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Venture Capital and Industrial Innovation: Evidence from Europe

Alexander Popov (ECB)
Peter Roosenboom (Erasmus University)

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Venture Capital and Industrial Innovation: Evidence from Europe*

Alexander Popov†
European Central Bank

Peter Roosenboom‡
Rotterdam School of Management,
Erasmus University

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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 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 national laws regulating the investment behavior of pension funds. Our estimates imply that a euro of VC is less potent than a euro of industrial R&D. We also find that VC is relatively more successful in fostering innovation in countries with lower barriers to entry, with less stringent labor regulations, and with higher human capital.

JEL classification: C23, G15, O16

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†Corresponding author. Email address: Alexander.Popov@ecb.int. European Central Bank, KaiserStr. 29, D-60311, Frankfurt, phone: +49 (0) 69 13448428.

‡Department of Finance, Rotterdam School of Management (RSM), Erasmus University Rotterdam, phone: +3110 408 1255, email: proosenboom@rsm.nl

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 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 exploring Kortum and Lerner's insight that the 1979 clarification by the US Department of Labour of the Employee Retirement Income Security Act (ERISA) was a policy shift that allowed pension funds to invest in venture capital. This policy can thus be used as a supply shifter for venture capital as it is unlikely to be correlated with the arrival of technological opportunities. We collect information on national regulations guiding the extent to which institutional investors (in particular, pension funds) can invest in venture capital in our sample of countries, and use changes in these rules in an instrumental variable regression framework to extract the endogenous element of venture capital finance.

We find that a euro of VC investment is less potent than a euro of traditional corporate R&D. While venture capital investment has accounted for around 5.7% of aggregate (venture capital plus R&D) industrial spending over the sample period, VC investment has accounted for around 3.9% of industrial innovation. Our results tend to be stronger in various sample partitions. For example, we find that VC investment had a pronouncedly stronger effect during 1998-2002, when in some specifications a euro of VC investment is estimated to be 1.5 times as potent as a euro in R&D, and VC turns out to have a much more significant effect on the propensity to patent in countries with lower barriers to entry, less stringent labor regulations, and higher human capital.

At first glance, this would suggest that 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 7 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 than neither VC nor R&D have a 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 does not appear to have been less efficient in promoting industrial innovation than its US counterpart.

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, 1999) 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).

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]

Prior to that period, the extend of recommended prudential behavior by institutional investors was left to the discretion of national governments, and consequently there were large differences across countries and over time in the degree of regulation of these activities before the current harmonization drive. As a result, only in 2006 did pension funds become the largest source of venture capital funds raised by investors, with this role asserted by banks prior to that. Nevertheless, recent years have seen a dramatic increase in the level of venture capital fund-raising and investment, with risk capital investment as a share of GDP approaching US levels in European countries like Denmark, Finland, and Sweden.

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).

[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.

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

[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.

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 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

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

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 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

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

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 1 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

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

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:

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

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

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

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.[8]

[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.

[8] Unlike Kortum and Lerner (2000) and Hirukawa and Ueda (2008a), we do not control for government-

2. We address the endogeneity of venture capital investment by exploiting changes at the national level in regulations concerning the investment behavior of domestic pension funds. As pointed out in Gompers and Lerner (1999), the 1979 clarification of the ERISA by the US Department of Labour led to a five-fold increase in VC investment in the next two decades. European law also offers variation over time and across countries in that respect: while the UK has been allowing pension funds to invest in risk capital since pre-1991, for many European countries restrictions were only lifted by the EU-wide Directive 2003/41/EC in 2003, which eliminated restrictions on the investment behavior of pension funds, only allowing national governments some discretion on, for example, maximum amounts pension funds are allowed to invest in risk capital markets.[9] (However, in one case - Sweden - the Directive was followed by a national legislative ban on investment in risk capital by pension funds, deeming such investments too risky).

In addition, industries sensitive to VC will respond more forcefully after the pension reform than industries that are naturally of little interest to venture capitalists. In order to capture such a "natural" or "technological" sensitivity, it would be problematic to use data from our sample as it may be endogenous to the industry's long term innovation profile. Instead, we make use of the idea originally proposed by Rajan and Zingales (1998) that capital usage in US industries derives from a more liquid financial market, making it a good exogenous benchmark for countries with less liquid such markets. To that end, we calculate $\frac{VC}{RD}$ ratios for each of the 10 industries in the dataset, using US data over the 1991-2005 period, and use it as a benchmark industry sensitivity to VC investment.

Thus, the variation in the timing of deregulation of investment in risk capital by pension funds across countries, in combination with each industry's "natural" VC-sensitivity, allows

funded R&D investment because such information is unavailble at the industry level.

[9] See Appendix 2 for details.

us to use the structural shift induced by this regulation to extract the endogenous response of venture capital investment to innovation booms. In practice, we first establish in which year each country liberalized risk capital investment rules for domestic pension funds.[10] Next, we create a variable equal to 0 in the pre-liberalization years, and to the industry's average $\frac{VC}{RD}$ ratio in the US in the post-liberalization years. Similar to the approach in Kortum and Lerner (2000), this resulting instrumental variable should constitute a VC supply-shifter: pension fund reform should result in higher VC investment in the future, more so in industries that are "naturally" of interest to venture capitalists. The resulting instrument varies across all three dimensions (industry, country, and time).

This approach is subject to two caveats. The first caveat involves the possibility that the laws regulating risk-capital investment by pension funds were enacted following pressure from a growing VC industry, which would make them endogenous to the size of venture capital investment and hence violate the exclusion restriction. However, our investigation into the genesis of these laws confirms that the formal motive expressed during the legislative process was universally diversification of risk. The second caveat concerns the risk that a pension reform need not result immediately in an inflow of funds from pension funds into private equity funds, especially if the enactment of a pension directive (like the EU-wide Directive 2003/41/EC) has been anticipated. However, the data implies a structural break around 2003, the year in which 10 of the 21 countries in the sample liberalized their pension funds investment regime. For example, the annual investment by pension funds in private equity increased by 54.3% in 2004-2007 compared to the period 1998-2003. In addition, for 14 of our sample countries[11], we were able to look at information collected by the European

[10] See Appendix 2 for details.

[11] These countries are Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Ireland, Italy, The Netherlands, Portugal, Spain, and Switzerland. Pre-prudent rule data is not available for some countries (Hungary, Poland, and Slovakia) because EVCA data collection for these countries was still in a pilot phase in those years. Other countries (Norway, Iceland) have no changes in prudent rules

Venture Capital Association on how much money venture capital funds raised from pension funds during this period. We find that the average [median] share of pension funds in total fundraising has increased significantly in the three year period after the prudent rule change (11.8%, [8.6%]) compared to the three year period before (7.8%, [3.6%]), implying an increased role for pension funds in VC fundraising as a result of the regulatory shift.

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 suscpiciously 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 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.[12] 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

or already enacted these rules prior to 1991 (UK) or introduced new regulation following the EU directive (Sweden).

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

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, a variable equal to 0 for all industries in a country prior to pension reform, and to the industry's average $\frac{VC}{RD}$ ratio in the US for each industry in the years after pension reform. 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.[13]

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

Panel A of Table 6 reports the estimates from these two first-stage regressions. In both cases, the instruments are positively and significantly correlated with the endogenous variables, implying that the relevance condition is satisfied. Both regressions also control for country, industry, and year fixed effects.

In Panel B of Table 6, we report the 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,[14] 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 columns (iv)-(vi), we estimate an instrumental variable version of the three regressions

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

just reported, using our instruments tested in Panel A.[15] Using this specification, we find that R&D investment is consistently associated with a higher propensity to patent, regardless of which sub-sample we look at. However, we estimate a negative correlation between VC and patent grants in the full sample and in the sample where countries with low VC/VC coverage are excluded (columns (iv)-(v)). When we look at country-industry-year observations with strictly positive VC investment (column (vi)), we obtain a positive estimate of the coefficients of ab of 0.278, implying that venture capital is 0.69 times as potent as R&D investment. However, the estimate of ab is not significant.

Finally, the effect of government R&D outlays is generally positive and insignificant.

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 disbursments 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

[15] Iceland, Norway, and the UK experienced no changes to their pension framework over the sample period, and hence are excluded from the empirical tests.

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).[16] 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.[17] Strikingly, both the effect of R&D and that of VC on patent grants disappear. 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.

[16] Nevertheless, there is a slight numerical difference 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.

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

5.4 Venture capital and innovation: The case of high-tech

We now explore further the differential effect of VC on innovation across industries and countries. We start by separating high-tech from low-tech industries. One of the most important industry from the point of view of venture capital involvement in the past two decades has been the computer industry. This sector is at the forefront of scientific research and its technological advances offers a myriad of applications in a wide range of areas (see, e.g., Bloch, 2004). As such, it exemplifies the comparative advantage of VC in bringing science to the marketplace, and so this industry is where we expect venture capital to have a pronouncedly stronger effect.[18]

It is therefore logical to hypothesize that the effect of venture capital would be more pronounced in high-tech in the European setting. In Table 8, we put this hypothesis to the test by restricting our analysis to industry class 9, which to a large degree subsumes computers, electronics, and instruments (see Table 1). However, the data do not consistently confirm our conjecture. For example, in our preferred IV specification, when we exclude low-VC countries, we find that VC investment has a statistically significant effect on the propensity to patent and that it is half as potent as R&D in this respect (column (v)). However, when we look at non-zero VC investments only (column (vi)), the effect of VC becomes negative and significant. We conclude that there is some evidence that venture capital has a stronger effect in industries where it has a natural advantage due to their high reliance on cutting-edge science and on patent protection, but the results are not fully consistent across different sample partitions.

[18] Biotech is another candidate, but it very imperfectly captured in our industrial specification.

5.5 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 period before 1998 to mitigate concerns that Thomson VentureXpert has limited coverage during that period. The resulting 1998-2002 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.[19]

In Table 9, we repeat the estimations reported in Table 6 on this sub-period. This time, we find a strong positive effect of VC investment on the propensity to patent, and the evidence is consistent across the OLS and the IV specifications. In particular, in the OLS case we find a statistically significant effect of VC when we exclude low-VC industries (column (ii)) and when we look at observations with non-zero VC investment only (column (iii)), with implied VC potency of 0.38 and 0.14, respectively. In our preferred IV specification when we look at strictly positive VC investment, venture capital again has a significant positive effect on the number of ultimately successful patent grants. The effect is marginally insignificant (significant at the 14% statistical level) when we cluster the standard errors by country-industry (column (vi)), but it becomes significant at the 5% if we do not cluster the standard errors (unreported). Finally, in this case we estimate a relative VC potency of 1.57, implying that a euro of VC during 1998-2002 was one and a half times as efficient as a euro of R&D in generating patents.

This result is 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

[19] On the downside, much of the cross-country variation in our pension-reform based instrument is lost in this sub-sample.

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.

5.6 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 10 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. The estimate in column (i) suggests that venture capital is more efficient in generating industrial innovation in countries with lower barriers to entry. In column (ii), we find that venture capital is also more efficient in generating patents in countries with less stringent labor regulations. In both cases, the effect is significant at the 10% statistical level. The data suggest that VC is not 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 high average schooling (column (v)).

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).[20]

Our results show that the impact of venture capital on innovation is weak at best and that it varies widely across European countries. It is stronger for countries with lower barriers to entry, 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 companies, 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

[20] 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.

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 15 manufacturing industries over the 1991-2008 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, in the case of non-zero VC investment in column (vi) of Table 6, the implied relative VC potency of 0.73. The mean ratio of VC investment to total disbursements (venture capital plus industrial R&D) between 1991 and 2005 was 5.7%. Using these two values (although both effects are statistically insignificant), we calculate that venture capital investment has accounted for around 3.9% of industrial innovation in Europe since the early 1990s.[21] Using the estimates from Table 9 for the 1998-2002 sub-period, we calculate that VC has accounted 14.1% of all industrial innovation during the peak of the dot-com bubble. While at first glance our estimates imply that European risk capital markets are substantially less efficient than their US counterparts in spurring innovation (for comparison, Kortum and

[21] As in Kortum and Lerner (2000), we use the value of b implied by the coefficient from the IV linearized regression (column (vi) of Tables 6). The ratio of venture capital to R&D (V/R) is an average over the years 1991-2005. Our calculation of the share of innovation due to venture capital is $b(V/R)/(1 + b(V/R))$.

Lerner (2000) find that venture capital accounted for at least 8% of industrial innovation between 1965 and 1992, while standing at less than 3% of industrial R&D), we show that VC has had a comparably weak effect on innovation in the US over the 1991-2005 period. We also demonstrate that part of the low effect of VC on innovation is due to higher barriers to entry, 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.

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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)-(ii)) and Model 2 (columns (iiv)-(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)
	VC/R&D	Log R&D
VC/R&D in US × Pension reform	1.388	
	(0.403)***	
Log Value added		0.669
		(0.033)***
Fixed effects	Country Industry Year	
F-value	1.93	457.00
Observations	3,124	3,094
R^2	0.03	0.87

Panel B. OLS and IV analysis of the linear production function

	(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	0.007	0.036	0.023	-0.197	-0.142	0.278
	(0.005)	(0.013)***	(0.011)**	(0.198)	(0.244)	(0.253)
Log R&D	0.043	0.101	0.115	0.271	0.289	0.404
	(0.022)*	(0.032)***	(0.037)***	(0.071)***	(0.103)***	(0.103)***
Log Government R&D	0.025	0.057	0.057	0.027	-0.010	0.051
	(0.017)	(0.041	(0.101)	(0.016)*	(0.043)	(0.088)
Implied potency of venture funding	0.16	0.36	0.20	-0.72	-0.53	0.73
Fixed effects			Country Industry Year			
Observations	3,134	2,250	675	3,110	2,220	685
R^2	0.95	0.95	0.97	0.95	0.95	0.97

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)). Panel B reports 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. ‘VC/R&D in US’ denotes the average ratio of venture capital investment to private R&D disbursements in a particular industry in the U.S over 1991-2005. ‘Pension reform’ is a dummy variable equal to 1 if domestic pension funds are allowed to invest in risk capital in this particular country-year. ‘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) of Panel B, observations with zero VC investment are excluded. In columns (iv)-(vi) of Panel B, VC has been instrumented by ‘VC/R&D in US $\times$ Pension reform’, and R&D has been instrumented using the logarithm of value added in this particular country-industry-year. Standard errors clustered by country-industry 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
Venture capital and industrial innovation: High-tech industries

	(i)	(ii)	(iii)	(iv)	(v)	(vi)
		OLS			IV	
	Full data	Low VC countries excluded	Non-zero VC investment only	Full data	Low VC countries excluded	Non-zero VC investment only
VC/R&D	-0.003	-0.027	-0.102	-0.024	-0.228	-0.329
	(0.018)	(0.152)	(0.097)	(0.305)	(0.0327)	(0.370)
Log R&D	0.018	-0.067	-0.181	0.060	0.308	0.365
	(0.034)	(0.140)	(0.085)**	(0.183)	(0.172)*	(0.113)***
Log Government R&D	0.051	-0.139	-0.138	0.055	-0.202	-0.153
	(0.062)	(0.111)	(0.123)	(0.062)	(0.103)**	(0.108)
Implied potency of venture funding	0.04	0.65	0.59	-0.12	0.53	-0.15
Fixed effects			Country Year			
Observations	314	225	159	314	225	159
R^2	0.99	0.99	0.99	0.99	0.99	0.99

Note: Table 8 reports the estimates of Model 3 where the dependent variable is the logarithm of patent grants in a given country-year, by year of application, over 1991-2005, where the sample is restricted to industry 9 (see Table 1). '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 has been instrumented by 'VC/R&D in US× Pension reform' (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
Data robustness: 1998-2002

	(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	0.007	0.041	0.019	0.116	0.365	0.754
	(0.004)*	(0.011)***	(0.006)***	(0.412)	(0.534)	(0.550)
Log R&D	0.051	0.112	0.141	0.295	0.316	0.506
	(0.026)**	(0.035)***	(0.044)***	(0.081)***	(0.112)***	(0.119)***
Log Government R&D	0.057	0.193	-0.294	0.033	0.127	-0.314
	(0.040)	(0.083)**	(0.232)	(0.038)	(0.079)	(0.223)
Implied potency of venture funding	0.12	0.38	0.14	0.39	1.13	1.57
Fixed effects	Country Industry Year					
Observations	1,044	750	324	1,040	740	326
R^2	0.95	0.95	0.97	0.96	0.95	0.97

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. 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 has been instrumented by 'VC/R&D in US $\times$ Pension reform' (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-industry are reported in parentheses, where ***, **, and * report significance at the 1%, 5% and 10% level, respectively.

Table 10
Venture capital and industrial innovation: Country heterogeneity

	(i)	(ii)	(iii)	(iv)	(v)
			IV		
VC/R&D× Barriers to entry	-0.057				
	(0.030)*				
VC/R&D× Labor regulations		-0.010			
		(0.006)*			
VC/R&D× Intellectual property protection			-0.109		
			(0.075)		
VC/R&D× Tax and legal index				-0.112	
				(0.187)	
VC/R&D× Human capital					0.122
					(0.070)*
VC/R&D	0.108	0.079	0.429	-0.141	-1.237
	(0.272)	(0.286)	(0.423)	(0.177)	(0.653)*
Log R&D	0.272	0.275	0.271	0.270	0.273
	(0.071)***	(0.071)***	(0.071)***	(0.071)***	(0.071)***
Log Government R&D	0.032	0.030	0.035	0.031	0.033
	(0.017)**	(0.016)*	(0.017)**	(0.017)*	(0.016)**
Fixed effects			Country Industry Year		
Observations	3,120	3,120	3,120	3,120	3,120
R^2	0.95	0.95	0.95	0.95	0.95

Note: Table 10 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. 'Labor 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, VC has been instrumented by 'VC/R&D in US× Pension reform' (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-industry are reported in parentheses, where ***, **, and * report significance at the 1%, 5% and 10% level, respectively.

Appendix 1

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).
Labor 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.

Appendix 2
Changes in prudential rules concerning risk capital investment by pension funds

Country	Year enacted	Type of change
Austria	2003	EU-wide Directive 2003/41/EC.
Belgium	2003	EU-wide Directive 2003/41/EC.
Czech Republic	2003	EU-wide Directive 2003/41/EC.
Denmark	2003	An 'action plan for risk capital' by the Danish Government to enable owners of private pension funds to spend a share of their funds on direct investment in non-listed companies.
Finland	1995	EU-wide Directive 2003/41/EC.
France	2003	EU-wide Directive 2003/41/EC.
Germany	2003	EU-wide Directive 2003/41/EC.
Greece	2003	EU-wide Directive 2003/41/EC.
Hungary	1998	New legislation has facilitated the channelling of domestic savings into private equity funds and the new national pension scheme now involves a privately managed element.
Iceland		None.
Ireland	1993	The government has requested the pension fund industry to increase its investment in Irish unquoted equities as a means of developing small and medium sized businesses. The pension fund industry and government jointly undertook a study of the equity requirements of SMEs and also the performance of unquoted equities over the past 20 years. The study concluded that the provision of funds to established VCs with good track records is an activity which the members of the pension fund industry should participate in.
Italy	1993	On 8 April 1993, as a part of the Pension Reform, a specific law on private pension plans was approved. One of its requirements is that closed-end funds must invest between 40% and 80% of the total value of the fund in unquoted companies.
Netherlands	1993	A new fund was initiated by the Dutch government for larger investments in larger industrial firms. The fund, partly financed by banks, insurance companies and pension funds, amounts to some Dfl 1 billion.
Norway		None.
Poland	2001	A law came into place providing Polish investment institutions with new types and structures of investment funds, such as securitisation funds. The law will also permit the soliciting of funds from the Polish financial institutions, such as pension funds and insurance companies, for investment into private equity.

Portugal	2003	EU-wide Directive 2003/41/EC.
Slovakia	2002	The current government has started pension and tax reforms, in part intended to produce measures to allow pension funds to invest in risk capital.
Spain	2003	Spanish pension funds may now invest up to 30% of their assets in free transferable securities issued by audited PE entities, provided that the investment does not imply a direct or indirect control over the investor entity and there are no economic links with the investor entity's shareholders or directors.
Sweden	2003	EU-wide Directive 2003/41/EC.
	2005	A new legislation entered into force stating that pension funds and employment saving trusts may not invest in partnerships or act as a general partner in a limited liability partnership. The reason behind is that this such investments are deemed too risky for the beneficiaries of the trusts.
Switzerland	2000	Swiss pension fund regulations were revised as of April 1, 2000 in order to permit Swiss pension funds to invest in both Swiss and foreign VC funds.
UK	Pre-1991	Pension funds allowed to invest in risk capital.