Discussion Paper No. 12-018

Which Form of Venture Capital is Most Supportive of Innovation?

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Wirtschaftsforschung GmbH

Centre for European
Economic Research

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Non-technical summary

There is a substantial body of literature on the extent to which firms that receive venture capital financing generate more innovation than non-venture-backed companies. Most studies find that, on average, venture capital leads to increased innovation. However, this average impact is likely to be the result of the aggregation of very diverse cases. Venture capital investors are different from one another, and their deals may be based on different transaction structures. Both the characteristics of the investor and the structure of the deal are likely to moderate the relationship between venture capital financing and innovation. This paper is an attempt to shed light on this issue.

First, we distinguish between two fundamentally different types of investors: governmental and private venture capitalists. These two types of investors have different objectives, skills, and investment horizons. Second, we differentiate between two transaction structures: syndicated and stand-alone deals. We further distinguish between syndicated deals led by private investors and those led by governmental investors, and between syndicated deals that are homogeneous (i.e., composed of investors of the same type) and those that are heterogeneous (i.e., composed of both private and governmental investors).

By combining existing theories with empirical evidence on venture capital, we expect (i) firms backed by private investors to outperform firms backed by governmental investors, (ii) firms backed by a syndicate to outperform firms backed by a stand-alone investor and (iii) firms backed by a heterogeneous syndicate to outperform firms backed by a homogeneous syndicate. We hypothesize that private-led heterogeneous syndicates should be the form of venture capital that is most effective at promoting innovation in portfolio companies.

We perform an empirical analysis on a sample of 865 young biotech and pharmaceutical companies from seven European countries and measure innovation output based on each firm's patent stock. Our results, which are robust to alternative measures of patent stock, alternative econometric specifications and other alterations, confirm our hypotheses as follows: companies financed by syndicates and by private venture capital investors have a greater increase in innovation output than comparable non-venture-backed companies, and the form most supportive of innovation is a heterogeneous syndicate led by a private investor.

Das Wichtigste in Kürze

Eine breite Literatur untersucht, ob Venture-Capital-finanzierte Unternehmen im Vergleich zu Unternehmen ohne Venture-Capital-Finanzierung innovativer sind. Ein Großteil der Studien kommt zu dem Ergebnis, dass Venture Capital Innovationen fördert. Es gibt jedoch unterschiedliche Typen von Venture-Capital-Investoren, deren Finanzierungen divergierende Strukturen aufweisen. Sowohl Investorentypen als auch Finanzierungstrukturen bedingen die Beziehung zwischen Venture-Capital-Finanzierung und Innovation. Die vorliegende Studie soll diesen Umstand genauer untersuchen.

Zunächst wird zwischen zwei unterschiedlichen Investorentypen unterschieden: zwischen öffentlichen und privaten Venture-Capital-Investoren. Sie haben verschiedene Ziele, verschiedene Fähigkeiten und Investitionshorizonte. Darüber hinaus wird zwischen zwei Finanzierungsstrukturen, der syndizierten und der alleinigen Finanzierung, unterschieden. Bei syndizierter Venture-Capital-Finanzierung wird nicht nur differenziert, ob das Syndikat von einem privaten oder öffentlichen Investor angeführt wird. Es wird außerdem zwischen homogenen (bestehend aus Investoren des gleichen Typs) und heterogenen (bestehend aus öffentlichen und privaten Investoren) Syndikaten unterschieden.

Ausgehend von bestehenden Theorien wird erwartet, dass (i) von privaten Investoren finanzierte Unternehmen innovativer sind als von öffentlichen Investoren finanzierte Unternehmen, (ii) von einem Syndikat finanzierte Unternehmen innovativer sind als von alleinigen Investoren finanzierte Unternehmen und, dass (iii) von einem heterogenen Syndikat finanzierte Unternehmen innovativer sind als Unternehmen, die von einem homogenen Syndikat finanziert werden. Dies führt zu der Hypothese, dass heterogene Syndikate, die von einem privaten Venture-Capital-Investor angeführt werden, die effektivste Art von Venture Capital in Innovationsförderung ist.

Um dies zu untersuchen, wird das Innovations-Output von 865 jungen Biotechnologie- und Pharmaunternehmen aus sieben europäischen Ländern untersucht. Ihr Innovations-Output wird anhand ihrer angemeldeten Patente gemessen. Die Ergebnisse bestätigen, dass Unternehmen, die von Syndikaten oder von privaten Investoren finanziert werden, einen höheren Innovations-Output aufweisen als vergleichbare Unternehmen ohne Venture-Capital-Finanzierung. Die geeignetste Venture-Capital-Form für Innovation ist ein heterogenes Syndikat, das von einem privaten Investor angeführt wird.

Which form of venture capital is most supportive of innovation?

Fabio Bertoni[a], Tereza Tykvová[b]

Abstract: Although there seems to be consensus in the literature that venture capital investors increase the innovation output of their portfolio companies, there is little evidence about how investor type (governmental vs. private) and transaction structure (syndicated vs. non-syndicated) moderate this impact. Using a sample of 865 young biotech and pharmaceutical companies from seven European countries, we investigate which form of venture capital is most supportive of innovation. Our results suggest that in companies financed by syndicates and by private venture capital investors, the innovation output increases significantly faster than in non-venture-backed companies. The most supportive form is a heterogeneous syndicate (i.e., consisting of both types of venture capital investors) led by a private investor.

JEL Codes: G24, H0, O3

Keywords: Innovation, patents, private venture capital investors, governmental venture capital investors, syndication, biotech and pharmaceutical companies, Europe

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Acknowledgements: We thank Massimo Colombo, Frédéric Delmar, Gary Dushnitsky, Hans Landström, Marianna Mazzucato, Miguel Meuleman, Frédéric Perdreau, Thomas Åstebro, and all of the participants at the VICO conference in Stresa (Italy), the XXV RENT Conference in Bodø (Norway), and the 12th Symposium on Finance, Banking, and Insurance in Karlsruhe (Germany) for their helpful comments. All errors in the manuscript are our own. Support from the 7th European Framework Program (Grant Agreement no. 217485) is gratefully acknowledged.

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1 Introduction

The development of innovation faces a significant funding gap which may hamper long-term economic growth and recovery (Hall and Lerner, 2010). This scenario may be particularly true in Europe, whose market is fragmented and insufficiently innovator friendly (European Commission, 2009). Moreover, in Europe, venture capital investors (VCs), which are one of the most appropriate candidates for financing young, innovative companies (Carpenter and Petersen, 2002), are disproportionately involved in late-stage and low-tech deals (Lawton, 2002; Da Rin et al., 2006). Aware of these circumstances, European policymakers have repeatedly stressed the importance of developing a viable venture capital industry that would serve as the bedrock for future growth and economic stability (e.g., European Commission, 2010).

Another aspect of venture capital in Europe that is an interesting subject for academic research is the heterogeneity in the VCs' governance structures, which often deviate from the classic Silicon-valley paradigm of independent venture capital funds (Bottazzi et al., 2004; Bottazzi et al., 2008). In many European countries, governmental venture capital funds have been established at the national or regional level; a few of the most active include The Biotech Fonds Vlaanderen in Belgium, SITRA in Finland, CDC Innovation in France, High-Tech Gründerfonds in Germany, Piemontech in Italy, and Scottish Enterprise in the UK. Bertoni et al. (2011) estimate that between 1994 and 2004, governmental venture capital investors were responsible for 19.3% of all high-tech investments in Europe; however, this figure is much higher in early stages and in sectors that have been specifically targeted by public policy. In our sample, at least one governmental VC is involved in as many as 43.1% of the investments. Whether governmental VCs are effective in fostering the innovative output of portfolio companies (which is one of the main reasons why they were set up in the first place) is a question that has received surprisingly little attention from academics. However, this is an important issue given the large importance of these investors in Europe and the hopes that European governments have for them. Do governmental VCs justify these hopes?

In this work, we explore this question. Specifically, we investigate the extent to which private and governmental VCs differ in their impact on firms' innovation output. In one respect, private VCs, as a result of their governance structure and profit-oriented behavior (Jääskeläinen et al., 2007), may possess better skills and incentives to spur innovation than governmental VCs. At the same time, private VCs may suffer from short-termism (Gompers, 1996), which could hamper R&D spending and innovation (Lerner, 2002). A second aspect that deserves closer scrutiny is the effectiveness of syndicates between private and governmental VCs. The literature shows that, in general, transaction structure (i.e., syndicated vs. non-syndicated investments) matters. Syndicates may lead to a better selection of investments and a higher value-added through the combination of complementary resources (e.g., Bygrave, 1987; Manigart et al., 2004). However, because several parties must coordinate within a syndicate, syndication gives rise to agency and transaction costs (e.g., Wright and Lockett, 2003), which may offset the positive effects. Both effects are potentially moderated by the type of VCs that are involved in the syndicate, although the empirical evidence supporting this potential is scarce. To investigate these issues, we rely upon a novel and extensive dataset of 865 young European biotech and pharmaceutical companies. We identify 159 first-round venture capital investments in sample companies between 1994 and 2004.

Our results confirm the view that, on average, VCs increase firms' innovation output. We highlight significant differences in the impact of VCs on innovation with regard to both the VC type and the transaction structure. The innovation output of companies financed by private VCs increases significantly faster than that of companies financed by governmental VCs, and the innovation output of syndicates outpaces that of stand-alone investors as well. Heterogeneous syndicates led by private VCs (i.e., syndicates in which a private VC takes the lead but in which a governmental VC is also involved) seem to produce the economically and statistically most significant effect. These results are in line with the conjecture that syndication gives rise to both benefits and costs. The benefits that come from the combination of complementary resources within a syndicate are particularly pronounced in heterogeneous syndicates combining private and governmental VCs. Only in this case, and only under the leadership of a private VC, do these benefits seem to outweigh syndicate costs. These results are robust to the endogenous choice of VCs' targets, which we control for with the use of different matching techniques, and to several alterations.

This paper contributes to three strands of the existing literature. The first strand addresses the impact of VCs on innovativeness. In their seminal contribution, Kortum and Lerner (2000) find that venture capital is associated with a substantial increase in innovations in US manufacturing industries. The approach taken by Kortum and Lerner (2000) has often been replicated by later studies focusing on different samples and different levels of analysis. For example, Hirukawa and Ueda (2011) choose the same approach as Kortum and Lerner (2000) but include more recent data in their sample. Popov and Rosenboom (2009) carry out a country-level analysis across Europe. Bertoni et al. (2010) employ firm-level data of Italian new-technology-based firms. These studies confirm that venture capital spurs innovations.

However, VCs are also attracted by innovative companies (e.g., Haeussler et al., 2009; Cao and Hsu, 2011). Some studies find that this selection effect dominates and, once it is controlled for, VCs do not increase innovation (e.g., Engel and Keilbach, 2007). The present paper, which benefits from a large sample of European biotech and pharmaceutical companies, contributes to this literature and provides evidence on how venture capital is related to innovativeness.

Second, the findings of this study contribute to the literature regarding the heterogeneity of VCs, particularly on the different impacts of governmental vs. private VCs on innovativeness. The empirical literature describes mixed results, and, therefore, additional research is needed in this area. For example, Brander et al. (2008) conclude that companies funded by governmental VCs generate fewer innovations, whereas Brander et al.'s (2010) results indicate the opposite. Our paper adds to this literature in that it shows whether, and under what circumstances, the governmental VCs are beneficial.

Third, our research contributes to the literature on syndication. There is an extensive literature documenting the benefits and costs associated with syndication (see, e.g., Tykvová and Schertler, 2011, for a recent discussion). However, research analyzing the consequences of different syndicate structures on innovations is rare. To the best of our knowledge, there is only one study that addresses the impact of syndicate structure on innovative activity, namely, the study by Brander et al. (2010). They show that companies financed by syndicates consisting of private and governmental VCs outperform control companies when a substantial fraction of funding comes from the private VC. In accordance with this result, we find that companies backed by heterogeneous syndicates outperform control companies only when a private VC takes the lead. Our paper makes two original contributions beyond the state of the art. Brander et al. (2010) only include VC-backed companies, whereas our sample also contains a matched control group of non-VC-backed companies. Thus, to Brander et al.'s (2010) findings on the differences between governmental and private VCs, we add new findings related to the forms of venture capital that are more beneficial to innovation when compared to non-VC-backed companies. It is important not only to know how governmental VCs (and different forms thereof) perform when compared to private VCs, but – to justify public policy actions – it is also crucial to know whether, and under what circumstances, governmental VC support is beneficial at all, i.e., in generating a higher innovative output than we observe with non-VC-backed companies. The second major contribution to this emerging research is that we not only focus on different forms of governmental support but also include different forms of private VC activities (private stand-alone vs. private syndicates) in our analysis and find important differences that contribute to our understanding of the role different VC forms have on the innovative output of their portfolio companies. Specifically, our results suggest that private VCs are better at increasing innovative output only in heterogeneous syndicates and in stand-alone transactions but not in homogeneous private syndicates.

The rest of the paper is structured as follows. In Section 2, we review the related literature and describe our research hypotheses. In Section 3, we present and describe our sample. In Section 4, we report the results of our analyses. In Section 5, we present concluding remarks.

2 Theoretical background and hypothesis development

VCs are financial intermediaries able to efficiently screen investment proposals in knowledge-based firms (Chan, 1983; Tyebjee and Bruno, 1984; Amit et al., 1998). The selected portfolio firms receive long-term equity funding and are closely monitored (Sahlman, 1990; Lerner, 1995; Kaplan and Strömberg, 2003). Additionally, VCs provide value-added services (Hellmann and Puri, 2000; Sørensen, 2007; Luukkonen and Maunula, 2007a), such as coaching or mentoring. Investee firms also benefit from the network of contacts provided by reputable, well-connected VCs (Colombo et al., 2006; Hsu, 2006; Lindsey, 2008), which may, for instance, result in improved access to investment bankers. All of these activities could result in certification effects throughout the investment period up to the IPO phase (Megginson and Weiss, 1991). Consequently, VCs can have a positive impact on the innovation and performance of portfolio firms.

Several studies link venture capital to innovation, in general, and to patenting activity, in particular. In their seminal contribution, Kortum and Lerner (2000) establish a stylized model of R&D expenditures, venture capital and innovation. By testing various specifications of a patent production function with US manufacturing industry-level data from 1965-1992, these authors find that venture capital is associated with a substantial increase in patenting. There is further evidence of the positive relation between venture capital financing and innovations at the country (Popov and Roosenboom, 2009), industry (Hirukawa and Ueda, 2011) and portfolio firm levels (Hellmann and Puri, 2000; Baum and Silverman, 2004; Bertoni et al., 2010). Based on these findings, we formulate the first hypothesis:

H1: VCs increase the innovation output of their portfolio companies.

VCs are far from being homogeneous and, especially in Europe, there is a significant involvement of governmental investors (e.g., Bottazzi et al., 2004; Tykvová, 2006). The role of governmental VCs in supporting knowledge-based companies is heavily discussed both in the academic literature and among practitioners, with a particular focus on the extent to which governmental VCs attract or crowd out private VCs (Leleux and Surlemont, 2003; Cumming and MacIntosh, 2006; Cumming, 2007; Brander et al., 2008; Cumming and Johan, 2009).[1] Private and governmental VCs differ in terms of their objectives, skills, and governance structures, and these differences affect the innovative output of their companies. First, whereas the primary objective of private VCs is to generate profits, which result from successful innovations, governmental VCs often focus on a broader set of goals, including building links between universities and the private sector, supporting the development of the venture capital industry, and increasing local employment levels (see, e.g., Cumming and MacIntosh, 2004; Cumming and Johan, 2009). Second, private VCs may have better skills than governmental VCs in selecting promising portfolio companies and in coaching and monitoring these companies (Leleux and Surlemont, 2003; Luukkonen and Maunula, 2007b; Luukkonen et al., 2011), which, again, may lead to a greater innovative output of these companies. Third, in general, private VCs have more performance-sensitive contracts than governmental VCs (Jääskeläinen et al., 2007). Therefore, private VCs posses increased incentives to provide their portfolio firms with the financial and non-financial resources they need to pursue the development of innovations. For all these reasons, we would expect a higher increase of innovative activities associated with the involvement of private VCs compared to the involvement of governmental VC. We summarize this discussion in our second hypothesis:

H2: Private VCs increase the innovation output of their portfolio companies more than governmental VCs.

VCs may either invest alone or form a syndicate. Syndication is beneficial because it combines the financial and non-financial resources of syndicate members (e.g., Bygrave, 1987; Manigart et al., 2004). A syndicate partner delivers an alternative opinion on company future prospects during the screening and selection phase (see Casamatta and Haritcahbalet, 2007; Lerner, 1994). During the investment phase, the combination of complementary non-financial resources may provide companies with better coaching and monitoring (e.g., Cumming and Walz, 2010; Brander et al., 2002; Tian, 2012). In addition, syndicates are able

[1] See, more generally, Lerner (2009) for a comprehensive survey of how governments have supported entrepreneurs and VCs across decades and continents.

to provide more financial resources for costly R&D than stand-alone investors. For all these reasons, we would expect a higher innovative output in companies backed by syndicates compared to those backed stand-alone investors:

H3: Syndicates increase the innovation output of their portfolio companies more than stand-alone VCs.

The complementarities in resources, which we expect to be beneficial in increasing patenting activity, will be particularly pronounced when syndicates are heterogeneous. As argued above, private VCs may be better at fostering innovative activity due to their objectives, skills, and governance structures. However, private VCs, at least those that invest via closed-end funds, may follow short-term goals (e.g., Gompers, 1996) and have tight budget constraints that may deter innovative projects (Lerner, 2002). Governmental VCs are typically not under pressure to generate fast returns as private VCs do and may therefore more easily implement long-term projects. This is likely to be particularly relevant in sectors such as biotechnology and pharmaceuticals, where R&D requires a long time to market and substantial resources (Di Masi et al., 1991; Di Masi and Grabowski, 2007). Syndication between more efficient and better-skilled private VCs and long-term-oriented governmental VCs (i.e., heterogeneous syndicates) may therefore be more successful in increasing innovative output than homogeneous (private or governmental) syndicates. Moreover, governmental financing is most successful when it attracts additional money from private investors (Takalo and Tanayama, 2010), consistently with what Lerner (1999) finds about the Small Business Innovation Research (SBIR) program in the US. We therefore expect the following:

H4: Syndicates consisting of private and governmental VCs (heterogeneous syndicates) increase the innovation output of their portfolio companies more than homogeneous syndicates.

Finally, we expect that heterogeneous syndicates may differ markedly in their effects depending upon which part leads. The lead investor is the most actively involved in the management of the company (Wright and Lockett, 2003). Because we expect private VCs to be more successful than governmental VCs at increasing innovative output, we also expect syndicates led by private VCs to dominate those led by governmental VCs:

H5: When a private VC leads a heterogeneous syndicate, the innovation output of the portfolio companies increases more than when a governmental VC leads the heterogeneous syndicate.

In the preceding paragraphs, we have gradually introduced the dimensions that describe venture capital transactions: the type of investors, the presence of a syndicate, and the syndicate characteristics. By combining these dimensions, we obtain six different transaction forms: private stand-alone, governmental stand-alone, homogenous private syndicate, homogeneous governmental syndicate, government-led heterogeneous syndicate, and private-led heterogeneous syndicate. The above discussion suggests that the latter transaction form should dominate the others in terms of its impact on innovation output because it combines all the beneficial features discussed above: the presence of a private VC (H2), syndication (H3), and a heterogeneous syndicate (H4) led by a private VC (H5). We therefore expect the following:

H6: Private-led heterogeneous syndicates increase the innovation output of their portfolio companies more than other forms of venture capital.

3 Data and descriptive statistics

Our sample includes 865 European VC-backed (159) and non-VC-backed (706) companies from the biotechnology (673) and pharmaceutical (192) industries from seven countries (see Table 1). All VC-backed and non-VC-backed companies included in this sample were founded after 1984 and were independent at foundation. All VC-backed companies received their first round of venture capital financing between 1994 and 2004 and were less than 10 years old at that time. The sample is extracted from the VICO database, a large-scale dataset on European high-tech entrepreneurial companies that was created with the support of the EC Seventh Framework Programme. The sampling process and the overall structure of the VICO database are described by Bertoni and Martí (2011).

We use patent stock to measure innovation output. We obtain information on patenting activity from the PATSTAT database. PATSTAT provides detailed information on patent applications and grants (over 70 million records) in more than 80 countries worldwide, including patent assignee names, citations, publications, application and grant years, industry patent classes, priority countries, and other information. This database allows us to analyze the evolution of the patenting activity of sample firms as reflected in their patent stock. We are also able to compute quality-weighted measures of patent stock that may more effectively capture the value of innovative output (see, e.g., Griliches, 1998; van Pottelsberghe and van Zeebroeck, 2011). The main dependent variable of our analysis is the increase in (log) patent stock between the investment year *t* and year $t+\tau$. As is customary, we compute the patent stock of sample companies based on the number of granted patents (since the application year) and depreciated at 15% (see, e.g., Griliches, 1998).[2] Our main dependent variable, therefore, equals $[log(1+patent\ stock_{t+\tau})-log(1+0.85^{\tau}\ patent\ stock_t)]$ with $\tau=1,\ldots,5$.[3] This variable, which has a lower bound of zero, captures the extent to which the patent stock of a company in year $t+\tau$ exceeds the patent stock in year *t* (discounted τ years).

Biotechnology and pharmaceutical industries provide an attractive setting for investigating how different forms of venture capital financing affect innovation output reflected in patent stock changes. In these industries, patents are considered most important as a device for protecting innovation (see, e.g., Hall, 2009), which makes patents a reasonably reliable measure of innovation. The more patenting is considered to be an important means of intellectual property rights protection, the less an increase in patenting after a venture capital investment is due to reverse causality. This reverse causality would be an issue when companies change their protection mechanism after receiving venture capital. For example, firms that based their intellectual property rights protection mostly on secrecy before receiving venture capital would most likely shift toward a different protection mechanism, such as patenting, because secrecy may be jeopardized for firms that receive venture capital financing (Ueda, 2004). Accordingly, we would expect to observe an increase in patenting activity after venture capital investments even without any real increase in innovative activity. In other words, if measures of intellectual property rights protection other than patents are most important, patenting, as a proxy for innovation, would be affected by a measurement error that is correlated with venture capital investments. Another benefit of focusing on these industries is that this focus helps to reduce the heterogeneity that may arise not only in response to the different use and valuation of patents across technological regimes (e.g.,

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[2] A variety of depreciation rates are used in the literature: Griliches (1998), Hall et al. (2000) and Bertoni et al. (2010) use 15%; Henderson and Cockburn (1996) and Ahuja and Katila (2001) use 20%; Blundell et al. (1995) and Dushnitsky and Lenox (2005) use 30%. Each of these authors verify the robustness of their results using different depreciation rates, and, to the best of our knowledge, in no case do they find any substantial difference in the results. We also estimate our models using alternative discounting rates and a non-discounted measure of patent stock as robustness checks and obtain qualitatively identical results.

[3] The use of a log transformation to address the skewness of patent stock is customary in the literature (e.g., Chemmanur et al., 2011). In our sample, the skewness of untransformed patent stock is 5.94, which drops to 2.89 after the log transformation.

Cohen et al., 2000) but also as a result of the different likelihoods of venture capital financing across industries, which would be difficult to control for in a multi-industry setting.

Table 1 provides an overview of our dataset (all companies, VC-backed companies, non-VC-backed companies) composition by country, sector, and foundation period. Table 1 also reports some descriptive statistics. The UK, Germany and France represent a large portion of the population (accounting for 70% of the total). The ranking is broadly consistent with the relative size of biotechnology industries in Europe (OECD, 2006). With regard to the number of VC-backed companies in our sample, Germany is the most represented country, followed by the UK. Again, this finding is comparable to OECD (2006) statistics pertaining to venture capital activity in biotech. Germany and the UK have the second and third highest number of VC-backed biotech companies, respectively, after the US (German venture capital investments in biotech account for 23% of all non-US investments; UK venture capital investments in biotech account for 15%).

Overall, the distribution of companies in our sample by foundation period exhibits an increasing trend over time, with 204 companies (23.6%) founded between 1984 and 1995, 292 (33.8%) between 1995 and 1999 and 369 (42.7%) between 2000 and 2004. The time trend is much more pronounced for VC-backed companies: only 9 VC-backed companies (5.7%) were founded before 1995, 65 (40.9%) between 1995 and 1999 and 85 (53.5%) between 2000 and 2004. This trend can be explained by the relatively young history of venture capitalism in Europe. The number and amounts invested increased substantially in the late 1990s and early 2000s (see EVCA Yearbook, different issues). As a result, companies founded during this period had a much higher chance, other things being equal, of obtaining venture capital than companies founded in the 1980s and early 1990s. Consequently, VC-backed firms were significantly younger than non-VC-backed firms. The average age of the two groups in 2008 was 8.86 and 10.94 years, respectively, with the difference significant at the 1% level. On average, companies in our sample had 3.8 million Euro net annual sales and 23.5 employees when the company is at median age (5 years), with no significant difference between VC-backed and non-VC-backed companies.

Our descriptive statistics highlights whether VC-backed and non-VC-backed companies differ, on average, in terms of their patent stock. For this, we compute the average level of patent stock of VC-backed and non-VC-backed companies at median age. We find a very large and statistically highly significant difference in the average patent stock, which was 1.13 for VC-backed companies and 0.28 for non-VC-backed companies.

[Insert Table 1 about here]

To understand whether the difference in the patent stock is driven by selection (i.e., by VCs selecting more innovative companies) or treatment (i.e., by VCs unlocking firms' innovation potential), we extract a matched control sample from the group of non-VC-backed companies. The rationale for this extraction is that we want to compare the post-investment evolution of a VC-backed company with a company that, at the time of financing, exhibits similar characteristics. In particular, VC-backed firms may already have an above-average patent stock at the time of first investment because VCs normally select firms with larger patent stocks (e.g., Haeussler et al., 2009).

To build the matched control sample, we rely on propensity-score matching. For every VC-backed (i.e., treated) company, we select (without replacement) the non-VC-backed (i.e., non-treated) company that, in the same year in which the investment occurs, has the most similar propensity score (i.e., the estimated likelihood of receiving venture capital). The panel structure of our dataset makes it possible to estimate propensity scores using a survival model. We compute the probability that a company receives its first round of VC financing in any given year conditional upon not having received it before. In computing the propensity score, we control for company stage, number of employees, and patent stock and include a full set of country and year dummies. We are able to compute the propensity score (at the time of financing) for 153 VC-backed companies.

In the robustness section, we perform an alternative matching process because the selection criteria for VCs can differ depending upon their typology. Accordingly, we employ two separate survival models, one for private and one for governmental VCs, to estimate the probability that a company will receive its first round of private or governmental venture capital financing in any given year. In computing the two propensity scores, we control for company age, sales and entry patent stock and include a full set of country and year dummies. We then build the estimation sample by matching any private VC-backed company with a non-VC-backed company with the closest probability (propensity score) of receiving investment from a private VC. We then repeat the same procedure for governmental VC-backed firms. A detailed description of the matching procedures is reported in the Appendix.

The result of the primary matching process is reported in Table 2. As expected, the matched control sample exhibits a distribution that is much closer to the VC-backed sample than that of the non-VC-backed sample presented in Table 1. The distribution across countries and industries is not significantly different between the VC-backed and the matched control samples ($\chi^2(6) = 1.88$ and $\chi^2(1) = 0.51$, respectively). However, VC-backed companies were, on average, still significantly younger than their counterparts in the matched control sample (t-statistic = -3.18). Despite its statistical significance, this difference is limited in magnitude: VC-backed companies had an average age (at 2008) of 8.86 years compared to an average of 10.32 years in the matched control sample. At the time of the matching, the sales and employment of VC-backed and matched control companies did not statistically differ. More interestingly, as a result of the matching procedure, VC-backed and matched control companies had a similar patent stock at the time of the match, equal to 0.78 and 0.53, respectively.[4]

[Insert Table 2 about here]

As a first, illustrative, example of the progress of innovation output after venture capital investments, we report in Figure 1 the average increase in log patent stock of VC-backed and matched control companies over a five-year period after the first investment. Consistently with Hypothesis 1, the patent stock of VC-backed companies grows at a faster rate than that of the matched control sample in each of the five years after the investment event, and this difference is highly statistically significant. Five years after the investment event, the increase in log patent stock is 2.7 times greater for VC-backed companies than for the matched control sample (0.236 vs. 0.086).

[Insert Figure 1 about here]

In Table 3, we report the breakdown of the VC-backed sample according venture capital form. Of the 153 investments, 109 (71.2%) are stand-alone, and 44 (28.8%) are syndicated. These numbers confirm the low syndication rates in Europe found in previous studies (e.g., Manigart et al. (2004) report a syndication rate of 28.7% in Europe). Out of the 109 stand-alone deals, 70 (64.2%) are conducted by a private VC and 39 (35.8%) by a governmental VC. Out of the 44 syndicated deals, 30 (68.2%) are led by a private VC and 14 (31.8%) by a governmental VC. Overall, governmental VCs are involved in 66 of the 153 deals (43.1%), confirming the importance of governmental VCs in the European biotech and pharmaceutical sectors. Of the 25 heterogeneous syndicates, 13 are led by private VCs and 12 by governmental VCs. Homogeneous governmental syndicates, in contrast, are represented by only two observations in our sample: governmental VCs seem either to invest in stand-alone

[4] The values of sales, employment and patent stock are much lower than in Table 1 because in Table 1, the values are measured at the company age of five years, and in Table 2, they are measured at the time of matching (with an average of one year).

deals or together with private VCs but very rarely form syndicates with other governmental VCs.

[Insert Table 3 about here]

Figure 2 provides some preliminary insights on the evolution of the log patent stock across different forms of venture capital. For reference, we also depict, in each panel, the development of the log patent stock for the matched control sample. The vertical axis shows the increase in log patent stock in $t+\tau$ over the discounted level of log patent stock in t. Panel A of Figure 2 compares the evolution of firms backed by private VCs with those backed by governmental VCs (in case of a heterogeneous syndicate, the firm is assigned to the category of the syndicate leader). The increase in patent stock is only slightly higher for firms backed by governmental VCs than it is for the matched control sample. The increase is much higher for companies backed by private VCs, in line with Hypothesis 2. Panel B of Figure 2 compares the increase in patent stock of syndicated and stand-alone deals. We observe that both transaction types lead to a steady increase in firms' patent stocks over the matched control sample but that the pace seems to be more sizeable for syndicated than for stand-alone investments (in line with Hypothesis 3). Panel C compares different forms of syndicated deals. The patent stock development in firms backed by homogeneous syndicates is similar to that of firms backed by stand-alone VCs. The increase in patent stock in heterogeneous syndicates, in contrast, seems to be much greater, consistent with Hypothesis 4. Finally, in Panel D, we compare private- and government-led heterogeneous syndicates. Private-led heterogeneous syndicates seem to outperform not only government-led heterogeneous syndicates, consistent with Hypothesis 5, but also all other forms of venture capital, consistent with Hypothesis 6.

[Insert Figure 2 about here]

4 Empirical analyses

4.1 The role of VCs, VC type and syndication

4.1.1 Specifications

Table 4 presents our regression results for the increase in patent stock one to five years after the investment in the sample of VC-backed and matched control companies. We regress the increase in log patent stock on the VC dummy (Model 1) as well as on different variables related to venture capital forms (Models 2-5). With these regressions, we test Hypotheses 1 to

5. We control for patent stock at the time of the investment. Blundell et al. (1995) show that, due to path dependence in innovation activity, the "entry patent stock" adequately controls for fixed effects. Essentially, including the entry patent stock allows us to partially control for the unobservable "innovativeness" of companies (see also Ahuja and Katila, 2001; Dushnitsky and Lenox, 2005; Bertoni et al., 2010).

We also add company age to account for the influence of maturity on patenting. We estimate alternative specifications in which company size is used instead of company age (both variables cannot be included simultaneously due to their high correlation) as a robustness check. We include country dummies to capture country-specific time-invariant characteristics that may affect patenting. As a robustness check, we exclude countries one by one to determine whether a single country dominates the results. In another robustness check, we estimate the models excluding pharmaceuticals. Finally, we employ year dummies to account for effects that are caused by changing environments over time.

We employ OLS regressions (with standard errors corrected for heteroscedasticity) in this main analysis. In the robustness section, we use Tobit models to take into account the fact that the majority of companies do not patent, and, as a result, their patent stock and, consequently, their patent stock increase is equal zero. Although the Tobit model is appropriate for censored data such as ours, it is susceptible to misspecification (see, e.g., Nelson, 1981), which prevents us from using it for the main analysis.

4.1.2 Results

Panel A of Table 4 depicts the results for the patent stock in *t+3*. Panel B of Table 4 presents the results for years *t+1, t+2*, *t+4*, and *t+5* (only coefficients on the VC-related variables are reported for the sake of readability).

Model 1 suggests that venture capital financing is positively related to the post-VC patent stock increase two to five years after the venture capital investment. For example, three years after the investment, the increase in patent stock is higher in VC-backed than in matched control companies by a factor of 0.064. The difference is significant at the 10% level and lends support to our Hypothesis 1. The size of the effect is better understood by looking at its absolute level. The expected patent stock for an average non-VC-backed company in year *t+3* is 0.276.[5] If the same company received funding from a VC in year *t*, we would expect instead a patent stock of 0.360. Interestingly, Panel B of Table 4 shows that, as suggested by Figure 1,

[5] The expected patent stock of an "average company" is computed by incorporating population averages of company age and initial patent stock. Country and year fixed effects are also population averaged.

the difference between VC-backed companies and the matched control sample widens over time and becomes more statistically significant.

In Models 2-5, we look into the group of VC-backed companies in more detail and compare different VC forms by testing for differences in their coefficients. In addition, by determining whether a coefficient is significant, we compare the different forms of VC to the matched control group. This latter comparison provides important information on how the different VC forms contribute to increased innovation output when compared to that of the matched control firms. In Model 2, we compare two groups of companies: those whose lead investor is a private VC and those whose lead investor is a governmental VC. The first group includes stand-alone deals made by private VCs, homogenous syndicates of private VCs and heterogeneous syndicates led by private VCs; the latter group consists of stand-alone deals of governmental VCs, homogeneous syndicates of governmental VCs and government-led heterogeneous syndicates. Model 2 reveals that companies in which a private VC takes the lead exhibit a significantly higher increase in patent stock than the matched control group in years $t+2$ to $t+5$. In absolute terms, an average company backed in year t by a private VC would have, in year $t+3$, an expected patent stock of 0.405. In contrast, companies with a lead governmental VC do not increase their patent stock more than the matched control group in any of the five years after the investment. The difference between the coefficients for the private and governmental lead dummies is significant at the 10% level in years $t+2$ to $t+5$. These results are in line with our Hypothesis 2.

Model 3 compares syndicated to stand-alone transactions. Syndicated transactions include homogeneous private syndicates, homogeneous governmental syndicates, private-led heterogeneous syndicates, and government-led heterogeneous syndicates. Stand-alone transactions consist of governmental and private stand-alone deals. In years $t+1$ to $t+5$, the coefficient of the syndicate dummy is highly statistically significant, indicating that syndicates realize a greater increase in patent stock than the matched control group. In absolute terms, an average company backed in year t by a syndicate of VCs would have, in year $t+3$, an expected patent stock of 0.490. The coefficient of the stand-alone dummy is always insignificant. The difference between the coefficients of the syndicated and stand-alone dummies is statistically significant in years $t+3$ to $t+5$. These results lend support to our Hypothesis 3.

Model 4 examines the impact of the syndicate structure. The question is how VC heterogeneity within a syndicate affects the evolution of the patent stock. To address this question, syndicated transactions are divided into two further subgroups: heterogeneous and homogeneous syndicates. In all five years, the coefficient of the heterogeneous syndicate dummy is highly statistically and economically significant, whereas the coefficient of the homogenous syndicate dummy is always insignificant. In absolute terms, an average company backed in year *t* by a heterogeneous syndicate would have, in year *t+3*, an expected patent stock of 0.617. These results suggest that only companies financed by heterogeneous, but not by homogeneous, syndicates increase their patent stock more than matched control companies. The difference between the coefficients of the heterogeneous and homogeneous syndicate dummies is statistically significant at the 5% level in years *t+1* to *t+5*. These results are in line with Hypothesis 4.

Finally, Model 5 examines the effects of heterogeneous syndicates in more detail and investigates whether the leader of the syndicate has an effect. To analyze this issue, we interact the lead private dummy with the heterogeneous syndicate dummy. The coefficient of this interaction term is statistically significant and positive, whereas the effect of the heterogeneous syndicate dummy and the effect of the lead private dummy remain statistically insignificant. In absolute terms, an average company backed in year *t* by a heterogeneous syndicate led by a private VC would have, in year *t+3*, an expected patent stock of 0.896. These results suggest that a significant increase in patent stock is observed when VCs combine complementary resources (in a heterogeneous syndicate) with an efficient syndicate structure (under a private-led VC). The difference between the coefficients of the heterogeneous syndicate dummy and the interaction term is statistically significant at the 5% level in years *t+1*, *t+2*, *t+4* and *t+5*, giving support to our Hypothesis 5.

[Insert Table 4 about here]

4.2 Transaction forms

4.2.1 Specifications

In this section, we compare transaction structures directly by studying the innovation output associated with each of them. Table 5 examines this issue by regressing the increase in log patent stock, 1 to 5 years after the venture capital investment, on a dummy for five transaction forms: private stand-alone, governmental stand-alone, homogeneous private syndicate, private-led heterogeneous syndicate and governmental syndicate. This latter form is a combination of two forms that do not have a sufficient number of observations to justify keeping them separate: the homogeneous governmental syndicate and government-led heterogeneous syndicate. (The results are, however, robust toward their separate inclusion.)

The reference category is again the matched control group. With these regressions, we test Hypothesis 6. The control variables and regression approach remain the same as in Table 4. We perform the same robustness checks as for the regressions in Table 4.

4.2.2 Results

The results presented in Table 5 indicate that in each of the years 1 to 5 after the transaction, firms backed by private-led heterogeneous syndicates increase the patent stock substantially more than the matched control companies. The gap increases over time, is economically sizeable and is statistically significant. More interestingly, private-led heterogeneous syndicates dominate all other forms in all other years in terms of their effect on the innovation output. From year *t+2* onward, the difference between the coefficient of the private-led heterogeneous syndicate dummy and any of the other forms' dummies is always economically and statistically highly significant at the 1% level (in year *t+1*, the dummy is also significant, albeit at a lower level). Thus, even if other venture capital forms (such as private stand-alone) may be beneficial to innovative output (as compared to matched control companies), private-led heterogeneous syndicates are the most beneficial form of venture capital for promoting innovation in biotech and pharmaceuticals. These results strongly support our Hypothesis 6.

[Insert Table 5 about here]

4.3 Robustness

We perform various checks, which we mentioned in previous sections, to verify that our results from Tables 4 and 5 are robust. In particular, we employ (i) alternative econometric approaches, (ii) alternative patenting variables, (iii) alternative control variables, (iv) alternative sample specifications, and (v) an alternative matching technique. We also re-estimate all models on a balanced sample including 258 companies (for which we have observations in all years *t+1* to *t+5*). Our main outcomes remain robust toward these checks.

We present selected results (for the model from Table 5 and year *t+3*) in Table 6. In all these alternative models, companies backed by private-led heterogeneous syndicates have a significantly greater increase in patent stock after the venture capital investment compared to matched control firms. In addition, in all specifications, private-led heterogeneous syndicates have a much larger effect on the increase in patent stock than any other venture capital form. This difference is (with one exception) always highly statistically significant, in most cases at the 1% significance level. We present results from the following specifications: (i) in Column 1, we employ Tobit models instead of the multivariate regression models; (ii) in Columns 2 and 3, we use as dependent variables patent stock weighted by family size (i.e., the geographical scope of the patent) and non-discounted patent stock, respectively; (iii) in Column 4, we estimate an alternative specification in which company size is used instead of company age; (iv) in Columns 5 and 6, we report the results of estimates excluding the UK (i.e., the country with the largest venture capital activity) and pharmaceutical companies, respectively; and (v) in Column 7, we present results based on an alternative matching process based on a separate matching equation for private and governmental VCs.

[Insert Table 6 about here]

5 Conclusion

Our paper contributes to a better understanding of the effects of venture capital on portfolio companies. Using a novel sample of young European companies from the biotechnology and pharmaceutical sectors, we investigate how venture capital financing, in its different forms, affects the innovation output of portfolio companies as measured by the increase in their patent stock. Our results indicate that venture capital investments encourage patenting, as the existing literature has suggested, but that this effect is only present for certain forms of venture capital. Specifically, private venture capital investors and syndicates seem to be the forms that increase innovative output. Our findings lend support to the conclusion that syndicates between private and governmental venture capital investors, in which the private investor takes the lead, are the most efficient form in terms of innovation production that outperforms all other forms. These results contribute to recent discussions in the literature (i) on the impact of venture capital on patenting, (ii) on the consequences of venture capital heterogeneity and (iii) on syndication.

Because our results help to better understand the role of governmental venture capital investors in the process of generating innovations, they provide not only a contribution to the academic literature but also have important implications for public policies that aim at fostering innovation. Whereas most of the literature has focused on the extent to which governmental venture capital attracts or crowds out private investors, in this work, we show that the mode of investment used by governmental venture capital investors is also a key variable in the design of effective innovation policies. Specifically, to support innovation, governmental venture capital investors should not invest alone but should syndicate with private partners. In addition, private venture capital investors should be allowed by their governmental partners to lead the syndicate.

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Tables and Figures

Table 1: Distribution and descriptive statistics on the population of companies

	VC-backed	Non-VC-backed	All	
No. of companies	**159**	**706**	**865**	
Distribution				
Belgium	18	48	66	
Finland	14	45	59	
France	14	111	125	
Germany	55	148	203	
Italy	7	38	45	
Spain	15	77	92	
United Kingdom	36	239	275	
Biotechnology	133	540	673	
Pharmaceuticals	26	166	192	
Founded 1984-1995	9	195	204	
Founded 1995-1999	65	227	292	
Founded 2000-2004	85	284	369	
Mean				
Age in 2008	8.86	10.94	10.56	[-4.79]***
Sales at median age	3,782	3,845	3,835	[-0.03]
Employees at median age	25.76	22.96	23.49	[0.36]
Patent stock at median age	1.13	0.28	0.43	[4.85]***

Legend: Sales are expressed in thousands of Euros (deflated using CPI and expressed at the real 2008 level). Patent stock is the number of granted patents since the application year depreciated at 15%. ***, ** and * indicate differences in means significant at the 1%, 5%, and 10% level, respectively. The value of the t-test (on VC-backed and non-VC-backed group equality) is shown in square brackets. The median age is 5 years.

Table 2: Distribution and descriptive statistics on VC-backed companies and the matched control sample

	VC-backed	Matched	All	
No. of companies	**153**	**153**	**306**	
	Distribution			
Belgium	18	17	35	
Finland	14	12	26	
France	13	14	27	
Germany	54	45	99	
Italy	7	14	21	
Spain	15	14	29	
United Kingdom	32	37	69	
Biotechnology	127	120	247	
Pharmaceuticals	26	33	59	
Founded 1984-1995	9	30	39	
Founded 1995-1999	62	49	111	
Founded 2000-2004	82	74	156	
	Mean			
Age in 2008	8.86	10.32	9.59	[-3.18]***
Sales at time of matching	2,183	1,514	1,860	[0.46]
Employees at time of matching	10.80	13.35	12.02	[-0.37]
Patent stock at time of matching	0.78	0.53	0.66	[0.84]

Legend: Sales are expressed in thousands of Euros (deflated using CPI and expressed at the real 2008 level). Patent stock is the number of granted patents since the application year depreciated at 15%. ***, ** and * indicate differences in means significant at the 1%, 5%, and 10% level, respectively. The value of the t-test (on VC-backed and matched control group equality) is shown in square brackets.

Table 3: The distribution of VC-backed companies by venture capital forms

	Private-led	Government-led	Total
Syndicate	30	14	44
…heterogeneous	*13*	*12*	*25*
…homogeneous	*17*	*2*	*19*
Stand-alone	70	39	109
Total	100	53	153

Legend: In stand-alone deals, only one VC (either private or governmental) invests in the company in the first round. In syndicated deals, more than one VC is involved in the first round of financing. Syndicates are homogeneous if the group of investors belongs to a single category (either private or governmental). In heterogeneous syndicates, private and governmental investors co-invest.

Table 4: Venture capital, VC type, syndication and patent stock

Panel A: 3 years after VC involvement

	Model 1	Model 2	Model 3	Model 4	Model 5
VC dummy	0.064*				
	(0.032)				
Private-led		0.097**[+]			0.061
		(0.041)			(0.051)
Government-led		0.005			
		(0.037)			
Syndicate			0.155***[++]		
			(0.054)		
Stand-alone			0.027	0.028	-0.009
			(0.037)	(0.037)	(0.044)
Heterogeneous syndicate				0.237***[++]	0.064
				(0.069)	(0.064)
Homogenous syndicate				0.035	-0.020
				(0.069)	(0.077)
(Heterogeneous)x(Private-led)					0.273**
					(0.121)
Age	-0.010***	-0.010***	-0.010***	-0.010***	-0.009***
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
Initial patent stock	0.145***	0.141***	0.140***	0.146***	0.147***
	(0.034)	(0.034)	(0.033)	(0.034)	(0.034)
Country dummies	Yes	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes	Yes
N	298	298	298	298	298
R^2	0.245	0.255	0.262	0.278	0.307
F	4.76***	4.41***	4.88***	5.04***	5.29***

Panel B:

	VC dummy	Private-led	Syndicate	Heterogeneous syndicate	(Heterogeneous) x (Private-led)
1 year	0.032	0.042	0.063*	0.125**[++]	0.282**[++]
2 years	0.051*	0.080**[+]	0.099**	0.176**[++]	0.313**[++]
4 years	0.093**	0.135***[+]	0.210***[++]	0.297***[++]	0.452***[++]
5 years	0.118***	0.164***[+]	0.250***[++]	0.350***[++]	0.543***[++]

		Governmental lead	Stand-alone	Homogenous syndicate	
1 year		0.012	0.019	-0.019	
2 years		-0.002	0.032	-0.002	
4 years		0.025	0.049	0.065	
5 years		0.045	0.066	0.079	

Legend: The sample consists of 153 VC-backed and 153 matched control companies. An OLS regression with robust standard errors (White, 1980) is used. The number of observations for the 1-year, 2-year, 4-year and 5-year model is 306, 305, 286, and 258, respectively. The dependent variable is the increase in log patent stock in *t+3* (Panel A), *t+1*, *t+2*, *t+4*, and *t+5* (Panel B) over the discounted level of log patent stock in *t* and is computed as [log(1+patent $stock_{t+\tau}$)-log(1+0.85^{τ} patent $stock_t$)] with $\tau=1,\ldots,5$. *VC dummy* is equal to one for the companies from the VC-backed sample. *Private-led* is equal to 1 for deals led by a private VC. *Government-led* is equal to 1 for deals led by a governmental VC. *Syndicate* is equal to 1 if multiple VCs are involved in the transaction. *Stand-alone* is equal to 1 if only one investor is involved in the deal. *Heterogeneous syndicate* is equal to 1 when both private and governmental VCs participate. *Homogenous syndicate* is equal to one for syndicates in which only one type of investor participates (i.e., governmental homogeneous syndicates and private homogeneous syndicates). *(Heterogeneous) x (Private-led)* is the interaction between *Heterogeneous syndicate* and *Private-led*. *Age* is the firm *log(1+age)* at time of the investment. *Initial patent stock* is the firm's *log(1+patent stock*$_t$*)*. Panel B shows only coefficients on VC-related variables. ***, **, and * indicate that the coefficients are significant at the 1%, 5%, and 10% level, respectively. ++ and + in squared brackets indicate that the difference between the coefficients of interest (i.e., *Private-led* and *Government-led* in Model 2, *Syndicate* and *Stand-alone* in Model 3, *Heterogeneous syndicate* and *Homogeneous syndicate* in Model 4, *Heterogeneous syndicate* and *(Heterogeneous) x (Private-led)* in Model 5) is significant at the 5% and 10% level, respectively. Standard errors are in brackets and appear below the related coefficients (Panel A).

Table 5: Venture capital forms and patent stock

	1 year	2 years	3 years	4 years	5 years
Private-led heterogeneous syndicate	0.255**	0.347***	0.397***	0.559***	0.671***
	(0.099)	(0.101)	(0.097)	(0.137)	(0.150)
Private stand-alone	0.018[++]	0.052[+++]	0.053[+++]	0.074[+++]	0.091*[+++]
	(0.027)	(0.036)	(0.046)	(0.051)	(0.055)
Governmental stand-alone	0.026[++]	0.003[+++]	-0.013[+++]	0.016[+++]	0.032[+++]
	(0.035)	(0.039)	(0.044)	(0.056)	(0.061)
Governmental syndicate	-0.019[+++]	-0.006[+++]	0.061[+++]	0.057[+++]	0.081[+++]
	(0.031)	(0.051)	(0.056)	(0.051)	(0.061)
Homogeneous private syndicate	-0.022[+++]	-0.005[+++]	0.031[+++]	0.062[+++]	0.070[+++]
	(0.021)	(0.050)	(0.078)	(0.084)	(0.120)
Age	-0.003	-0.007**	-0.009***	-0.010***	-0.013***
	(0.002)	(0.003)	(0.003)	(0.004)	(0.005)
Initial patent stock	0.077***	0.113***	0.147***	0.156***	0.195***
	(0.021)	(0.027)	(0.034)	(0.039)	(0.045)
Country dummies	Yes	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes	Yes
N	306	305	298	286	258
R^2	0.195	0.269	0.307	0.336	0.384
F	1.98***	4.30***	5.32***	4.73***	4.64***

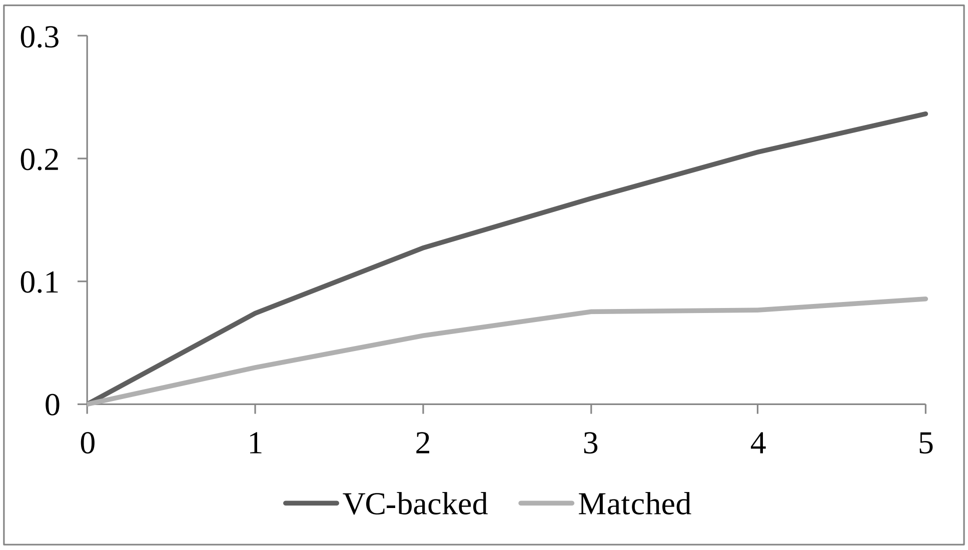
Legend: The sample consists of 153 VC-backed and 153 matched control companies. The OLS regression with robust standard errors (White, 1980) is used. The dependent variable is the increase in log patent stock in *t+3* (Panel A), *t+1*, *t+2*, *t+4*, and *t+5* (Panel B) over the discounted level of log patent stock in *t* and is computed as [log(1+patent $stock_{t+\tau}$)-log(1+0.85^{τ} patent $stock_t$)] with $\tau=1,\ldots,5$. *Private stand-alone* indicates a stand-alone private venture capital investment. *Governmental stand-alone* indicates a stand-alone governmental venture capital investment. *Governmental syndicate* indicates either a syndicate led by a governmental VC, in which private VCs are also present, or a syndicate composed only of governmental VCs. *Private-led heterogeneous syndicate* indicates a syndicate led by a private VC in which governmental VCs are also involved. *Homogeneous private syndicate* indicates a syndicate composed only of private VCs. *Age* is the firm log(1+age) at the time of the investment. *Initial patent stock* is the firm's log(1+patent $stock_t$). ***, **, and * indicate that the coefficients are significant at the 1%, 5%, and 10% level, respectively. +++, ++, and +, in squared brackets, indicate that the difference between the coefficient of this form and the form "Private-led heterogeneous syndicate" is significant at the 1%, 5%, and 10% level, respectively. Standard errors are in brackets and appear below the related coefficients.

Table 6: Robustness checks – Venture capital forms and patent stock

	Tobit estimation	Family size	Non-discounted	Size control	Excluding UK	Excluding pharma.	Split matching
Private-led heterogeneous syndicate	1.051***	0.432***	0.712***	0.396***	0.426***	0.384***	0.403***
	(0.202)	(0.106)	(0.193)	(0.094)	(0.097)	(0.094)	(0.097)
Private stand-alone	0.307**[+++]	0.067[+++]	0.101[+++]	0.058[+++]	0.026[+++]	-0.004[+++]	0.056[+++]
	(0.151)	(0.046)	(0.075)	(0.048)	(0.053)	(0.048)	(0.046)
Governmental stand-alone	0.220[+++]	-0.001[+++]	0.010[+++]	-0.007[+++]	-0.029[+++]	-0.030[+++]	-0.010[+++]
	(0.183)	(0.047)	(0.082)	(0.057)	(0.056)	(0.045)	(0.043)
Governmental syndicate	0.283	0.060[+++]	0.152[++]	0.077[++]	0.028[+++]	0.062[+++]	0.065[+++]
	(0.501)	(0.050)	(0.120)	(0.098)	(0.061)	(0.058)	(0.055)
Homogeneous private syndicate	0.422[++]	0.038[+++]	0.063[+++]	0.039[+++]	-0.054[+++]	-0.029[+++]	0.032[+++]
	(0.264)	(0.079)	(0.142)	(0.093)	(0.040)	(0.045)	(0.079)
Age	-0.038	-0.009***	-0.016***		-0.012**	-0.013***	-0.010***
	(0.030)	(0.003)	(0.006)		(0.004)	(0.005)	(0.003)
Initial patent stock	0.563***	0.095***	0.189***	0.147***	0.170***	0.148***	0.149***
	(0.091)	(0.028)	(0.050)	(0.042)	(0.040)	(0.034)	(0.034)
Size				-0.002			
				(0.007)			
Country dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	298	298	298	222	230	240	298
R^2 (Tobit: Pseudo R^2)	0.291	0.261	0.274	0.299	0.329	0.370	0.296
F (Tobit: LR Chi^2)	107.450	5.178	5.471	4.070	5.162	5.303	5.471

Legend: We employ OLS regressions with robust standard errors (Columns 2-7) and a Tobit model with bootstrapped standard errors (Column 1). The dependent variable is the increase in log patent stock in year *t+3* over the discounted value of patent stock in year *t* shown in Columns 1 and 4-7. The dependent variable in Column 2 is the increase in family size-weighted log patent stock in *t+3* over the discounted level of family size-weighted log patent stock at year *t*. The dependent variable in Column 3 is the increase in non-discounted log patent stock in *t+3* over the level of non-discounted log patent stock at year *t*. Column 4 includes size instead of age as a regressor. Model 5 excludes companies from the UK. Model 6 excludes pharmaceuticals. Model 7 is performed on a matched control sample obtained by computing different propensity scores for private and governmental VC. *Private stand-alone* indicates a stand-alone private venture capital investment. *Governmental stand-alone* indicates a stand-alone governmental venture capital investment. *Governmental syndicate* indicates a either syndicate led by a governmental VC in which private VCs are also present or a syndicate composed only of governmental VCs. *Private-led heterogeneous syndicate* indicates a syndicate led by a private VC in which governmental VCs are also involved. *Homogeneous private syndicate* indicates a syndicate composed only of private VCs. *Age* is the firm log(1+age) at the time of the investment. *Size* is the firm log(1+total assets) at the time of the investment. *Initial Patent stock* is the firm's log(1+patent $stock_t$). ***, **, and * indicate significance at the 1%, 5%, and 10% level, respectively. +++, ++, and +, in squared brackets, indicate that the difference between the coefficient of this form and the form "Private-led heterogeneous syndicate" is significant at the 1%, 5%, and 10% level, respectively. Standard errors are in brackets and appear below the related coefficients.

Figure 1 – The evolution of patent stock: VC-backed companies vs. the matched control sample

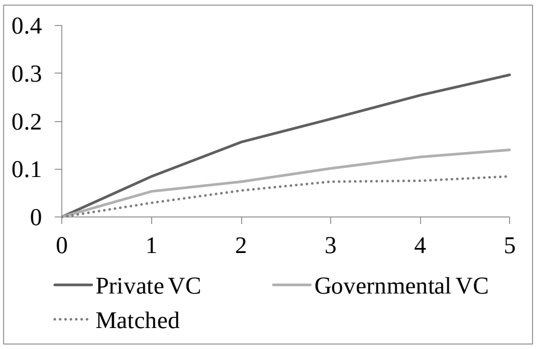


Legend: The vertical axis reports the increase in log patent stock over the discounted level of the beginning-of-period log patent stock and is computed as [log(1+patent stock$_{t+\tau}$)-log(1+0.85$^{\tau}$ patent stock$_{t}$)]. The horizontal axis represents the years since the initial venture capital investment, τ=1,…,5.

Figure 2 – The evolution of patent stock for different venture capital forms and the matched control sample

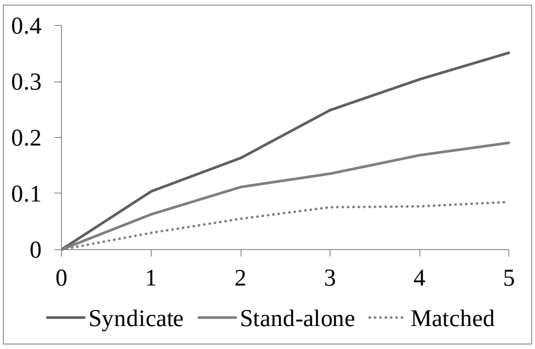
Panel A

Private and governmental VCs



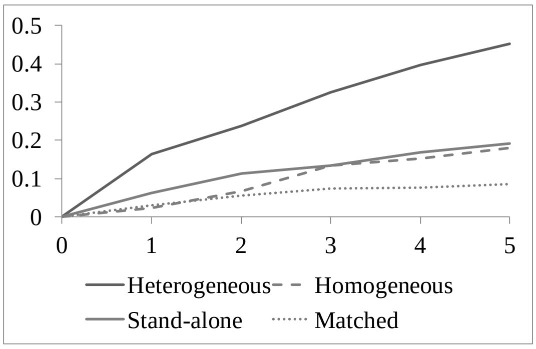
Panel B

Syndicate and stand-alone investments



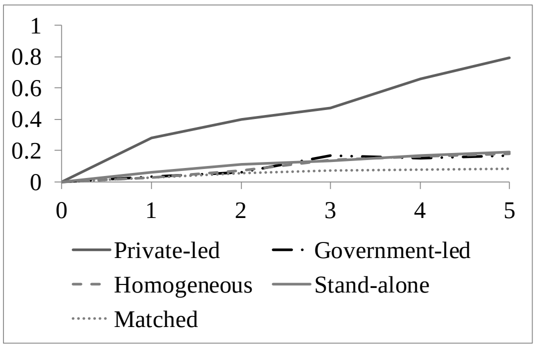
Panel C

Homogeneous and heterogeneous syndicates



Panel D

Private- and government-led heterogeneous syndicates



Legend: The vertical axis reports the increase in log patent stock over the discounted level of the beginning-of-period log patent stock and is computed as [log(1+patent stock$_{t+\tau}$)-log(1+0.85$^{\tau}$ patent stock$_t$)]. The horizontal axis represents the years since the initial venture capital investment, τ=1,…,5.

Appendix

Our matching procedure relies on propensity scores (Rosenbaum and Rubin, 1983; Heckman et al., 1998). First, our sample is divided into a treated group (VC-backed companies) and a non-treated group (companies that do not receive VC). To each firm from the former group, we match the firm from the latter group that has the closest propensity score to be a target for VCs. The longitudinal nature of the dataset allows us to compute the propensity score using a survival model, which is more appropriate for estimating the likelihood of absorbing state events.

We use a Weibull distribution, a common parametric specification, for the hazard function and include among the regressors a firm's lagged patent stock and the log number of employees together with a full set of country and year dummies. We also include a seed dummy that is equal to 1 when the firm is in the seed stage. The results are reported in Column 1 of Table A.1. Interestingly, Table A.1 shows that the ideal candidate for European VCs, at least in biotech and pharmaceuticals, seems to be a relatively small, young company with a large patent stock.

As a robustness check, we allow private and governmental VCs to follow different selection criteria and re-estimate the model for private and governmental VCs separately. The results, presented in Columns 2 and 3 in Table A.1, show that private and governmental VCs have similar selection criteria; governmental VCs, however, seem to more readily invest at the seed stage and less interested in patent stock.

Table A.1: VC survival estimates

	VC	Private VC	Governmental VC
Patent stock	0.872***	0.898***	0.732***
	(0.154)	(0.154)	(0.213)
Employees	-1.128***	-1.211***	-0.956***
	(0.240)	(0.313)	(0.334)
Seed	2.566***	2.199***	3.773***
	(0.356)	(0.420)	(0.740)
Constant	-8.106***	-9.408***	-9.412***
	(0.520)	(1.013)	(0.826)
Country dummies	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes
N observations	7,520	7,854	8,103
N companies	859	859	859

Legend: The sample (panel) consists of the biotech and pharmaceutical portion of the VICO dataset. The dependent variable is the hazard ratio of obtaining a first-round investment from a VC (Column 1), from a private VC (Column 2) or from a governmental VC (Column 3) in a given year *t*. Estimations are performed using a Weibull regression. *Patent stock* is the log (1+patent stock) in year *t-1*. *Employees* is the log(1+employees) in year *t-1*. *Seed* is a dummy equal to 1 if a firm is at the seed stage in year *t*. ***, **, and * indicate significance at the 1%, 5%, and 10% level, respectively. Robust standard errors are in brackets below the related coefficients.