., European Commission, 2009). When technologies are in their gestation period their trajectories are far from defined and success is highly uncertain. Venture capitalists provide equity investment and therefore share in both the profits and losses from innovation. Banks provide loans which only gives them a share in the losses. Moreover, venture capitalists can spent time and money on individual firms and assist them with their development whereas banks often cannot (Amit, Brander, and Zott, 1998; Kaplan and Stromberg, 2001). Venture capitalists are active investors that can help companies to reduce the time to bring a new product to the market (Hellmann and Puri, 2000), pursue more influential innovations (Kortum and Lerner, 2000), arrange subsequent financing and help with recruiting managers in the United States (Hellmann and Puri, 2002) and to a smaller degree in Europe (Bottazzi and Da Rin, 2002; Bottazzi, Da Rin, and Hellmann, 2008).

In Innovation Commissioner Máire Geoghegan-Quinn's words, Europe is facing an "innovative deficit"[1] and needs to be more successful in turning science into new technologies,

[1] See Speech of Commissioner Geoghegan Quinn to a meeting of IMCO (Internal Market and Consumer Protection Committee of the European Parliament) on the role of public procurement policies in supporting

products and services. Many of these innovations reside in the so-called "Value of Death" because small innovative European firms lack the necessary access to financial support. The European Commission views a more efficient venture capital market as a potential solution for this funding gap (European Commission, 2009). They argue that venture capital helps to further develop early and mid-stage innovative firms, with high-growth potential. If this funding gap is not addressed Europe may experience difficulty to catch up with the US and Asia in commercializing inventions. This assumes there is a yet untested link between venture capital and innovation in Europe. Our study is the first to provide cross-country cross-industry evidence on this relation using a sample of 21 European countries and 10 industries during the period 1991-2005. This sample period includes the unprecedented increase in European venture capital investment in the late 1990s, as well as its subsequent decline.

The extant literature provides mixed evidence of the relation between venture capital and innovation. Kortum and Lerner (2000) investigate the influence of venture capital on patented innovations across twenty manufacturing industries in the United States. They report that, while the ratio of venture capital to industrial R&D averaged less than 3% between 1983 and 1992, venture capital accounted for 8% of industrial innovation in the United States over that period. Hirukawa and Ueda (2008b) extend Kortum and Lerner's sample period to 2001. They conclude that it is the arrival of new technologies that increases demand for venture capital ("innovation first") and not the other way around ("venture capital first") as suggested by Kortum and Lerner (2000). This "innovation first" explanation is supported by studies using firm-level data that show that venture capital does not foster new innovations but instead invests in already innovative firms in the United States (Hellmann and Puri, 2000), Germany (Engel and Keilbach, 2007) and Italy (Caselli, Stefano, and Perrini, 2009).

EU innovation strategies, 1 February 2011.

In this paper we add to this literature by examining whether venture capital acts as a catalyst for innovation in Europe using the Kortum and Lerner (2000) empirical framework in a cross-country cross-industry setting. This allows us to test whether the perception of European policymakers that venture capital stimulates innovation is supported by the data. This is not obvious given the debate in the literature between the "venture capital first" and "innovation first" explanations for the positive association between venture capital investments and patented innovations. Moreover, the European venture capital industry is smaller and less developed compared to the venture capital industry in the United States (Bottazzi and Da Rin, 2002). European venture capitalists have been documented to be less active monitors than venture capitalists from the other side of the Atlantic, especially in the early 1990s (Sapienza, Manigart, and Vermeir, 1996) with their level of involvement improving in the late 1990s and early 2000s (Bottazzi, Da Rin, and Hellmann, 2008). Hence, the results of Kortum and Lerner (2000) may not necessarily apply to the European setting.

Another contribution of this paper is that we can differentiate European countries according to their barriers to entry, intellectual property rights protection, human capital, labour market regulations and tax and legal rules regarding venture capital. This allows us to investigate whether these institutional factors influence the relation between venture capital and innovation. This can potentially help policymakers to design national regulations to strengthen the influence of venture capital on innovation.

We estimate reduced form regressions of patented innovations on industrial R&D and venture capital. The knowledge production associated with an increase in research input has been shown to affect growth via the process of innovation both theoretically (for example, Romer (1990)) and empirically (for example, Griliches (1979) and Ulku (2007)). We also address the main problem identified by Kortum and Lerner, namely that both venture capital funding and patenting are positively related to the arrival of technological opportunities.

We do so by using data on private equity fundraising and on the structure of private equity funds in each country. Private equity funds can be organized via limited partnerships (i.e., independent funds) or be owned by one large financial institution (i.e., captive funds). Limited partnerships raise money from limited partners (i.e. institutional investors) for a fixed period of ten years and are managed by a general partner (i.e. the fund manager) that decides in which companies to invest the money. The limited lifespan of the fund and the need to show a return on investment creates time pressure on the general partner to invest the money in the first three years of the lifespan of the fund. This implies that independent funds have to invest within a relatively short time window and invest in the investment opportunities that happen to be available at that point in time. This differs from captive funds that do not have a limited lifespan and do not raise capital from outside investors other than the single owner of the private equity fund (e.g., a bank or insurance company). We therefore argue that increased money flows in venture capital translate into investments in companies at a faster pace when a country has a higher fraction of private equity funds organized as limited partnerships as opposed to captive funds. Moreover, private equity fundraising better reflects changes in strategic allocation to venture capital in institutional investor's portfolios in countries with a higher fraction of independent limited partnerships. These strategic allocation decisions can be considered exogenous in the sense that they are made for the longer term.

We find that venture capital has a sizeable effect on industrial innovation, but that this effect is statistically weak. We find that while venture capital investment has accounted for around 6% of aggregate (venture capital plus R&D) industrial spending over the sample period, VC investment has accounted for around 9.7% of industrial innovation. However, in the full sample the impact of venture capital is not significant statistically. Our results do tend to be stronger in various sample partitions. For example, we find that VC investment has had a pronouncedly stronger effect in non-transition economies, where a euro of VC investment is estimated to be as much as 3 times as potent as a euro in R&D. In addition, VC turns out to have a much more significant effect on the propensity to patent in countries with less stringent labour regulations and higher human capital.

At first glance, our results are weaker, in an economic sense, and less consistently significant, in a statistical sense, than the ones found in similar studies using US data. In particular, Kortum and Lerner (2000) and Hirukawa and Ueda (2008a) - focusing on the 1965-1992 and on the 1968-2001 periods, respectively - find that VC is between 4 and 28 times more efficient than R&D in generating ultimately successful patents. However, when we replicate our analysis on US data for the same period we use in this paper, namely 1991-2005, we find that VC does not have a statistically significant effect on the propensity to patent in the US, suggesting that much of the effect measured in these prior studies is driven by the interplay between VC, R&D, and patent counts in the early days of the modern VC industry. Due to data unavailability, we cannot perform our analysis on the effect of VC on innovation in Europe on a sample period starting before 1991. Therefore, based on our evidence, we conclude that in terms of patenting activity, the European VC industry appears to have been less efficient in promoting industrial innovation than its US counterpart, when the US venture capital industry's long-term performance is taken into account, but not necessarily since 1991.

The paper proceeds as follows. Section 2 provides an overview of the European venture capital industry. Section 3 describes the data. Section 4 presents the empirical methodology. In Section 5, we report the estimates from our main tests. Section 6 discusses the policy implications of our results. Section 7 concludes.

2 Venture capital and the financing of young innovative companies

Young innovative companies usually require substantial sums of money to be invested for a longer term with success being highly uncertain. Financing innovative firms is subject to a severe information asymmetry problem known as the lemons problem, first introduced by Akerlof (1970). In such models, innovative firms themselves are better informed about the quality of the invention than investors who are in the dark about whether they are dealing with a good or bad invention. If this information asymmetry problem is left unresolved it may lead to underinvestment in innovation and in the extreme case no innovative firm in the economy will be financed. It is difficult to mitigate this problem by having innovative firms fully disclose their ideas since this will benefit competing firms (Bhattacharya and Ritter, 1983).

How is innovation financed? To begin with, companies will try to finance innovative project themselves by retaining profits. This may be a viable alternative for larger firms that are already profitable but impossible for young innovative firms that have not yet reached this stage. Banks are unlikely to fund innovative projects given their highly uncertain outcome and banks' reliance on collateral. If capital markets are imperfect and information asymmetries are severe some innovative firms in the economy may therefore not get financed.

Venture capital has developed to provide a solution to this "missing market" problem (Hall and Lerner, 2010). Venture capital has a comparative advantage in dealing with information asymmetry problems via monitoring and staged financing (Kaplan and Stromberg, 2001). Venture capital can thus be an important engine for the Schumpeterian process of "creative destruction" and a major force in transforming scientific knowledge into commercial output.

As Gompers and Lerner (1998, 1999a) report, the venture capital industry dates back to the formation of American Research in Development in 1946 and the Small Business Investment Company Act in 1953, designed to increase the availability of funds to new ventures. However, the flow of money into venture funds really only picked up in the late 1970s and the early 1980s after the 1979 clarification of the "prudent man" rule governing pension funds investment. Prior to that, the ERISA severely limited the ability of pension funds to invest in risk capital markets, but in 1979 the US Department of Labour issued a clarification of the rule stating that diversification is an inalienable part of prudent investment behavior. As a result, in the eight years following this decision the amount invested in new venture funds soared from $481 million to nearly $5 billion, with pension fund accounting for nearly half of all contributions (Gompers and Lerner, 1999). This surge of funds into the venture capital industries is often credited with the high-tech revolution in the US in the 1990s (Gilson, 2003).

Most venture capital funds in the United States are organized as a limited partnership with a fixed life of ten years (Sahlman, 1990). This model was successfully pioneered in Silicon Valley in the 1980s to organize third-party investment in technology firms. The limited partnership raises money from limited partners comprising both high net worth individuals and institutional investors (e.g., pension funds, university endowments, pooled investment vehicles (fund of funds) and insurance companies). A general partner manages the venture capital fund and decides in which companies to invest the money. The general partner is expected to increase the value of the investee companies. Value can be added by close monitoring, giving investee companies access to the network of business contacts of the general partner and/or professionalizing the firm (Hellmann and Puri, 2002). The general partner receives compensation for his efforts in the form of an annual management fee of up to 2% of the committed capital and carried interest, typically a 20% share in the profits of the fund (Gompers and Lerner, 1999b). Limited partnerships face pressure to do deals in the first years of the limited lifespan of the venture capital fund such that enough time remains to add value to the investee companies. In the second half of the life of the fund the general partner seeks to sell the shares in the investee companies. At the end of the fixed life of ten years all the money from the sale proceeds of the shares in the investee companies is returned to the limited partners. Limited partners can then decide to reinvest the money into a new fund managed by the same general partner but are typically only willing to do so if they earned an attractive return on investment in the previous funds managed by that general partner. General partners therefore face substantial pressure to do deals early on in the life of the fund and to show a return on investment in order to be able to successfully raise money from institutional investors in follow-on funds (Gompers, 1996).

The venture capital industry in Europe has been slow to reproduce this development. In fact, only recently did the European Commission undertook explicit regulatory intervention to prohibit national legislation from preventing insurance companies and pension funds from investing in risk capital markets[2], and as of the end 2006, some EU countries hadn't adopted these directives yet.[3]

This change in prudential rules has been accompanied by an increase in the fraction of European venture capital funds that are organized as limited partnerships as opposed to captive funds. Nevertheless, captive funds owned and funded by a single large financial institution, typically a bank, continue to play an important role in Europe (Bottazzi, Da Rin and Hellmann, 2008). These captive funds do not have a limited lifespan and can draw upon financial institution for more funding at the time when interesting investment opportunities

[2]Directives 2002/13/EC and 2002/83/EC concerns the investment behavior of insurance companies, and directive 2003/41/EC the investment behavior of EU pension funds.

[3]See the December 2006 "Benchmarking European Tax and Legal Environments" report of the EVCA for details.

present themselves. In some European countries like Denmark, Finland and Sweden these changes in prudential law and private equity fund structures contributed to risk capital investment as a share of GDP approaching US levels.

3 Data description

This paper uses data from four main sources: on venture capital from Thomson VentureXpert; on patent grants from the United States Patent and Trademark Office (USPTO); on R&D from ANBERD-OECD; and on value added from the STAN Database on Industrial Analysis. We focus on manufacturing industries only in order to make our analysis comparable to the results in Kortum and Lerner (2000) and Hirukawa and Ueda (2008a).

3.1 Data sources

The venture capital investment data come from Thomson VentureXpert. The Thomson VentureXpert database contains information on all venture capital deals realized in the following 21 European countries: Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Netherlands, Norway, Poland, Portugal, Slovakia, Spain, Switzerland, Sweden, and UK. The data start in 1991. Venture capital investment in the database only includes seed/start-up, development, early, balanced, expansion and later stage investments. It therefore excludes buyouts, mezzanine financing, turnaround financing, distressed debt investments, and other private equity investments by secondary funds and fund of funds. These investments can be made by venture capitalists from the same country in which the portfolio firm is located but also by foreign venture capitalists. We downloaded all venture capital deals from Thomson VentureXpert for each country starting in 1991 (VentureXpert does not have a good coverage of European VC deals prior to that year). The data are in current euro and we convert them into constant euros using 2006 as a base year. Finally, the data are classified using Thomson VentureXpert's own VE Primary Industry Sub-Group 3 Classification.

The patent data come from the United States Patent and Trademark Office (USPTO) and are available annually.[4] We extract the raw USPTO patent data from Eurostat. We focus on the period which starts in 1991 in order to match these data to our data on venture capital disbursements. We sort the data by country of residence of the inventor rather than by country of residence of the applicant. We do so in order to eliminate the contamination in the data by, for example, UK venture capitalists filing patent applications from the UK for their portfolio companies in eastern Europe. We also sort the patent data by year of application instead of by year of grant.[5] As in Kortum and Lerner (2000) and Hirukawa and Ueda (2008a), we intrapolate missing patent values. Patents are classified using the International Patent Classification (IPC).

Data on in-house R&D investment come from ANBERD-OECD. We download data at the industry level starting in 1991 period using the NACE Rev. 1.1 classification. Again, as Kortum and Lerner (2000) and Hirukawa and Ueda (2008a) do, we intrapolate missing R&D values. The data come in local currency which we convert into constant euros using 2006 as a base year. We complement these data with data on aggregate government outlays on R&D.

Finally, we download data on industry value added from the STAN Database for Structural Analysis. The data are classified using the NACE Rev. 1.1 classification and come in

[4]There are a number of reasons we prefer to work with USPTO rather than with EPO data. For example, USPTO patents are more cited than EPO patents, most USPTO patents are also EPO filed but not the other way around, and most of the preceding relevant literature has looked at patents granted by the USPTO (see, e.g., Hall, Thoma, and Torrisi, 2007). Finally, the ANBERD-OECD reports EPO data on patent applications only, rather than on patent grants.

[5]There tends to be an at least one year lag between application and grant (see Hirukawa and Ueda, 2008a).

current euros, so we convert them into constant euros using 2006 as a base year.

In all cases, we download data until 2008, which is the last year for which data are available for some of the series. In Section 3.3, we revisit the validity of this sample period.

3.2 Concordance

As emphasized in the previous sub-section, the relevant data are available in different industrial classifications. The original venture capital data from Thomson VentureXpert contain information about deal value as well as each portfolio company's industry affiliation codes using Thomson VentureXpert's own VE Primary Industry Sub-Group 3 and SIC codes. However, for 13.8% of the deals, the SIC industry affiliation information is missing. For these cases we developed a unique concordance key to translate these companies' VE Primary Industry Sub-Group 3 to a SIC code. The concordance key is constructed based on the most frequently observed SIC code from all deals in that VE Primary Industry Sub-Group 3 realized in 21 European countries from 1991 until 2008. By using this key, we are able to assign all target companies to a SIC code. Aggregate values of venture capital invested in each industry are then calculated for each year and for each country. This procedure is based on Hirukawa and Ueda (2008a).

SIC codes are then converted into NACE Rev. 1.1 codes through the NAICS industrial classification. The US Census Bureau provides a concordance key between SIC and NAICS and between NACE Rev. 1.1 and NAICS. To each NAICS 6-digit class, we match the corresponding SIC and NACE Rev. 1.1 classes. This results in a non-unique matching between 2-digit SIC and 2-digit NACE Rev. 1.1 classes. We also exclude some industries for different reasons. In particular, we exclude NACE Industry 16 (Tobacco products) which has no VC investment in the sample; NACE Industry 19 (Leather products) which is not in the samples used in Kortum and Lerner (2000) and Hirukawa and Ueda (2008a); NACE Industry 23 (Coke and petroleum products) for which there are only six country-industry-year observations with non-zero VC investment; and NACE Industry 22 (Publishing and printing) in which there are no patents in the sample.

We collapse the remaining 18 NACE manufacturing industries (corresponding to 16 SIC manufacturing industries) into 10 industry classes such that no information is lost. This results in five unique matches and five aggregated industrial classes. In particular, our new Industry 9 (Machinery and equipment n.e.c.; office machinery and computers; electrical machinery n.e.c.; radio, television, and communication equipment; medical, precision, and optical instruments) now includes 3 SIC and 5 NACE Rev. 1.1 classes. See Table 1 for the concordance key used in the paper and for the resulting industry classification.

Patent grants are assigned to industrial sectors using the International Patent Classification (IPC). This classification is finer than the 2-digit SIC and NACE classifications, yielding a total of 632 patent classes. This allows for a relatively precise aggregation into broader sectors, and so patent data are converted into 2-digit NACE industry classes using a concordance key developed by the Chair of Economics and Management of Innovation (CEMI) at the Ecole Polytechnique Federale de Lausanne.[6] The NACE classes are further converted into our industrial classification in Table 1. The same procedure is followed for the data on value added which come in NACE Rev. 1.1 format.

3.3 Data summary

Table 2 summarizes all relevant data by country. Clearly, venture capital disbursements are heavily skewed, with three countries (France, Germany, and the UK) accounting for almost 2/3 (64.4%) of all VC investment in Europe. Germany also accounts for more than

[6] See http://wiki.epfl.ch/patstat/sector for details.

a third (34.2%) of all R&D investment and for almost a third (31.3%) of all patent grants in Europe. In all, the data suggest that large difference in absolute (but also in per-unit-of-GDP) differences exist across European countries in both the propensity to finance innovation and in the propensity to patent innovation.

Table 3 gives an idea of the distribution of our variables by industry. Again, venture capital disbursements are heavily skewed across manufacturing sectors. For example, four SIC 2-digit industries (Chemicals and chemical products; Industrial machinery and equipment; Electrical and electronic equipment; and Instruments and related products), subsumed in our industry classes 5 and 9 (see Table 1) account for around three quarters of all VC disbursements and of all patent grants (73.1% and 75.4%, respectively). Analogously, four SIC 2-digit industries (Industrial machinery and equipment; Electrical and electronic equipment; Instruments and related product; and Transportation equipment), subsumed in our industry classes 9 and 10 (see Table 1) account for 65.9% of average annual R&D investment.

Finally, Table 4 looks at the data from a time dimension. One striking fact relates the development of VC disbursements and R&D investment over time. In particular, while VC and R&D investment increased together between 1991 and 2002, VC investment collapsed in the wake of the dot-com bubble, while R&D investment remained relatively steady. Ultimately successful patent applications decline towards the end of the period, as many patent applications were still under consideration during the last update of the database. Given the pronounced drop in patent grants starting in 2006, in the empirical tests we restrict our attention to the period 1991-2005 in order not to contaminate our estimates by missing data which may be systematically different across industries.

See Appendix for all data sources.

4 Empirical methodology

In this section we present the empirical methodology. We start by imposing no structure on the relationship between venture capital, R&D investment, and patent grants. In the simplest case, we estimate a model of the form

$$\ln P_{ijt} = a \ln RD_{ijt} + b \ln VC_{ijt} + c\Psi_{ijt} + u_{ijt}, \quad (1)$$

where P_{ijt} denotes the number of patent grants in industry i in country j at time t; RD_{ijt} denotes R&D investment in industry i in country j at time t; VC_{ijt} denotes venture capital disbursements in industry i in country j at time t; and Ψ_{ijt} is a matrix of country, industry, and year fixed effects. The coefficients a and b measure the elasticity of ultimately successful patent applications to R&D and VC, respectively.

Next, we assume that the arrival of patents is derived from a Poisson process. From the properties of the Poisson distribution, $E[P_{ijt}] = \lambda_{ijt}$. Therefore, we estimate the following model which uses as a group a country-industry pair:

$$Prob(P_{ijt}) = \frac{e^{-\lambda_{ijt}} \lambda_{ijt}^{P_{ijt}}}{P_{ijt}!}, \text{ where } \ln \lambda_{ijt} = aRD_{ijt} + bVC_{ijt} + c\Psi_{ijt} \quad (2)$$

Finally, in most of the empirical tests, we employ the empirical model from Kortum and Lerner (2000) and Hirukawa and Ueda (2008a). More precisely:

1. We assume a Constant Elasticity of Substitution (CES) of the general form

$$P_{ijt} = (RD_{ijt}^{\rho} + bVC_{ijt}^{\rho})^{\frac{a}{\rho}} u_{ijt}$$

As noted by Kortum and Lerner (2000), in the case when VC investment is small relative to R&D (a sample average of 0.047 in our case), it is reasonable to estimate b through a linear approximation of the patent production function.[7] We therefore set $\rho = 1$ and estimate a linearized version of the CES production function (accounting for country, industry, and year fixed effects) of the form

$$\ln P_{ijt} = a \ln RD_{ijt} + ab\frac{VC_{ijt}}{RD_{ijt}} + c\Psi_{ijt} + \ln u_{ijt} \quad (3)$$

The coefficient of interest is b, calculated as the ratio of the OLS coefficient on $\frac{VC}{RD}$ to the OLS coefficient on $\ln RD$. It measures the implied potency of VC relative to R&D. The regression also include industry dummies, country dummies, and time dummies, in an attempt to net out the effect of unobservables that are common across countries/industries, as well as of the global business cycle.

2. We address the endogeneity of venture capital investment by exploiting data on private equity fundraising and on the structure of private equity funds in each of the 21 countries. We argue that increases in fundraising more quickly translate into venture capital investments in countries with a higher fraction of private equity funds organized as limited partnerships (i.e. independent funds). These independent funds face pressure to invest the money they raised early on in the fixed ten year lifespan of the fund as opposed to captive funds who do not experience similar time pressure. This implies that independent funds have to invest within a relatively short time window and invest in the investment opportunities that happen to be available at that point in time. Private equity fundraising is therefore expected to better reflect changes in strategic allocation to venture capital in institutional investor's portfolios in countries with a higher fraction of independent limited partnerships. These strategic allocation decisions to venture capital can be considered exogenous in the sense that they

[7] This linear approximation was suggested by Griliches (1986), who argued that a Taylor expansion of the logarithm of the function is reasonable when one is trying to evaluate the impact on output of a variable whose values are relatively small to the other input in the production function.

are made for the longer term.

Therefore, we construct our instrument by interacting the logarithm of funds raised by PE funds in each country-year with the share of investment by independent (as opposed to captive) funds in the past 5 years in each country. This instrument should satisfy both IV conditions. More funds raised by limited partnerships under pressure to invest quickly should result in more immediate VC investment and a higher $\frac{VC}{R\&D}$ ratio, satisfying the relevance conditions. At the same time, there is no reason to expect that private equity funds raised would affect innovation through any other channel but actual VC investment, so the exclusion restriction should be satisfied too. We formally test for the strength of this instrument in the next section.[8]

Finally, in all regressions we control for government outlays on R&D. Unfortunately, this variable is coded by Eurostat using an industrial classification that is inconsistent with SIC and NACE, preventing us from matching the data at the industry level, and so instead we control for aggregate government R&D outlays.

5 Empirical estimates

5.1 Venture capital and innovation: Preliminary results

We begin by estimating our Models 1 and 2. As noted before, there are suspiciously few patents granted to applications made in 2006-2008 (see Table 4 for details), implying that many ultimately successful grants were not counted in the last update of the database. For

[8] We have also used the changes that occurred in prudential rules as a result of the EU Directive in 2003 This allowed pension funds to invest in risk capital markets and acts as a supply shifter for venture capital. However, we find pension fund reform is not such a good instrument in the European setting as it was in the United States. The implementation of this EU Directive was a lengthy process that made its effect anticipated. This contrasts with the sudden implementation of ERISA in 1979 in the United States that is used as an instrument by Kortum and Lerner (2000).

that reason, we do not use information from these years, and focus on the 1991-2005 period in all regressions to follow.

In Table 5, we first estimate the elasticity of patent grants to VC and to R&D investment.[9] We find that a doubling of VC investment is associated with between 2.4% and 2.6% more patent grants, depending on whether we control for R&D (column (ii)) or not (column (i)). Doubling R&D investment is associated with 10% more ultimately successful patent applications (column (ii)). Both the effect of VC and that of R&D are statistically significant at least at the 5% level, while the effect of government R&D (column (iii)) is not (although it is positive).

The estimates of the Poisson regression give a similar picture of the effect of VC on industrial innovation. In particular, the data suggest a positive and significant correlation between VC and patent grants both when we do not control for R&D investment (column (iv)), and when we do (column (v)). R&D itself is once again associated with a positively and significantly higher number of patent grants. The effect of government outlays turns out to be negative and significant (column (vi)).

5.2 Venture capital and innovation: Main result

We proceed by replicating Kortum and Lerner's (2000) and Hirukawa and Ueda's (2008a) OLS analysis of the linear patent production function (Model 3) on the 21 country-10 industry panel over the period 1991-2005. Consistent with our identification strategy, we begin by reporting the estimates from a first-stage regression of the $\frac{VC}{RD}$ ratio on our instrument, namely, the natural logarithm of total funds raised by private equity managers in that year in that particular country interacted with the 5-year average fraction of total private equity investment in that country made by independent PE funds (see previous section for discus-

[9] In all OLS regressions that follow we cluster standard errors by country-industry.

sion of the conceptual reasons behind using this instrument). Recognizing that R&D can also be endogenous to innovation, we instrument it with the country-industry's value added in each year, as in Kortum and lerner (2000) and Hirukawa and Ueda (2008a). The rationale behind this procedure is that R&D outlays may be correlated with the disturbances, just like VC investment, and a good instrument for R&D would be a variable that reflects shifts in industry demand, but is unrelated to technological opportunities. Value added presents itself as a good candidate, as the size of the market will be expected to stimulate R&D investment, and it is valid as long as technological opportunities do not affect the size of the market.[10]

Panel A of Table 6 reports the estimates from these two first-stage regressions. In column (i), we treat only $\frac{VC}{RD}$ as an endogenous variable, and instrument it with our instrument based on the size and structure of PE funds. As the instrument varies at the country level, we cluster the standard errors by country. All regressions also control for country, industry, and year fixed effects. The F-value for the significance of this excluded instrument is 6.16. This is lower than the critical value for an instrument to have no more than 10% of the bias of the OLS estimate (see Stock and Yogo, 2005, for details). Nevertheless, the instrument explains a fair share of the variation in $\frac{VC}{RD}$ across countries and industries and is significant at the 5%. In columns (ii) and (iii), we report the first-stage estimates from a regression where both $\frac{VC}{RD}$ and Log R&D are treated as endogenous variables. The instrument based on the size and structure of PE funds continues to be significantly correlated with $\frac{VC}{RD}$, and market size, proxied by the logarithm of value added, is significant at the 1% statistical level in explaining variations in Log R&D. The F-values from the test of the joint significance of the two excluded instruments are between 3.22 and 7.73. A test that the two variables are jointly exogenous is rejected at the 10% statistical level, and so in our 2SLS specifications

[10] See Kortum and Lerner (2000) for a more detailed discussion.

we resort to instrumenting both variables.

In Panel B of Table 6, we report the OLS estimates from Model 3. Column (i) of Table 6 reports the estimates from Model 3 on the full data, where neither VC nor R&D are instrumented. The point estimate of ab is 0.007 and the point estimate of a is 0.044, implying a relative venture capital potency of 0.16. For comparison, the corresponding estimates in Kortum and Lerner (2000) are 1.73 and 0.24,[11] implying a venture capital potency of 7.208. The difference is even larger when we compare to the estimates in Hirukawa and Ueda (2008a), who extend the original Kortum and Lerner (2000) sample to 2001. However, the point estimate of ab is not significant in the statistical sense.

In columns (ii)-(iii), we perform various data robustness checks. We first exclude the sub-sample of emerging economies and countries with limited venture capital investments (column (ii)). This sample consists of the 4 transition economies (Czech Republic, Hungary, Poland, and Slovakia), as well as Greece and Iceland. Countries with too little venture capital investment may be biasing the results if the VC coverage is low due to mis-reporting which varies systematically by industry and over time. We find that in this sample, venture capital is strongly correlated - in a statistical sense - with patenting activity. The implied potency of VC in this sample is 0.36. Finally, in column (iii) we only look at country-industry-year observations with strictly positive VC investment. In this sub-sample, VC investment is strongly, positively, and significantly associated with higher propensity to patent (point estimate of 0.023, significant at the 5%, with implied VC potency of 0.20).

In Panel C, we report the IV estimates from Model 3 using the instruments tested in Panel A. In columns (i)-(iii), we treat only $\frac{VC}{RD}$ as endogenous, and in columns (iv)-(vi) we treat both $\frac{VC}{RD}$ and Log R&D as endogenous. Using this specification, we find that R&D investment is consistently associated with a higher propensity to patent, regardless of which sub-sample

[11] See column 2 of Table 3 of Kortum and Lerner (2000).

we look at. The estimates on $\frac{VC}{RD}$ are generally positive and insignificant. Looking at our preferred specification where both $\frac{VC}{RD}$ and Log R&D are instrumented, in the full sample (column (iv)) the implied potency of VC is much larger than what we estimated in column (i) of Panel B, but the estimate is insignificant in the statistical sense. The same is the case when we look at strictly positive VC investment (column (vi)). However, when we exclude countries with low VC investment (column (v)), we find a significant effect of VC on the propensity to patent and the implied potency of VC relative to R&D is 2.94. Consequently, in countries with reasonably higher levels of VC investment, a euro of VC investment was almost 3 times as potent as a euro of traditional R&D in generating innovation over 1991-2005. Finally, the effect of government R&D outlays is positive and generally insignificant.

The relatively low values for the F-statistics reported in Panel A imply that we could be facing an underidentification problem deriving from weak instruments. We formally test for this possibility in the second stage. We find that indeed this is the case in the full sample (columns (i) and (iv)) - the Anderson's statistics is 0.89 and 0.93, respectively, and we fail to reject the hypothesis that all of the canonical correlations of the matrix of endogenous variables and instruments are zero. This implies that the equation is indeed underidentified and we have a weak instrument problem. However, in the reduced sample of countries (columns (ii) and (v)), as well as in the case when we look at non-zero VC investment (columns (iii) and (vi)), the instruments perform much better in this dimension (p-values of 0.13 and 0.07, respectively, in the case when both $\frac{VC}{RD}$ and Log R&D are instrumented).

Finally, in unreported regressions, we account for the concentrated nature of the European VC market (see Table 2), with France, Germany, and the UK getting around two thirds of all VC disbursements at any point in time. We create dummy variables for three regions (France, Germany, and the UK; the four Scandinavian countries; and the rest), interact them with year dummies, and replace the year dummies in our regressions with these interactions.

Our results remain qualitatively unchanged.

5.3 Venture capital and innovation: Europe vs. the US

What accounts for the large difference between the potency of VC in our sample and the potency of VC estimated in Kortum and Lerner (2000) and in Hirukawa and Ueda (2008a)? One potential explanation is the heterogeneity of our sample, which we explore later on. However, there are a number of potential explanations all of which deal with differences in the sample period and in the data sources used. For one, perhaps VC investment became less efficient (relative to R&D) in generating innovation in the 1990s and the 2000s than it was in the 1960s, 1970s, and the 1990s, which both Kortum and Lerner (2000) and Hirukawa and Ueda (2008a) capture in their studies on the US, but which due to insufficient coverage by VentureXpert of VC investments in Europe prior to 1991 we cannot look at. Second, Kortum and Lerner (2000) and Hirukawa and Ueda (2008a) use data on R&D from the National Science Foundation R&D database, which excludes R&D investment by small firms that may be resulting from VC investment. As far as we know, the ANBERD database we are using cannot make this distinction, implying that our measure of industrial R&D may partially be driven by VC investment, partially explaining the much lower effect of VC we estimate. Finally, the difference may come from the finer granularity of the industry classification used in US studies. Because in their case information on both VC and R&D come at the SIC level, no information is aggregated further and both studies work with 19 industries (instead of 10, as in our case).

To formally test the hypotheses associated with different sample periods, data sources, and industry matching, we collect data for the US from the same data sources we are using, and we match them in the same way. In particular, we download data on VC investment from

VentureXpert for the same set of VEIC industries; data from ANBERD on industrial R&D (which includes also R&D by small US firms); and data on patent grants from Eurostat. Then we match all data using our industry concordance key described in Table 1. Finally, data on R&D and patent grants go back as far as 1973, so we work with 5 years less than Hirukawa and Ueda (2008a) whose data run back to 1968.

In Table 7, we replicate our Model 3 on US data for the 1973-2001 period. In column (i), we use the same instrument as in Kortum and Lerner (2000) and Hirukawa and Ueda (2008a), namely, each industry's pre-1979 $\frac{VC}{RD}$ ratio, interacted with a dummy variable equal to 0 before 1979 and to 1 after that. The estimates are very consistent with what the two US studies have found in that both R&D and VC have a strong positive effect on patent grants. In addition, the numerical estimate of the effect of VC is broadly similar to the one in Table 3, column (ii) in Kortum and Lerner (2000) and the one in Table 5, column (iii) in Hirukawa and Ueda (2008a).[12] Finally, we estimate a VC potency of 17.2, which is even higher than what Kortum and Lerner (2000) and Hirukawa and Ueda (2008a) find (7.26 and 10.07). We conclude that the much lower effect of VC on patent grants in Europe we found in Table 6, compared with prior US studies, is likely not due to differences in data sources and in industry matching.

The remaining potential culprit is the different sample period. In columns (ii) and (iii), we re-estimate the same model with US data, but for the 1991-2005 rather than the 1973-2001 period, to make it consistent with our analysis on Europe. In addition, in column (iii) we cluster the standard errors at the industry level, to make the analysis consistent with our approach.[13] Strikingly, both the effect of R&D and that of VC on patent grants disappear.

[12] Nevertheless, there is a slight numerical difference, most probably induced by the fact that the two US studies 1) use data going back to the mid 1960s, and 2) control for industry-level federally-funded R&D.

[13] We only report results from an OLS regression as the ERISA-based instrument is meaningless if all of the sample period is after 1979.

This suggests that much of the effect of VC on innovation measured in prior US studies is driven by the interplay between VC, R&D, and patent counts in the earlier days of the modern VC industry. Due to data unavailability, we cannot perform our analysis on the effect of VC on innovation in Europe on a sample period starting before 1991. Therefore, based on our evidence, we conclude that in terms of patenting activity, the European VC industry does not appear to have been less efficient in promoting industrial innovation than its US counterpart during the 15 years starting in 1991.

5.4 Alternative data periods

We now look at an alternative time period to our primary one (1991-2005). We first exclude the years after 2002 when VC investment in manufacturing collapsed in the wake of the dot-com bubble. Next, we exclude the two years prior to 1993 to mitigate concerns that Thomson VentureXpert has limited coverage during that period. The resulting 1993-2002 period is thus different from the main one in that it has better data coverage and in that it corresponds to the peak of the first wave of VC activity in Europe.

In Table 8, we repeat the estimations reported in Table 6 on this sub-period. We find a somewhat stronger positive effect of VC investment on the propensity to patent. In particular, in the OLS case we find a statistically significant effect of VC when we exclude low-VC countries (column (ii)) and when we look at observations with non-zero VC investment only (column (iii)), with implied VC potency of 0.32 and 0.16, respectively. In our preferred IV specification, however, while venture capital has a significant positive effect on the number of ultimately successful patent grants in all samples, the effect is insignificant throughout the tests.

This test is conceptually subject to several caveats. For example, the dot-com bubble was the period when much money from institutional investors was starting to flow to venture capital and "money was chasing deals". Funds from these vintage years performed very poorly afterwards and as a result many institutional investors turned away from venture capital investments afterwards. This would imply that VC-funded projects which were successful in terms of acquiring a patent may have performed poorly in terms of commercial success, but such an investigation is beyond the scope of this current paper.

5.5 Cross-country heterogeneity

Finally, we test the hypothesis that the low impact of VC on the propensity to patent may be affected by systematic differences in the business environment across the countries in our sample. For example, Klapper, Laeven, and Rajan (2006) show that entry barriers are associated with relatively lower entry, implying potentially lower innovation in such countries through the channel of Schumpeterian "creative destruction". The propensity to innovate can also be affected by labour regulations: hiring and firing restrictions may increase implementation costs of innovations by hindering labour adjustments which are often needed after innovations have been introduced (e.g. Cappelli, 2000). Hence variations in innovation rates may be the result of variations in labour regulations rather than in the availability of start-up financing. The effect of intellectual property rights protection could also contaminate our estimates if the VC-intensive industries are at the same time the ones that rely most on intangible inputs. There could also be a tax and regulatory issue involved: entrepreneurs may be less able to garner funds to enter and innovate in more dynamic industries leading to IPOs if the tax and regulatory environment is unfavourable towards venture capitalists. Also, fewer people will undertake the transition from employees to entrepreneurs if this is the case (Da Rin, Nicodano, and Sembenelli (2010)). Finally, the average human capital in the economy could also play a crucial role - not only because most innovative industries tend to be at the same time the ones that require the most up-do-date knowledge and skills, but also because industry-specific human capital is an important channel through which venture capital firms respond to shifts in public market signals (Gompers, Kovner, Lerner, and Sharfstein, 2008). Hence, observed lower industrial innovation in VC-intensive industries in countries with lower venture capital investment may actually be the result of the lack of enough skilled workers due to the inability of the education system to provide those skills.

Table 9 directly tests these hypothesis by interacting the $\frac{VC}{RD}$ ratio with empirical proxies for the five regulatory dimensions just discussed. Throughout the Table, we report estimates from the IV case in order to be able to strengthen the case that the effects we report are causal.[14] The estimate in column (i) suggests that venture capital is more efficient in generating industrial innovation in countries with lower barriers to entry, but the effect is not significant in a statistical sense. In column (ii), we find that venture capital is more efficient in generating patents in countries with less stringent labour regulations. One potential explanation is that VC is less efficient in countries where young companies are constrained from growing fast by rigid labour markets. The effect is significant at the 5% statistical level. The data do not suggest that VC is more successful in fostering innovation in countries with a higher degree of intellectual property rights protection and in countries where the tax and regulatory environment is more friendly to venture capital (columns (iii) and (iv), respectively). Finally, the impact of venture capital on innovation is relatively stronger, in a statistical sense, in countries with higher levels of human capital as measured by higher average schooling (column (v)). This result is logical given that the relative advantage of

[14] Given that we now have three variables that need to be instrumented, we include legal origin dummies in the regressions. The exogenous component of the country's legal system is generally a good instrument for the contemporanous state of regulation (see La Porta, Lopes-de-Silanez, Shleifer, and Vishny, 1998).

venture capital finance rests in the utilization of cutting-edge knowledge for the purpose of the commercialization of science.

6 Policy implications

Our analysis speaks to European policymakers who set policies and reforms designed to make Europe's regulatory and economic framework more innovation friendly. The EU's "Europe 2020 Strategy" seeks to push Europe towards a more knowledge-based competitive economy with more and better jobs. About three quarters of the difference in private sector R&D spending between Europe and the United States is due to difficult access to finance for small innovative companies (European Commission, 2008). Venture capital is perceived as a solution to these market failures that prevent the provision of risk capital and sufficient funding of innovation by small and medium-sized enterprises (SMEs).[15]

Our results show that the impact of venture capital on innovation is relatively weak and that it varies widely across European countries. It is stronger in countries with more flexible labour regulations and higher education levels. These results indicate that, for example, labour market reforms and investment in education are essential for the efficiency of VC investment. A more coherent and harmonized legislation is therefore required before venture capital can start to influence innovation across European countries.

There are a number of recent developments that might limit the further development of venture capital markets in Europe. Regulations such as Basel III and Insolvency II are likely to further restrict the venture capital investments from banks and insurance com-

[15] The EU itself provides venture capital through the High Growth and Innovative SME Facility (GIF), which is part of the Competitiveness and Innovation Programme (CIP). GIF invests into venture capital funds which have an early stage focus and funds with a focus on SMEs with high growth potential in their expansion stage. The GIF venture capital funds are managed for the European Commission by the European Investment Fund (EIF), which is an EU financial body with expertise in making venture capital investments.

panies, respectively. The current financial crisis and increased regulatory capital demands on banks under Basel III are likely to restrict the financing of innovation in bank based systems even further (Ughetto, 2008). Pension funds have become the major investors in European venture capital after most European countries have abolished national regulations that prevented pension funds from investing in venture capital. However, some European countries continue to have pension fund regulations that continue to limit the percentage of assets under management that can be invested in private equity and venture capital (see OECD, 2009). Our results suggest that existing and pending regulations and frictions that restrict venture capital investment by (foreign) institutional investors might potentially have negative effects on innovation.

7 Conclusion

This paper examines the impact of venture investment on technological innovation in 21 European countries and 10 manufacturing industries over the 1991-2005 period. To our knowledge, it represents the first study to use both cross-country and cross-industry data to this end. The international dimension of our data also allows us to study which characteristics of the business and regulatory environment boost the effect of venture capital on industrial innovation.

Our estimates of the impact of a euro of venture capital relative to a euro of industrial R&D are generally positive, but their significance tends to vary depending on the sample partition used, and the implied VC potency is considerably lower than in similar US studies. For example, the only case when the estimate on $\frac{VC}{RD}$ is significant is in the reduced sample of non-transition economies with good data coverage (Table 6, Panel C, column (v)), with an implied relative VC potency of 2.94. The mean ratio of VC investment to total disbursements (venture capital plus industrial R&D) between 1991 and 2005 in that sample is 3.85%. Using these two values, we calculate that venture capital investment has accounted for around 10.2% of industrial innovation in 15 European countries since the early 1990s.[16] However, taking an average of the estimates in columns (iv)-(vi) of Panel C in Table 6 implies that VC has accounted for around 8.5% of industrial innovation. While the estimated relative VC potency in our sample is lower than what Kortum and Lerner (2000) estimate using US data for the 1965-1992 period (a relative VC potency of around 4, when both $\frac{VC}{RD}$ and Log R&D are instrumented), we show that VC's contribution to innovation in the US also declined during the 1991-2005 period. Finally, we also demonstrate that part of the reason VC has a lower effect on innovation than in the US in earlier periods is due to more stringent employment practices and to Europe's still rudimentary knowledge networks.

While the European venture capital industry has developed rapidly in recent years, with some countries surpassing at times the US in terms of share of the industry's share of GDP, labour market reforms have been slow and the deregulation of investment activity by large institutional investors like pension funds and insurance companies has only recently been enacted. Confounding the problem, the recent global financial crisis has unleashed a wave of regulatory measures which are designed to limit systemic risk, but which could also result in less funds being raised to finance risky innovative enterprises. Our study suggests that the combined effect of slow labour and institutional reforms and of stringent financial regulations can further diminish Europe's innovative potential.

[16] The share of innovation due to venture capital is $b(V/R)/(1 + b(V/R))$.

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Table 1
Industry conversion key: SIC and NACE

SIC-NACE Industry	SIC 1987 code	NACE Rev 1.1 code
1. Food products and beverages	20	15
2. Textiles and apparel	22, 23	17, 18
3. Wood products; furniture; manufacturing n.e.c.	24, 25, 39	20, 36
4. Paper and paper products	26	21
5. Chemicals and chemical products	28	24
6. Rubber and plastic products	30	25
7. Other non-metallic mineral products	32	26
8. Primary metals and fabricated metal products	33, 34	27, 28
9. Machinery and equipment n.e.c.; office machinery and computers; electrical machinery n.e.c.; radio, television, and communication equipment; medical, precision, and optical instruments	35, 36, 38	29, 30, 31, 32, 33
10. Motor vehicles and other transportation equipment	37	34, 35

Note: This table reports the conversion key used in the paper to match SIC and NACE industrial specifications. Matching is done through 6-digit NAICS industrial classes. See US Census Bureau for original classifications. Excluded industries are: Tobacco products (SIC 21, NACE 16) with no VC investment; Leather products (SIC 31, NACE 19), which is excluded from the Kortum and Lerner (2000) industry classification; Publishing and printing (SIC 27, NACE 22) with no patents; and Coke and petroleum products (SIC 29, NACE 23) with only 6 VC disbursements over the whole sample period.

Table 2
Summary statistics: VC, R&D, and patent data, by country

Country	VC	R&D	Patent grants
Austria	49.044	2,931.145	774.523
Belgium	57.440	2,952.779	922.137
Czech Republic	7.006	429.421	312.920
Denmark	64.189	2,202.903	756.680
Finland	14.235	3,784.712	1,034.130
France	558.760	16,715.360	3,672.629
Germany	304.954	39,722.370	9,439.099
Greece	3.393	258.109	302.280
Hungary	28.938	569.702	406.033
Iceland	6.780	85.985	358.903
Ireland	26.340	891.528	488.574
Italy	128.258	6,829.997	1,764.434
Netherlands	69.459	3,683.356	1,502.700
Norway	23.764	996.784	559.305
Poland	9.293	906.269	296.489
Portugal	7.133	321.025	279.046
Slovakia	0.154	37.821	245.481
Spain	91.341	3,363.233	574.727
Sweden	80.161	6,889.395	1,498.388
Switzerland	81.228	12,088.490	1,520.028
UK	488.843	10,554.300	3,495.323
Total	2,100.712	116214.672	30,203.828

Note: Table 2 summarizes the data on VC (euro), R&D (euro), and patent grants, averaged over the period 1991-2008, for all countries in the sample. Data on VC from VentureXpert; on R&D from ANBERD-OECD; and on patent grants from Eurostat. Patent grants refer to ultimately successful patent applications filed in each year. All euro figures are in millions of 2006 euros.

Table 3
Summary statistics: VC, R&D, and patent data, by industry

Industry code	VC	R&D	Patent grants
1. Food products and beverages	95.042	3,755.098	447.803
2. Textiles and apparel	15.870	2,862.796	306.855
3. Wood products; furniture; manufacturing n.e.c.	71.738	2,330.149	1,022.563
4. Paper and paper products	18.475	1,202.640	192.582
5. Chemicals and chemical products	660.783	20,283.610	5,333.872
6. Rubber and plastic products	34.351	3,312.424	845.358
7. Other non-metallic mineral products	106.408	1,685.404	493.931
8. Primary metals and fabricated metal products	95.148	4,225.708	1,601.701
9. Machinery and equipment n.e.c.; office machinery and computers; electrical machinery n.e.c.; radio, television, and communication equipment; medical, precision, and optical instruments	874.517	44,139.930	17,429.620
10. Motor vehicles and other transportation equipment	128.379	32,416.910	2,529.544
Total	2,100.712	116214.672	30,203.828

Note: Table 3 summarizes the data on VC (in euro), R&D (in euro), and patent grants, averaged over the period 1991-2008, for all industries in the sample. Data on VC from VentureXpert; on R&D from ANBERD-OECD; and on patent grants from Eurostat. Patent grants refer to ultimately successful patent applications filed in each year. All euro figures are in millions of 2006 euros.

Table 4
Summary statistics: Venture capital, R&D, and patent data, by year

Year	VC	R&D	Patent grants
1991	50.645	149,641.600	24,322.310
1992	98.092	138,684.100	24,360.190
1993	314.919	125,832.000	24,749.270
1994	184.452	122,388.100	27,178.070
1995	139.443	120,007.000	30,596.530
1996	320.029	115,841.300	30,225.730
1997	330.380	116,424.800	34,308.580
1998	1,028.815	114,881.800	34,516.420
1999	3,130.754	114,827.700	37,999.270
2000	5,573.525	116,235.500	39,641.530
2001	4,495.310	108,889.700	39,397.380
2002	5,725.086	108,535.500	38,572.860
2003	2,502.875	108,690.200	36,055.230
2004	2,267.116	104,542.100	38,719.290
2005	2,448.377	103,452.400	34,382.890
2006	3,665.054	106,832.100	21,092.240
2007	3,408.727	107,771.500	15,011.210
2008	2,129.216	108,386.700	12,539.910
Average	2,100.712	116,214.672	30,203.828

Note: Table 4 summarizes the data on VC (in euro), R&D (in euro), and patent grants, averaged over all countries. Data on VC from VentureXpert; on R&D from ANBERD-OECD; and on patent grants from Eurostat. Patent grants refer to ultimately successful patent applications filed in each year. All euro figures are in millions of 2006 euros.

Table 5
Venture capital and industrial innovation: Preliminary results

	(i)	(ii)	(iii)	(iv)	(v)	(vi)
		OLS			Poisson	
Log VC	0.026	0.024	0.024			
	(0.008)***	(0.008)***	(0.008)***			
Log R&D		0.100	0.100			
		(0.037)**	(0.037)***			
Log Government R&D			0.080			
			(0.104)			
VC				0.109	0.096	0.117
				(0.048)**	(0.048)**	(0.048)***
R&D					0.346	0.367
					(0.007)***	(0.007)***
Government R&D						-0.290
						(0.016)***
Fixed effects			Country Industry Year			
Observations	675	675	675	3,150	3,150	3,150
R^2	0.97	0.97	0.97	0.97	0.97	0.97

Note: Table 5 reports the estimates of Model 1 (columns (i)-(iii)) and Model 2 (columns (iv)-(vi)) where the dependent variable is the logarithm of patent grants in a given country-industry-year, by year of application, over 1991-2005. ‘Log VC’ denotes the natural logarithm of venture capital investment in a given country-industry-year. ‘Log R&D’ denotes the natural logarithm of private R&D disbursements in a given country-industry-year. ‘Log Government R&D’ denotes the natural logarithm of total government outlays on R&D in a given country-year. Estimates are from OLS regressions in columns (i)-(ii) and from Poisson regressions in columns (iii)-(iv). Standard errors clustered by country-industry are reported in parentheses, where ***, **, and * report significance at the 1%, 5% and 10% level, respectively.

Table 6
Venture capital and industrial innovation: Regression analysis of the linear production function

Panel A. First-stage regressions

	(i)	(ii)	(iii)
	VC/R&D endogenous	VC/R&D and Log R&D endogenous	
	VC/R&D	VC/R&D	Log R&D
PE fund-raising × Fraction independent PE funds	0.007	0.007	-0.007
	(0.003)**	(0.003)**	(0.005)
Log Value added		-0.017	0.665
		(0.024)	(0.169)***
Log R&D	-0.057		
	(0.037)		
Log Government R&D	-0.084	-0.071	-0.292
	(0.069)	(0.066)	(0.118)**
Fixed effects		Country Industry Year	
F-value	6.16	3.22	7.73
Observations	2,674	2,548	2,548
R^2	0.03	0.03	0.88

Panel B. OLS analysis of the linear production function

	(i)	(ii)	(iii)
	Full data	Low VC countries excluded	Non-zero VC investment
VC/R&D	0.007	0.036	0.023
	(0.005)	(0.013)***	(0.011)**
Log R&D	0.044	0.101	0.115
	(0.022)*	(0.032)***	(0.037)***
Log Government R&D	0.025	0.057	0.057
	(0.017)	(0.041)	(0.101)
Implied potency of venture funding	0.16	0.36	0.20
Fixed effects		Country Industry Year	
Observations	3,134	2,250	675
R^2	0.95	0.95	0.97

Panel C. IV analysis of the linear production function

	(i)	(ii)	(iii)	(iv)	(v)	(vi)
	IV					
	VC/R&D instrumented			VC/R&D endogenous and Log R&D instrumented		
	Full data	Low VC countries excluded	Non-zero VC investment	Full data	Low VC countries excluded	Non-zero VC investment
VC/R&D	0.369	0.729	0.076	0.495	0.736	0.087
	(0.323)	(0.395)*	(0.140)	(0.343)	(0.442)*	(0.171)
Log R&D	0.080	0.108	0.146	0.276	0.250	0.374
	(0.032)**	(0.036)***	(0.094)	(0.111)**	(0.122)**	(0.116)***
Log Government R&D	0.043	0.063	0.064	0.090	0.098	0.047
	(0.061)	(0.057)	(0.096)	(0.058)	(0.057)*	(0.103)
Implied potency of venture funding	4.61	6.75	0.52	1.79	2.94	0.23
Fixed effects	Country Industry Year					
Anderson's identification stats (*P*-value)	0.89 (0.35)	2.15 (0.14)	3.26 (0.07)	0.93 (0.33)	2.21 (0.13)	3.23 (0.07)
Observations	2,574	2,130	657	2,548	2,104	651
R^2	0.91	0.93	0.97	0.86	0.92	0.96

Note: Panel A of Table 6 reports the estimates from first-stage regression where the dependent variable is VC/R&D (column (i)) and Log R&D (column (ii)). 'PE fund-raising×Fraction independent PE funds' is an interaction term of the amount of PE funds raised in a country-year and the 5-year average fraction of PE funds that are organized as independent LPs. 'Log Value added' is the logarithm of value added in a particular country-industry-year. Standard errors clustered by country are reported in parentheses, where ***, **, and * report significance at the 1%, 5% and 10% level, respectively. *F-value* reports the statistics from the test that the first-stage estimates on the instrument(s) are different from zero.

Panel B reports OLS estimates of Model 3 where the dependent variable is the logarithm of patent grants in a given country-industry-year, by year of application, over 1991-2005. 'VC/R&D' denotes the ratio of venture capital investment to private R&D disbursements in a given country-industry-year. 'Log R&D' denotes the natural logarithm of private R&D disbursements in a given country-industry-year. 'Log Government R&D' denotes the natural logarithm of total government outlays on R&D in a given country-year. In column (ii), countries with low VC investment and/or transition economies (Czech Republic, Greece, Hungary, Iceland, Poland, and Slovakia) are excluded. In column (iii), observations with zero VC investment are excluded. Standard errors clustered by country-industry are reported in parentheses, where ***, **, and * report significance at the 1%, 5% and 10% level, respectively.

Panel C reports IV estimates of Model 3 where the dependent variable is the logarithm of patent grants in a given country-industry-year, by year of application, over 1991-2005. 'Log Value added' is the natural logarithm of value added in a given country-industry-year. In columns (ii) and (v) of Panel B, countries with low VC investment and/or transition economies (Czech Republic, Greece, Hungary, Iceland, Poland, and Slovakia) are excluded. In columns (iii) and (vi), observations with zero VC investment are excluded. In columns (i)-(iii), VC/R&D has been instrumented by 'PE fund-raising×Fraction independent PE funds'. In columns (iv)-(vi), also R&D has been instrumented using the logarithm of value added in this particular country-industry-year. Standard errors clustered by country are reported in parentheses, where ***, **, and * report significance at the 1%, 5% and 10% level, respectively.

Table 7
Data robustness: Venture capital and industrial innovation in the US

	(i)	(ii)	(iii)
	IV, 1973-2001	OLS, 1991-2005	OLS, 1991-2005
VC/R&D	3.520	0.071	0.071
	(1.605)**	(0.116)	(0.184)
Log R&D	0.205	0.050	0.050
	(0.076)***	(0.069)	(0.125)
Implied potency of venture funding	17.17	1.42	1.42
Fixed effects		Industry	
		Year	
Standard error clustered by industry	No	No	Yes
Observations	290	150	150
R^2	0.96	0.99	0.99

Note: Table 7 reports the estimates of Model 3 where the dependent variable is the logarithm of patent grants in a given industry-year in the US, by year of application. 'VC/R&D' denotes the ratio of venture capital investment to private R&D disbursements in a given industry-year. 'Log R&D' denotes the natural logarithm of private R&D disbursements in a given industry-year. In column (i), VC has been instrumented with a variable equal to the average pre-1979 within-industry VC/R&D ratio after 1979, and to 0 before 1979. Standard errors are reported in parentheses, where ***, **, and * report significance at the 1%, 5% and 10% level, respectively.

Table 8
Data robustness: 1993-2002

	(i)	(ii)	(iii)	(iv)	(v)	(vi)
		OLS			IV	
	Full data	Low VC countries excluded	Non-zero VC investment	Full data	Low VC countries excluded	Non-zero VC investment
VC/R&D	0.005	0.033	0.020	0.328	0.481	0.155
	(0.003)	(0.012)***	(0.007)***	(0.326)	(0.366)	(0.181)
Log R&D	0.045	0.103	0.126	0.295	0.267	0.544
	(0.023)*	(0.033)***	(0.043)***	(0.117)**	(0.127)**	(0.179)***
Log Government R&D	0.046	-0.014	-0.039	0.131	0.030	-0.083
	(0.015)***	(0.049)	(0.153)	(0.137)	(0.076)	(0.268)
Implied potency of venture funding	0.11	0.32	0.16	1.11	1.80	0.28
Fixed effects	Country Industry Year					
Observations	2,089	1,500	437	1,717	1,430	418
R^2	0.95	0.95	0.97	0.89	0.93	0.94

Note: Table 8 reports the estimates of Model 3 where the dependent variable is the logarithm of patent grants in a given country-industry-year, by year of application. All observations from 1991-1997 and from 2003-2005 are excluded. 'VC/R&D' denotes the ratio of venture capital investment to private R&D disbursements in a given country-industry-year. 'Log R&D' denotes the natural logarithm of private R&D disbursements in a given country-industry-year. 'Log Government R&D' denotes the natural logarithm of total government outlays on R&D in a given country-year. In columns (ii) and (v), countries with low VC investment and/or transition economies (Czech Republic, Greece, Hungary, Iceland, Poland, and Slovakia) are excluded. In columns (iii) and (vi), observations with zero VC investment are excluded. In columns (iv)-(vi), VC/R&D has been instrumented by 'PE fund-raising × Fraction independent PE funds' (See Table 6 for details), and R&D has been instrumented using the logarithm of value added in this particular country-industry-year. Standard errors clustered by country are reported in parentheses, where ***, **, and * report significance at the 1%, 5% and 10% level, respectively.

Table 9
Venture capital and industrial innovation: Country heterogeneity

	(i)	(ii)	(iii)	(iv)	(v)
			IV		
VC/R&D× Barriers to entry	-3.214				
	(3.218)				
VC/R&D× Labour regulations		-0.306			
		(0.120)**			
VC/R&D× Intellectual property protection			-0.836		
			(1.946)		
VC/R&D× Tax and legal index				-2.376	
				(3.482)	
VC/R&D× Human capital					4.710
					(1.942)**
VC/R&D	16.631	7.851	4.856	1.261	-40.191
	(15.988)	(2.849)***	(7.869)	(1.085)	(17.223)**
Log R&D	0.611	0.395	0.434	0.413	0.169
	(0.502)	(0.315)	(0.310)	(0.301)	(0.335)
Log Government R&D	-0.029	0.133	0.076	0.102	0.346
	(0.422)	(0.273)	(0.271)	(0.267)	(0.350)
Fixed effects			Country Industry Year		
Observations	2,548	2,548	2,548	2,548	2,548
R^2			0.34	0.35	

Note: Table 9 reports the estimates of Model 3 where the dependent variable is the logarithm of patent grants in a given country-industry-year, by year of application, over 1991-2005. In all regressions, observations with zero VC investment are excluded. 'VC' denotes venture capital investment in a given country-industry-year. 'Log R&D' denotes the natural logarithm of private R&D disbursements in a given country-industry-year. 'Log Government R&D' denotes the natural logarithm of total government outlays on R&D in a given country-year. 'Barriers to entry' denotes the number of procedures required to establish a limited liability company in the respective country. 'Labour regulations' denotes the difficulty associated with hiring and firing a worker in the respective country. Data on both variables come from the Doing Business Database. 'Intellectual property protection' denotes the degree of protection of intellectual property in the respective country. Data come from the Heritage Foundation. 'Tax and legal index' denotes the EVCA index of the friendliness of the tax and regulatory environment. Data come from the EVCA Benchmark Study (2003-2008). 'Human capital' denotes the average years of schooling in the respective country. Data come from the Barro-Lee "International Data on Educational Attainment" dataset. In all regressions, the interaction of VC/R&D has been instrumented using legal origin dummies, VC/R&D has been instrumented by 'PE fund-raising×Fraction independent PE funds' (See Table 6 for details), and R&D has been instrumented using the logarithm of value added in this particular country-industry-year. Standard errors clustered by country are reported in parentheses, where ***, **, and * report significance at the 1%, 5% and 10% level, respectively.

Appendix
Variables: Definitions and sources

Variable	Definition and source
Industry-level variables	
Venture capital	Venture capital investment, in euros, allocated to all private equity deals expect for buyouts. Source: VentureXpert.
R&D	Private R&D disbursements investment, in euros. Source: ANBERD-OECD.
Patents	Number of patents granted by the USPTO, by date of application or by date of grant. Source: Eurostat.
Value added	Value added, in euros. Source: STAN Database for Structural Analysis.
Country-level variables	
Government R&D	Total government outlays on R&D, for each country-year, in euros. Source: Eurostat
Barriers to entry	Number of procedures to register a business, for each country-year. Source: Doing Business Database (WB).
Labour regulations	Index of the legal ease of hiring and firing workers, for each country-year. Source: Doing Business Database (WB).
Intellectual property protection	Index of degree of protection of intellectual property rights, for each country-year. Source: Heritage Foundation.
Tax and legal index	EVCA index of the friendliness of the tax and regulatory environment to VC investment. Source: EVCA Benchmark Study (2003-2008).
Human capital	Average years of schooling for an individual in the respective country, for each country-year. Source: Barro and Lee "International Data on Educational Attainment" dataset.
PE fund-raising	The amount of funds, in euros, raised by private equity funds in each country in a particular year. Source: EVCA
Fraction independent PE funds	The fraction of PE investment by independent (as opposed to captive) PE funds in each country in the past 5 years. Source: VentureXpert
Legal origin	A set of dummy variables equal to 1 if the country's legal system has an English, French, German, or Nordic origin, respectively, and to 0 otherwise. Source: La Porta, Lopes-de-Silanez, Shleifer, and Vishny (1998).