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WHICH FORM OF VENTURE CAPITAL IS MOST SUPPORTIVE OF INNOVATION? EVIDENCE FROM EUROPEAN BIOTECHNOLOGY COMPANIES

Fabio Bertoni
Tereza Tykvová

Universität Hohenheim | Forschungszentrum Innovation und Dienstleistung
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Fabio Bertoni [a], Tereza Tykvová [b]

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a. Associate professor of Corporate Finance at the Department of Economics, Finance and Control of EMLyon Business School, 23 Avenue Guy de Collongue – 69134 Ecully – (France). Phone: +33 4 78 33 70 03. Email: Bertoni@em-lyon.com.

b. Full professor of Corporate Finance, Institut für Financial Management of Universität Hohenheim, Wollgrasweg 23 – 70599 Stuttgart (Germany) and Research Associate, ZEW, L 7,1 – 68161 Mannheim (Germany). Phone: +49 711 459 24500 Email: Tereza.Tykvova@uni-hohenheim.de

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Abstract: We argue that different forms of venture capital contribute differently to the innovation process and, consequently, differ in their impact on portfolio companies' innovation output. Our results suggest that the innovation output of companies financed by independent VCs increases significantly faster than that of both non-VC-backed companies and of companies financed by governmental VCs. However, governmental VCs may be beneficial for innovation by complementing the skills and resources provided by an independent VC in a heterogeneous syndicate.

1 INTRODUCTION

A rich set of different resources and capabilities is needed by companies to pursue innovation. Companies enhance their initial resource base through learning (Spender and Grant, 1996) and their absorptive capacity allows them to capture knowledge spillovers (Cohen and Levinthal, 1990). Dynamic capabilities help companies in reconfiguring their resource base, following the moving target of innovation (Eisenhardt and Martin, 2000). Moreover, innovation requires substantial financial resources, which companies may have problems to acquire through traditional sources such as debt (Berger and Udell, 1998).

Venture capitalist investors (VCs) may support the learning processes in their portfolio companies and increase their absorptive capacity. Companies benefit from VCs' industry-specific technical expertise (De Clercq et al., 2006), general business experience (Gupta and Sapienza, 1992), network of contacts (Fried and Hisrich, 1995) and collaboration with other portfolio companies (Lindsey, 2008). VCs also help companies to improve their dynamic capabilities (Eisenhardt and Martin, 2000). And, clearly, VCs may inject considerable funds in their portfolio companies, relaxing their financial constraints (Bertoni et al., 2010a).

Several empirical studies at country, industry and portfolio firm level confirm the existence of a positive relation between venture capital and innovation (Kortum and Lerner, 2000; Hellmann and Puri, 2000; Baum and Silverman, 2004; Bertoni et al., 2010b; Hirukawa and Ueda, 2011; Popov and Roosenboom, 2012). There is however an extreme variety in the characteristics of VCs and their transaction structure, and the extent to which this variety reflects in differences in VCs' support to innovation is not yet entirely understood. Our paper aims to contribute to filling this gap.

The first objective of this study is to investigate whether independent and governmental VCs differ in their support to the innovation of their portfolio companies. The most important aspect characterizing the organizational structure of VCs concerns their ownership type (Da Rin et al., 2011). While independent VCs are the most common type of venture capital, governmental VCs are particularly important in Europe (e.g., Bottazzi et al., 2004; Tykvová, 2006), especially in the biotechnology and pharmaceutical sectors. Independent VCs may possess better skills and incentives to support companies than governmental VCs (e.g., Jääskeläinen et al., 2007; Bottazzi et al., 2008; Luukkonen et al., 2013;). We thus expect that governmental VCs are less effective than independent VCs in fostering the innovative output of portfolio companies. This question has received relatively little attention from academics. However, this is an important issue given the large weight of these investors in Europe and the hopes that European governments have for them.

The second objective is to analyze the extent to which syndicates and stand-alone VCs differ in their support to the innovation. Syndicates combine complementary resources (e.g., Bygrave, 1987; Manigart et al., 2004), which may further increase companies' resource base, improve their internal learning processes and absorptive capacity compared to stand-alone VCs. We therefore expect to observe a higher innovative output in companies backed by syndicates than in those financed by stand-alone VCs.

Our third objective is to investigate how syndicate diversity affects portfolio companies' innovation. If the positive effect of syndication derives from the combination of complementary resources, then diversity among syndicate partners should imply higher benefits from syndication. In this study, we focus, in particular, on the heterogeneity between independent and governmental VCs. These two types of VCs have access to different networks of contacts, have different skills and experience. They also differ in the type of support they provide to their portfolio companies (Luukkonen et al., 2013). Finally, heterogeneity in teams is often associated with more innovation (e.g., Bantel and Jackson, 1989; Van der Vegt and Janssen, 2003). We thus expect to observe an additional innovation output in heterogeneous syndicates rather than in homogeneous syndicates.

To analyze these three issues, we rely on a novel and extensive dataset of 834 young European biotechnology and pharmaceutical companies, 128 of them being VC-backed. Our findings indicate that the innovation output of companies financed by independent VCs increases significantly faster than that of both non-VC-backed companies and of companies financed by governmental VCs. The innovation output of companies backed by an average syndicate of VCs does not seem to increase much faster than that of companies backed by a stand-alone VC. However, our findings suggest that if the syndicate is heterogeneous, it is more effective in supporting the innovation activity of portfolio companies than a stand-alone VCs. These results are robust to different sampling and estimation strategies, including controls for the quality of the innovation output, the observable and unobservable heterogeneity of target companies, and the endogeneity of VC investments and VC forms.

This paper adds to several strands of literature. We contribute to the literature studying the effectiveness of governmental VCs. The role of governmental VCs in supporting knowledge-based companies is heavily discussed both in the academic literature and among practitioners. More systematic research in this area is needed (e.g. Lerner, 2009) because most previous work is limited in scope as it typically focuses on one particular government program or one particular country. Several studies deal with the question whether governmental VCs attract or crowd-out independent VCs (Leleux and Surlemont, 2003; Cumming and MacIntosh, 2006; Cumming, 2007; Brander et al., 2010; Cumming and Johan, 2009). Our results highlight that crowding-out may be particularly perilous for innovation in European biotechnology and pharmaceutical companies, since governmental VCs are less able to support these companies' innovative activity than the investors they may push out of the market. However, our findings also suggest that governmental VCs may be beneficial for innovation, under some circumstances. In particular, we argue that the impact of a governmental VC on innovation cannot be correctly assessed without taking into account the structure of the syndicate in which it is involved.

Thus, our results also contribute to the literature on syndication between independent and governmental VCs. Brander et al. (2012) analyze how syndicates between private and governmental VCs affect companies' performance using successful exits as performance indicator. The authors find that syndicates consisting of private and governmental VCs are more supportive of successful exits when a substantial fraction of funding comes from the independent VC. To the best of our knowledge, there is no study that would address the impact of syndicate structure between independent and governmental VCs on the innovative output of portfolio companies as we do. Beyond a different performance metrics, our study adds another important piece of evidence to the results found by Brander et al. (2012). The presence of non-VC-backed companies in our sample allows us not only to rank different forms of venture capital, but also to compare them against the base case of a non-VC backed company. Finally, our work contributes to the literature that investigates the role of diversity on innovation. This literature shows that diversity leads to more innovation at different levels: more culturally diverse groups tend to be more innovative (Van der Vegt and Janssen, 2003), and companies whose top managers are more diverse in terms of expertise tend to exhibit a more positive attitude towards innovation (Bantel and Jackson, 1989). The results from our study lead to the conclusion that the diversity in shareholder base (at least for active investors, such as VCs) may affect innovation as well.

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

2 THEORETICAL BACKGROUND AND HYPOTHESIS DEVELOPMENT

A company needs more than financial resources to succeed in innovation (Teece, 2009). First, it requires the ability to integrate physical assets and human resources (O'Sullivan, 2000). Founders and managers bring their stock of skills, know-how and experience into the company. Once the resource base has been built, the firm will need the dynamic capabilities of reconfiguring it to be able to generate innovations and meet its performance expectations (Eisenhardt and Martin, 2000). In this process, internal learning will be an important factor (Spender and Grant, 1996). Hereby, the company's absorptive capacity (Cohen and Levinthal,

1990) will be beneficial, by allowing the company to profit from the interactions with its suppliers and customers, public institutions, industry associations, and investors.

VCs' support to innovative activities of portfolio companies goes well beyond the mere provision of finance. Portfolio companies profit from VCs' industry-specific expertise (De Clercq et al., 2006), which contributes to the internal learning process and the exploitation of external knowledge. Companies also learn from the general business experience that VCs gained from their prior investments (Gupta and Sapienza, 1992), for example on strategies to turn their ideas into marketable innovative products. Companies may also benefit from VCs' networks (Fried and Hisrich, 1995) towards potential alliance partners, suppliers and customers when establishing, increasing and reconfiguring their resource base. Networks are particularly important for high-tech companies as an integral part of the discovery of opportunities, the securing of resources, and the legitimization of the company (Elfring and Hulsink, 2003). The access to VC's networks is crucial for the innovation process in biotech and pharmaceuticals, where the locus of innovation is often found in networks of learning, rather than in individual firms (Powell et al. 1996) and alliances between new entrants and incumbents are common (Gans et al. 2000). Importantly, VCs provide their companies with access to qualified workforce (De Carvalho et al., 2008) hereby increasing the companies' stock of skills, know-how and experience. VCs also support collaborations among their portfolio firms (Lindsey, 2008), which may be beneficial to knowledge spillovers among incumbents. Finally, VCs improve firm's dynamic capabilities, thus allowing a more effective reconfiguration of their resource base to pursue investment opportunities (Arthurs and Busenitz, 2006).

The ability to support the innovative activity of portfolio companies beyond the mere provision of finance differs substantially across VCs. Hsu (2004) shows that entrepreneurs are willing to pay (i.e. accept a lower valuation) to get access to a VC which may better support them after the investment. The difference in the support obtained by portfolio companies is particularly accentuated across different types of VCs, independent and governmental VCs in particular.

Independent and governmental VCs differ in their skills, objectives and governance structures, and these differences affect their ability to support their portfolio companies in their innovative activities. First, independent VCs have better skills than governmental VCs in supporting companies' resource base building, internal learning and increasing the absorptive capacity (Lerner, 2002b; Leleux and Surlemont, 2003; Luukkonen and Maunula, 2007; Luukkonen et al., 2013), which, in turn, may lead to a greater innovative output of these companies.

Second, the primary objective of independent VCs is to generate profits which result from successfully commercialized innovative ideas. Governmental VCs, however, follow a broader set of goals, such as supporting a stable economic and regional development (see Lerner, 2009 and Appendix 3). Consequently, more innovations might be generated in companies backed by independent VCs than in companies backed by governmental VCs.

Third, due to the structure of their fees (Jääskeläinen et al., 2007) independent VCs have stronger incentives than governmental VCs to support companies' resource base building, internal learning and absorptive capacity, which, in turn, may lead to a more substantial increase in companies' innovative output. In line with these arguments, Bottazzi et al. (2008) find that independent VCs are more active than governmental VCs in supporting their portfolio companies.

We summarize this discussion in our first hypothesis:

H1: Independent VCs increase more than governmental VCs the innovation output of portfolio companies over that of non-VC-backed companies.

The next aspect that we want to address is how syndication affects innovative output. First, syndicates are able to provide more financial resources for costly R&D (as a pre-requisite for innovative output) than stand-alone VCs (Manigart et al., 2004; Lockett and Wright, 1999; Hopp, 2010). Second, syndication among VCs is also beneficial to innovations because it allows the combination of non-financial resources (Bygrave, 1987; Manigart et al., 2004). A syndicate partner delivers a second opinion on company future prospects in the screening and selection phase (Casamatta and Haritchabalet, 2007; Lerner, 1994). During the investment phase, different syndicate members contribute their unique skills, knowledge, experience and networks. The combination of these complementary non-financial resources may result in a higher value-added by a syndicate compared to stand-alone VCs (Cumming and Walz, 2010; Brander et al., 2002; Tian, 2012). The combination of different skills, knowledge, experience and networks will further increase companies' resource base, improve their internal learning and increase their absorptive capacity as well as dynamic capabilities compared to companies backed by stand-alone VCs. For example, companies backed by syndicates will have access to much broader networks towards potential alliance partners, suppliers, customers, public institutions, industry associations, further investors or qualified workforce.

Third, syndication enhances the likelihood of innovation due to reputational issues. Bachmann and Schindele (2006) argue that, in a syndicate, if one of the participating VCs steals the entrepreneurial idea, it is punished by a loss of reputation. Bachmann and Schindele (2006) conclude that syndication prevents VCs from stealing entrepreneurial ideas, which results in a higher likelihood of innovation in companies backed by VC syndicates compared to stand-alone VCs.

We conclude:

H2: Syndicates increase more than stand-alone VCs the innovation output of portfolio companies over that of non-VC-backed companies.

By combining the two dimensions of VC type and transaction structure, we obtain a series of distinct forms of venture capital investment. Independent and governmental VCs may carry out a stand-alone investment, lead a syndicate, or participate in a syndicate as additional partners. What makes this approach particularly interesting is that it allows us to distinguish two types of syndicates. On the one hand we have homogeneous syndicates, which are composed by only one type of VCs (independent or governmental). On the other we have heterogeneous syndicates, in which both types of VCs are present. The benefits stemming from resource complementarity will be particularly pronounced in heterogeneous syndicates for several reasons.

First, a company obtains access to a more complete network when it is financed by syndicate members which differ in terms of their acquaintances. Independent VCs can provide the company with unique contacts to qualified workforce, potential alliance partners, suppliers and customers while the governmental VC can serve as a link to public institutions and universities, which are less likely to be within the reach of independent VCs.

Second, independent and governmental VCs differ in the type of support they give to portfolio companies. As we mentioned above, the literature shows that independent VCs typically dominate governmental VCs in terms of the extent of their support to portfolio companies (e.g., Bottazzi et al., 2008). However, a more fine-grained analysis shows that while the support given by independent VCs tends to be more strategic and technological, the support provided by governmental VCs tends to rely more on signaling firm's quality to stakeholders and attracting additional financing (Lerner, 1999; Luukkonen et al., 2013). Accordingly, the combination of independent and governmental VCs' support may result in a more complete set of innovation-enhancing activities for portfolio companies.

Third, diversity in skills and objectives among VCs in a syndicate may, itself, be beneficial for innovation. The literature shows that group diversity in teams leads to more innovation (Van der Vegt and Janssen, 2003). Similarly, a seminal study by Bantel and Jackson (1989) finds that diversity in the area of expertise of members of the top management team is associated with a more positive attitude towards the adoption of innovation. To the extent to which these results may be generalized to diversity among VCs, we should expect heterogeneous syndicates to be more positively associated to innovation than homogeneous syndicates. The difference between governmental VCs and independent VCs is well illustrated by the time horizon of their investments. Independent VCs are under pressure to generate fast returns before a fund expires; this results in a substantial pressure on the management to achieve short-term goals which, if excessive, could harm innovation (Gompers, 1996) that typically requires an irreversible, and often long-term, commitment yielding highly uncertain returns. Governmental VCs, on the contrary, may commit to provide the long-term financing that is necessary to generate innovations but may lack the incentives to put the management sufficiently under pressure to deliver. The presence of a governmental VC may however increase the willingness of independent VCs to provide long-term financing as well. Such effect was demonstrated, for example, by Lerner (1999) for the US Small Business Innovation Research program or by Feldman and Kelley (2003) for the US Advanced Technology Program. In summary, the diversity between independent and governmental VCs in a heterogeneous syndicate may result in a combination of short-term pressure and long-term commitment which could be especially constructive for innovative activity.

We therefore expect the following:

H3: Heterogeneous rather than homogeneous syndicates increase the innovation output of their portfolio companies over that of companies invested by stand-alone VCs.

Despite the benefits that arise from complementarities between a governmental and an independent VC described above, still, the question may arise whether it pays for the independent VC to take a less experienced and less skilled governmental VC on board rather than another experienced independent VC with complementary skills and networks. Mella-Barral and Vaidyanathan (2012) deliver an argument why experienced VCs may be interested in syndication with less experienced partners. They argue that, in general, first round VCs may try to hold-up the entrepreneur in that they threat not to provide financing in later rounds. This non-provision has negative consequences for the entrepreneur, because it conveys a negative signal towards alternative outside VCs. This negative signal that first round VCs send is stronger when the first round VC is more experienced. Consequently, more experienced (independent) VCs may be inclined to involve less experienced (governmental) VCs in the first round in order to commit not to hold-up.

3 DATA AND DESCRIPTIVE STATISTICS

Our sample includes 834 VC-backed (128) and non-VC-backed (706) companies from the biotechnology (645) and pharmaceutical (189) industries from seven European countries

(Belgium, Finland, France, Germany, Italy, Spain, and United Kingdom). 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.

Biotechnology and pharmaceutical industries provide an attractive setting for investigating how different forms of venture capital financing affect innovation output, as reflected by changes in patent stock. In these industries, patents are considered most important as a device for protecting innovation (Hall, 2009), which makes patents a reasonably reliable measure of innovation. 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., 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.

Our main dependent variable is the increase in log patent stock between the year of the first VC investment t and year $t+\tau$.[1] As is customary, we compute the patent stock of sample companies as follows:

$$patent\ stock_t = patents_t + (1-\delta)\ patent\ stock_{t-1} \qquad , \qquad (1)$$

where $patents_t$ is the number of successful patent applications in a generic year t (i.e. the applications which eventually become granted patents) and δ is a depreciation rate which we set equal to 15% (see, e.g., Griliches, 1998).[2]

Our main dependent variable is the increase in patent stock in the years following the VC investment. Specifically, our dependent variables are computed as:

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[1] We base our analysis on the first VC investment in a company. We notice that in some cases the VC form may differ in a later round and that this later round may fall within the scope of our investigation period (time from t to $t+\tau$). For example, the lead VC may change from round to round (see Cumming and Dai, 2013) or the VC form may switch from a stand-alone to a syndicated one. So, if we have a company with a first round stand-alone investment and a second round syndicated investment two years later, we measure an effect of a first-round stand-alone investment in $t+3$, but the change in the patent stock between t and $t+3$ might be also affected by the syndicated investment in in $t+2$. We count 15 such cases in our sample. We devote attention to this issue in our robustness checks and panel regressions.

[2] A variety of depreciation rates are used in the literature: Griliches (1998), Hall et al. (2000) and Bertoni et al. (2010b) 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.

$$increase\ in\ patent\ stock_{\tau} = log(1{+}patent\ stock_{t+\tau}){-}log(1{+}(1{-}\delta)^{\tau}\ patent\ stock_{t}) \quad , \qquad (2)$$

where t is the time of the investment and $\tau=1,\ldots,5$.[3] The second term on the right-hand side of equation (2) represents the log patent stock that the company would have had in time $t+\tau$ if it had no further successful patent applications since the investment year. Equation (2) then defines the increase of the patent stock τ years after the investment, beyond the level that would be observed given the simple depreciation of the patent stock in place at time of investment.

Table 1 provides an overview of our sample by country, sector, and foundation period. 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 biotechnology.

[Insert Table 1 here]

The distribution of sample companies by foundation period exhibits an increasing trend over time, with 203 companies (24%) founded between 1984 and 1994, 283 (34%) between 1995 and 1999 and 348 (42%) between 2000 and 2004. The time trend is much more pronounced for VC-backed companies: only 8 VC-backed companies (6%) were founded before 1995, 56 (44%) between 1995 and 1999 and 64 (50%) between 2000 and 2004. This trend is consistent with the

[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.

relatively young history of the venture capital industry in Europe. The number and amounts of venture capital investments increased substantially in the late 1990s and early 2000s (see EVCA Yearbook, different issues). VC-backed firms in our sample are significantly younger than non-VC-backed firms. The average age of the two groups in 2008 was 8.94 and 10.94 years. On average, companies in our sample had 3.4 million Euro net annual sales (real 2008 level) and 24.5 employees when the company is at its median age (5 years), with no significant difference between VC-backed and non-VC-backed companies.

Table 1 also reports some descriptive statistics that highlight the extent to which 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 (see equation (1)) of VC-backed and non-VC-backed companies at median age (5 years). We find a very large and statistically highly significant difference in the average patent stock at median age, which was 1.11 for VC-backed companies and 0.26 for non-VC-backed companies.

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 each of the 128 VC-backed (i.e., treated) companies, we select (without replacement) one 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 described the matching procedure in Appendix 1 in more detail.

We report the result of the matching process in the last two columns of Table 1. As expected, the matched-control sample exhibits a distribution that is much closer to the VC-backed sample than that of the complete non-VC-backed sample. The distribution across countries and industries does not significantly differ between the VC-backed and the matched-control samples ($\chi^2(6) = 2.63$ and $\chi^2(1) = 0.20$, respectively). However, VC-backed companies were, on average, still significantly younger than their counterparts in the matched-control sample (t-statistic = -3.09). Despite its statistical significance, this difference is limited in magnitude: VC-backed companies had an average age of 1.52 years compared to an average of 2.82 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 importantly, 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 0.74 and 0.63, respectively.

In Table 2, we report the breakdown of the VC-backed sample according to different venture capital forms. First, we separate our sample in two mutually exclusive categories: independent VC investments and governmental VC investments. Each of the two categories includes stand-alone investments made by the relevant VC type and syndicates led by the relevant VC type (e.g.

independent VC investments include all stand-alone investments by independent VCs and all syndicated investments which are led by an independent VC).[4] Our sample is composed by 75 independent VC investments (59%) and 53 governmental VC investments (41%).

We distinguish between governmental and independent VCs on the basis of the characteristics of the management company. An independent VC is characterized a management company which operates independently from the providers of capital. Typically the independence of the management company is guaranteed by the establishment of a limited partnership in which the management company acts as general partner and the investors act as limited partners (Sahlman, 1990). A governmental VC is, instead, characterized by a management company the majority of which is appointed by the provider of capital, which is a supranational, national, regional or local public entity or university. The governance structure of governmental VCs does not shelter the management company from the clout of the entity which established the fund. It is important to highlight that what distinguishes governmental VCs from independent VCs is thus rather their governance structure than the origin of the capital they invest. We provide more information in Appendix 3.

Second, we split the sample based on the transaction structure: 97 investments (76%) are stand-alone, and 31 (24%) 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 29% in Europe). Finally, we split syndicates based on their homogeneity: 12 syndicates (39%) consist of one type of VC only (either governmental or independent), while 19 syndicates (61%) are heterogeneous (consisting of both independent and governmental VCs).

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[4] Appendix 2 gives details on how we determined the type of lead VC.

[Insert Table 2 here]

In Figure 1 we illustrate the mean increase in patent stock (see equation (2)) of sample companies along the classifications introduced in Table 2. Figure 1 provides some preliminary insights on the evolution of the increase in patent stock across different forms of venture capital. For reference, we also depict, in each panel, the increase in patent stock for the matched-control sample. Panel A suggests that 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 instead much higher for companies backed by independent VCs, in line with Hypothesis 1. In Panel B we observe that both syndicated and stand-alone investments lead to a steady increase in firms' patent stock 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 2). Finally, Panel C relates different forms of syndicated investments not only to matched-control companies, but also to stand-alone investments. 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 seems to be much greater, consistently with Hypothesis 3.

[Insert Figure 1 here]

4 EMPIRICAL ANALYSES

4.1 VC-backed companies and matched-control sample: main analysis

We start our empirical investigations by comparing the different VC forms to each other and to non-VC-backed companies. Table 3 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 patent stock computed as in equation (2) on different variables related to venture capital forms to test our Hypotheses 1-3. In each regression we control for the initial patent stock of the company. Blundell et al. (1995) show that, due to path dependence in innovation activity, the "entry patent stock" is very effective in capturing firm-specific unobserved differences in innovativeness (see also Ahuja and Katila, 2001; Dushnitsky and Lenox, 2005; Bertoni et al., 2010b). We also include in each regression company age (to account for the influence of maturity on patenting), country dummies (to capture country-specific time-invariant characteristics that may affect patenting) and year dummies (to account for effects that are caused by the changing technological and economic boundary conditions over time).

Panel A depicts the results for the patent stock in *t+5*. In Model 1, we compare companies backed by independent VCs and governmental VCs to the matched-control companies. Model 1 reveals that companies in which an independent VC takes the lead exhibit a significantly higher increase in patent stock than the matched-control group in years *t+2* to *t+5*. An average company backed in year *t* by a independent VC would expectedly have, in year *t+5*, a patent stock that is higher by 20.3% than in matched non-VC-backed companies (significant at 1%). 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 independent and governmental lead dummies is significant at the 10% level, indicating a higher increase in innovative output in companies backed by independent VCs than in companies backed by governmental VCs. These results are in line with our Hypothesis 1.

Model 2 compares syndicated and stand-alone investments to the matched control sample. In years *t+2* 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. An average company backed in year *t* by a syndicate of VCs would have, in year *t+5*, an expected patent stock higher than in matched non-VC-backed companies by 27.7% (significant at 1%). The coefficient of the stand-alone dummy is always insignificant, with the exception of year *t+5* where it becomes weakly statistically significant (at 10%), indicating that companies financed by stand-alone VCs do not perform better than matched-control companies. The difference between the coefficients of the syndicated and stand-alone dummy is statistically significant, indicating a higher increase in innovative output in companies backed by syndicates than in companies backed by stand-alone VCs. These results lend support to our Hypothesis 2.

Model 3 examines the impact of the syndicate structure. To address this question, syndicated investments are divided into two further subgroups: heterogeneous and homogeneous syndicates. In years *t+2* to *t+5*, 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+5*, an expected patent stock higher by 29.0% (significant at 5%). These results suggest that only companies financed by heterogeneous, and not by homogeneous, syndicates increase their patent stock more than matched-control companies.

Finally, in Model 4, we control jointly for the VC type, the transaction structure and the VC heterogeneity by introducing in the regression both the independent and governmental VC dummies and the heterogeneous and homogenous syndicates dummies. The positive and significant effects of an independent VC and of a heterogeneous syndicate found in previous models still hold. Also, governmental VC dummy and homogeneous syndicate dummy remain insignificant. However, the interpretation of the coefficients on the heterogeneous and homogeneous dummies differs from Model 3 because in Model 4 the independent and governmental VC dummies jointly capture the VC effect, while the heterogeneous and homogenous syndicate dummies jointly capture the syndicate effect vis-à-vis stand-alone investments.[5] Consequently, a positive coefficient on the heterogeneous dummy reflects a positive effect of a heterogeneous syndicate over a stand-alone investment. Consequently, our Hypothesis 3 is supported.

Panel B adds hypotheses tests for the years *t+1* to *t+4*, based on Model 4. Combined with the hypotheses tests from Panel A, these results suggest that independent VCs outperform governmental VCs in all years except the first one and heterogeneous syndicates outperform stand-alone VCs from the third year on, giving support to our Hypotheses 1 and 3. On the contrary, we do not find much support for our Hypothesis 2 as syndicates, on average, do not seem to outperform stand-alone VCs in the first four year after the investment.

[Insert Table 3 here]

4.2 VC-backed companies and matched-control sample: extensions and robustness checks

In this section, we analyze whether our results are robust towards alternative specifications and definitions of dependent variable (Panel A of Table 4) and towards alternative samples (Panel B of Table 4). We present results for the increase in patent stock in year *t+5* of specifications that include independent and governmental VC as well as heterogeneous and homogeneous syndicate as independent variables of interest (as in Model 4 in Table 3). In Model 1 patent stock is

[5] In order to test Hypothesis 2 in this setting, we test whether the coefficients of the two forms of syndication (homogeneous and heterogeneous) are jointly equal to zero (i.e. to the omitted category of stand-alone investments).

computed without discounting (i.e. δ=0, in equations (1) and (2)). Models 2 and 3 introduce different types of weights to capture patent quality. Quality weighted measures may more effectively capture the value of innovative output (see, e.g., Griliches, 1998; van Pottelsberghe and van Zeebroeck, 2011) than simple patent counts. In Model 2, we weight the patent stock by the number of IPC-classes, relating quality to the technological scope of the patent. In Model 3, we employ family-size weighted patent stock capturing the geographical scope of the patent. In Model 4, we estimate a specification in which company size is used instead of company age as control variable (we do not include both variables simultaneously because they are highly correlated). Model 5 uses a Tobit model to take into account the fact that our dependent variable is left-censored at zero.[6]

In Model 6, we perform an alternative matching process to account for possible differences in the selection criteria for independent and governmental VCs. Accordingly, we employ two separate survival models to estimate the probability that a company will receive its first round of independent 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 each independent VC-backed company with a non-VC-backed company with the closest probability (propensity score) of receiving investment from a independent VC. We then repeat the same procedure for governmental VC-backed firms (see Appendix 1 for more details). In Model 7, we include only VC-backed companies. In Model 8 we report the results of estimates excluding the

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[6] Although the Tobit model is appropriate for censored data such as ours, it is susceptible to misspecification (see, e.g., Nelson, 1981), which prevented us from using it for the main analysis.

UK to check whether the sample country with the largest venture capital activity drives the results. In Model 9, we restrict the sample to biotechnology companies only. Finally, in Model 10 we focus only on those companies in which the VC form does not change during the five years after the investment. Thus, we exclude companies, in which, for example, a single VC invested in the first round, but, the second round investment two years later was performed by a VC syndicate.

All models confirm our previous results that independent VCs outperform governmental VCs (only in Model 9, the different is only significant at the 11.4% level). Albeit an average syndicate performs better than a stand-alone investment only in six models (and the significance levels are often quite low), heterogeneous syndicates tend to outperform stand-alone deals in all models. In addition, homogeneous syndicates do not outperform stand-alone deals in any of the models.

[Insert Table 4 here]

4.3 Panel regressions, time-invariant heterogeneity, endogeneity

As a final step, we make use of the time dimension of our dataset and estimate different panel regression models on VC forms. This allows us to better control for unobserved heterogeneity and endogeneity. The sample includes all VC and all non-VC-backed companies. The results are reported in Table 5. We adapt the estimation strategy used in the previous sections to a panel setting, where repeated annual observations are used. Accordingly, we compute the dependent variable in each year as the log increase in patent stock beyond the discounted value of previous year's patent stock. From equations (1) and (2), the year-on-year increase in patent stock is easily derived as $log(1{+}patent_t)$. Again, only successful patent applications are considered in the calculations. The control variables include *age* and the lagged level of patent stock *log(1+patent*

$stock_{t-1}$). We model VC investments using the same categories of dummies as in Model 4 of Table 3. In this setting, however, the variables are modeled as step dummies, equal to 1 since the year after the investment, which means that we are implicitly assuming that the impact of VC on the innovative activity of portfolio companies is constant over time.

We estimate seven models using the same specification, but different assumptions about the structure of the error terms. In Model 1, we employ a pooled OLS regression. Model 2 presents the results of a random effect regression, while model 3 shows the outcomes from a fixed effects model. Model 4 is a random effects Tobit model, which controls for left-censoring. Models 5 and 6 control for possible endogeneity of VC investments. In Model 5, we use a two-stage least-squares random-effects estimator to control for the fact that our results on independent-led heterogeneous syndicates might be driven by unobserved time-variant heterogeneity (i.e., correlation with the idiosyncratic error term). We use the VC fundraising relative to GDP in the country and year of the observation as instrument. This variable proxies for the potential availability of venture capital in the country and year and should, other things being equal, be positively related to the likelihood that a firm obtains venture capital. At the same time, the level of VC fundraising will unlikely be correlated to the innovative output of a specific company in our sample. In Model 6 we employ the Hausman-Taylor estimator to control for the possible correlation between the dummy variables capturing VC forms and the individual-level random effect. Finally, in Model 7 we remove all observations in which the VC form differs from the initial one.

Results in Table 5 confirm that companies backed by independent VCs experience a boost in patenting over non-VC-backed companies and companies backed by governmental VCs and that heterogeneous syndicates are associated to a stronger increase in patenting that stand-alone investments, consistently with Hypotheses 1 and 3. These effects are largely statistically and economically significant. The only exception is the insignificant coefficient on the independent VC dummy in Model 3. The reason might be due to the fact that a large portion of VC-backed companies in our sample are invested at foundation. As a result, for all these companies the fixed effects absorbs the effect of VC. In all seven regressions, the coefficients on governmental VC and homogeneous syndicate remain statistically insignificant, consistently with our previous results from cross-sectional analyses. Syndicates outperform stand-alone VCs in four cases, giving only weak support to our Hypothesis 2.

[Insert Table 5 here]

5 CONCLUSION

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. Our findings lend support to the conclusion that, in terms of innovation output, (i) independent VCs strongly outperform governmental investors, (ii) syndicates, in general, do not significantly outperform stand-alone VCs, but (iii) syndicates between independent and governmental VCs strongly outperform stand-alone VCs. Moreover, firms backed by independent, but not governmental, investors and by heterogeneous, but not homogeneous, syndicates have higher innovative output than non venture-backed companies.

Our results help to better understand the role of governmental VCs in the process of generating innovations, and 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 independent investors, in this work we show that the mode of investment used by governmental VCs is also a key variable in the design of effective innovation policies. Specifically, to support innovation, governmental VCs should not invest on a stand-alone basis or join other governmental VCs but rather syndicate with independent VCs. Our findings lend support to the conclusion that otherwise the governmental injection will have no positive effect on innovation output.

Our research opens several interesting directions for future research. Given the importance of governmental VCs in European biotechnology and pharmaceutical industries, it would be important to examine and compare the different ways these investors operate. One interesting topic could be to investigate how the different governance structures of these VCs (see Appendix 3) reflect into different investment practices and post-investment innovative performance. Governmental VCs also differ in the constraints they face when investing: while some are required to co-invest with private partners, others are left more leeway in their investment decisions, which, again, will have effects on post-investment innovative performance. Another aspect which deserves specific attention is how the relationship between different types of VCs in a syndicate is moderated by their previous syndication experience. As the size of our sample does not allow us to study these aspects, we leave these issues to future research. A better understanding of these effects would contribute to finding a better design for governmental VCs.

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TABLES AND FIGURES

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

	All population	VC-backed	Non-VC-backed	Matched-control	VC-backed and matched-control
No. of companies	**834**	**128**	**706**	**128**	**256**
Distribution					
Belgium	63	15	48	14	29
Finland	59	14	45	11	25
France	121	10	111	12	22
Germany	195	47	148	40	87
Italy	42	4	38	12	16
Spain	89	12	77	11	23
United Kingdom	265	26	239	28	54
Biotechnology	645	105	540	101	206
Pharmaceuticals	189	23	166	27	50
Founded 1984-1994	203	8	195	30	38
Founded 1995-1999	283	56	227	39	95
Founded 2000-2004	348	64	284	59	123
Mean					
Age in 2008	10.63	8.94	10.94***		
Age at time of matching		1.52		2.82***	2.17
Sales at median age	3,423	2,187	3,636		
Sales at time of matching		898		692	798
Employees at median age	24.5	19.9	25.6		
Employees at time of matching		6.4		7.4	6.9
Patent stock at median age /	0.38	1.11	0.26***		
Patent stock at time of matching		0.74		0.63	0.68

Legend: *Age* is expressed in years. *Sales* are in thousands of Euros (deflated using CPI and expressed at the real 2008 level). *Employees* is the number of employees. *Patent stock* is the number of granted patents since the application year depreciated at 15%, computed as in equation (1). *** indicates differences in means significant at the 1% level (using t-test with unequal variances across groups). The median age is 5 years.

Table 2: Distribution and descriptive statistics on VC-backed companies

	Independent VC	Governmental VC	Stand-alone	Syndicate	Homogeneous syndicate	Heterogeneous syndicate
No. of companies	**75**	**53**	**97**	**31**	**12**	**19**
Distribution						
Belgium	7	8	9	6	2	4
Finland	7	7	13	1	0	1
France	7	3	8	2	0	2
Germany	30	17	35	12	4	8
Italy	2	2	4	0	0	0
Spain	6	6	10	2	1	1
United Kingdom	16	10	18	8	5	3
Biotechnology	57	48	78	27	8	19
Pharmaceuticals	18	5	19	4	4	0
Founded 1984-1994	4	8	11	1	1	0
Founded 1995-1999	36	16	37	15	5	10
Founded 2000-2004	35	29	49	15	6	9
Mean						
Age at time of investment	1.44	1.64	1.46	1.71	2.33	1.31
Sales at time of investment	898	897	864	1,013	1,763	663
Employees at time of investment	6.8	5.9	5.8	8.0	13.3	5.0
Patent stock at time of investment	1.01	0.36	0.81	0.53	0.54	0.51

Legend: *Age* is expressed in years. *Sales* are in thousands of Euros (deflated using CPI, expressed at the real 2008 level). *Employees* is the number of employees. *Patent stock* is the number of granted patents since the application year depreciated at 15%, computed as in equation (1). *Independent VC* indicates an independent venture capital investment. *Governmental* indicates a governmental venture capital investment. *Stand-alone* indicates a stand-alone venture capital investment. *Syndicate* indicates a syndicated venture capital investment. *Homogeneous syndicate* indicates a syndicate composed only of one VC type. *Heterogeneous syndicate* indicates a syndicate in which both independent and governmental VCs are involved.

Table 3: Venture capital forms and patent stock – basic regressions

Panel A: 5 years after VC involvement

	Model 1	Model 2	Model 3	Model 4
Independent VC	0.203***			0.174**
	(0.069)			(0.067)
Governmental VC	0.061			-0.014
	(0.050)			(0.065)
Syndicate		0.277***		
		(0.099)		
Stand-alone		0.092*	0.093*	
		(0.054)	(0.054)	
Heterogeneous syndicate			0.290**	0.263**
			(0.115)	(0.122)
Homogenous syndicate			0.245	0.132
			(0.174)	(0.174)
Age	-0.017***	-0.019***	-0.018***	-0.018***
	(0.006)	(0.007)	(0.007)	(0.006)
Initial patent stock	0.181***	0.184***	0.184***	0.175***
	(0.053)	(0.053)	(0.053)	(0.053)
Country dummies	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes
N	211	211	211	211
R^2	0.335	0.337	0.338	0.364
F	3.419	3.575	3.379	3.426
Independent VC= Governmental VC	0.059			0.018
Syndicate=Stand-alone		0.006	0.022	0.092

Panel B: 1-4 years after VC involvement, hypotheses tests

	1 year	2 years	3 years	4 years
Independent VC = Government VC	0.573	0.033	0.031	0.033
Syndicate = Stand-alone	0.151	0.265	0.116	0.166
Heterogeneous synd. = Stand-alone	0.865	0.164	0.040	0.060

Legend: An OLS regression with robust standard errors (White, 1980) is used. The number of observations for the 1-year, 2-year, 3-year, 4-year and 5-year model is 256, 255, 248, 236, and 211 respectively. The dependent variable is the increase in patent stock (in *t+5* for Panel A, between *t+1* and *t+4* in Panel B) over the discounted level of log patent stock in *t* and is computed as in equation (2). *Independent VC* indicates a firm invested by an independent VC or by a syndicate led by an independent VC. *Governmental VC* indicates a firm invested by a governmental VC or by a syndicate 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 independent and governmental VCs participate. *Homogenous syndicate* is equal to one for syndicates in which only one VC type participates. *Age* is the firm *log(1+age)* in *t*. *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. Standard errors are in round brackets and appear below the related coefficients. The tests at the bottom of Panel A report the p-values of the Chi-2 tests on *Independent VC = Government VC* and *syndicate =stand-alone*. Panel B shows hypotheses tests for Model 4 for the years *t+1* and *t+4*. The first line reports the p-values of the Chi-2 test corresponding to the hypothesis that the coefficients of independent VC and government VC are equal. The second line reports the p-values of the Chi-2 test corresponding to the hypothesis that the coefficient of both syndicate forms are jointly null (i.e. that the effect of syndicates is not different from that of the omitted category of stand-alone investments). The bottom line shows the p-value of the t-test corresponding to the null hypothesis that the coefficient of heterogeneous syndicates is zero (i.e. that heterogeneous syndicates are not different from the omitted category of stand-alone investments).

Table 4: Venture capital forms and patent stock - robustness checks

Panel A: Different specifications and definitions of the dependent variable

	Model 1	Model 2	Model 3	Model 4	Model 5
	Non-discounted	IPC classes weighted	Family size weighted	Control for size	Tobit model
Independent VC	0.242***	0.124**	0.326***	0.208***	0.615***
	(0.074)	(0.062)	(0.109)	(0.074)	(0.187)
Governmental VC	0.019	-0.026	0.060	0.017	0.264
	(0.073)	(0.066)	(0.120)	(0.075)	(0.205)
Heterogeneous syndicate	0.283**	0.235*	0.423**	0.239*	0.458**
	(0.132)	(0.138)	(0.214)	(0.125)	(0.219)
Homogeneous syndicate	0.155	-0.011	0.202	0.236	0.373
	(0.186)	(0.086)	(0.299)	(0.188)	(0.632)
Age	-0.020***	-0.012**	-0.031***		-0.059
	(0.007)	(0.005)	(0.011)		(0.046)
Initial patent stock	0.411***	0.197***	0.105*	0.136**	0.602***
	(0.043)	(0.064)	(0.054)	(0.059)	(0.106)
Size				0.004	
				(0.010)	
Country dummies	Yes	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes	Yes
N	211	211	211	152	211
R^2 (Pseudo R^2)	0.550	0.312	0.321	0.342	0.360
F (LR Chi-2)	13.557	2.315	3.581	3.604	139.92
Independent VC= Governmental VC	0.011	0.061	0.064	0.027	0.052
Syndicate=Stand-alone	0.095	0.209	0.138	0.094	0.031

Panel B: Different samples

	Model 6	Model 7	Model 8	Model 9	Model 10
	Alternative matching	VC-backed only	Excluding UK	Excluding pharma	Excluding switching syndicates
Independent VC	0.181***	0.132*	0.151*	0.116*	0.196***
	(0.065)	(0.070)	(0.078)	(0.067)	(0.073)
Governmental VC	-0.011	-	-0.017	-0.004	-0.052
	(0.063)	-	(0.074)	(0.069)	(0.080)
Heterogeneous syndicate	0.263***	0.250**	0.288**	0.270***	0.278**
	(0.119)	(0.116)	(0.144)	(0.096)	(0.129)
Homogeneous syndicate	0.116	0.232	-0.019	0.058	0.125
	(0.170)	(0.170)	(0.113)	(0.172)	(0.181)
Age	-0.014***	-0.040**	-0.020**	-0.023**	-0.014**
	(0.005)	(0.016)	(0.008)	(0.010)	(0.006)
Initial patent stock	0.171***	0.084	0.231***	0.181***	0.191***
	(0.044)	(0.080)	(0.064)	(0.048)	(0.056)
Country dummies	Yes	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes	Yes
N	212	100	173	167	196
R^2	0.365	0.466	0.381	0.418	0.388
F	4.178	4.001	3.115	5.561	3.440
Independent VC= Governmental VC	0.013	0.063	0.058	0.114	0.009
Syndicate=Stand-alone	0.086	0.071	0.109	0.021	0.096

Legend: We employ OLS regressions with robust standard errors (White, 1980), except for Model 5 in which a Tobit model with bootstrapped standard errors is used. The dependent variable is the increase in patent stock in year *t+5* over the discounted value of patent stock in year *t*, computed as in equation (2). Model 1 is computed by discounting the dependent variable using δ=0, instead of 15%. In model 2 the dependent variable is weighted by IPC classes. In model 3 the dependent variable is weighted by family size. In Model 4 size is used instead of age as regressor. Model 5 is estimated using a Tobit model. Model 6 is estimated using a separate matching process for firms backed by independent and governmental VCs as explained in Appendix 1. Model 7 includes only VC-backed companies. Model 8 excludes companies from the UK. Model 9 excludes all pharmaceuticals. Model 10 excludes 15 firms in which the form of VC was not stable during the 5 years after the first VC investment. *Independent VC* indicates a firm invested by an independent VC or by a syndicate led by an independent VC. *Governmental VC* indicates a firm invested by a governmental VC or by a syndicate led by a governmental VC. *Heterogeneous syndicate* is equal to 1 when both independent and governmental VCs participate. *Homogenous syndicate* is equal to one for syndicates in which only one VC type participates. *Age* is the firm log(1+age) in *t*. *Size* is the firm *log(1+total assets)* in *t*. *Initial Patent stock* is the firm's $log(1+patent\ stock_t)$. The last two lines in both Panels report the p-values of: the Chi-2 test corresponding to the hypothesis that the coefficients of independent VC and government VC are equal, and the Chi-2 test corresponding to the hypothesis that the coefficient of both syndicate forms are jointly null (i.e. that the effect of syndicates is not different from that of the omitted category of stand-alone investments). ***, **, and * indicate significance at the 1%, 5%, and 10% level, respectively. Standard errors are in brackets and appear below the relevant coefficients.

Table 5: Venture capital forms and patent stock - panel regressions

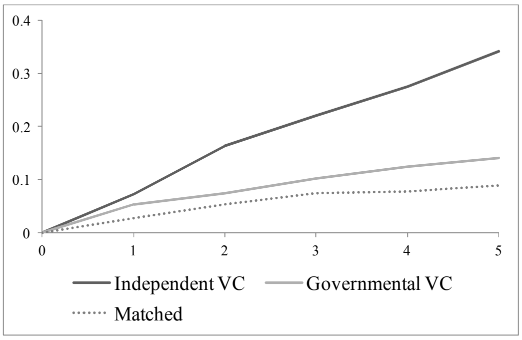
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
	Pooled OLS	Random effects (RE)	Fixed effects	Tobit RE	IV-RE	Hausman-Taylor	RE excl. switchers
Independent VC	0.060***	0.044***	0.003	1.326***	0.055***	0.041***	0.062***
	(0.007)	(0.011)	(0.033)	(0.245)	(0.014)	(0.013)	(0.012)
Governmental VC	0.012	0.006	-0.002	0.707**	0.009	0.006	0.016
	(0.008)	(0.012)	(0.026)	(0.306)	(0.016)	(0.015)	(0.013)
Heterogeneous syndicate	0.079***	0.080***	0.062*	1.147**	0.096***	0.075*	0.066***
	(0.016)	(0.023)	(0.034)	(0.503)	(0.031)	(0.044)	(0.025)
Homogeneous syndicate	-0.013	-0.017	-0.005	-0.559	-0.025	-0.019	-0.033
	(0.019)	(0.025)	(0.037)	(0.625)	(0.031)	(0.036)	(0.026)
Age	-0.000	-0.000	-0.001***	-0.036*	-0.000	-0.000	-0.000
	(0.001)	(0.001)	(0.000)	(0.019)	(0.001)	(0.001)	(0.001)
Country dummies	Yes	Yes	No	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	10,476	10,476	10,476	10,476	8,096	10,476	10,345
Groups	-	822	822	822	822	822	822
Overall R^2	0.041	0.040	0.028	-	0.039	-	0.040
Chi-2 (F for models 1 and 3)	11.57	356.90	3.16	129.22	213.78	340.75	343.59
Ind. VC= Gov. VC	0.000	0.012	0.891	0.079	0.016	0.045	0.006
Synd.=Stand-alone	0.000	0.002	0.130	0.045	0.432	0.173	0.008

Legend: The dependent variable is the log number of patent applications in year t computed as *log(1+patent applications$_t$)*. Model 1 is estimated using a pooled OLS model. Random effects are used in Model 2 and Model 7. Model 3 uses fixed effects. Model 4 uses a random-effect tobit model. Model 5 uses a two-stage least-squares random-effects estimator (external instrument is venture capital fundraising in the country and year). In Model 6, the Hausman-Taylor estimator is employed. In Model 7 firms are excluded from the sample once their syndicate form changes. *Independent VC* indicates a firm invested by an independent VC or by a syndicate led by an independent VC. *Governmental VC* indicates a firm invested by a governmental VC or by a syndicate led by a governmental VC. *Heterogeneous syndicate* is equal to 1 when both independent and governmental VCs participate. *Homogenous syndicate* is equal to one for syndicates in which only one VC type participates. *Age* is the firm log(1+age) in *t*. The last two lines report the p-values of: the Chi-2 test corresponding to the hypothesis that the coefficients of independent VC and government VC are equal, and the Chi-2 test corresponding to the hypothesis that the coefficient of both syndicate forms are jointly null (i.e. that the effect of syndicates is not different from that of the omitted category of stand-alone investments). ***, **, and * indicate that the coefficients are significant at the 1%, 5%, and 10% level, respectively. Standard errors are in round brackets and appear below the relevant coefficient.

Figure 1 – Patent stock evolution: Venture capital forms and the matched-control sample

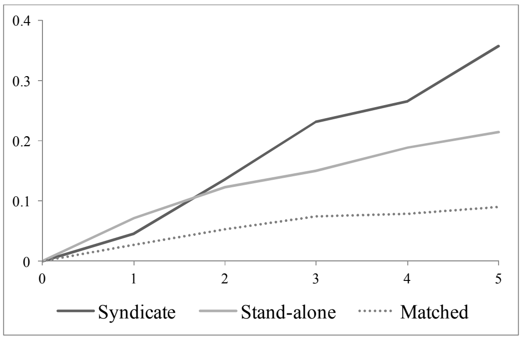
Panel A

Independent and governmental VCs



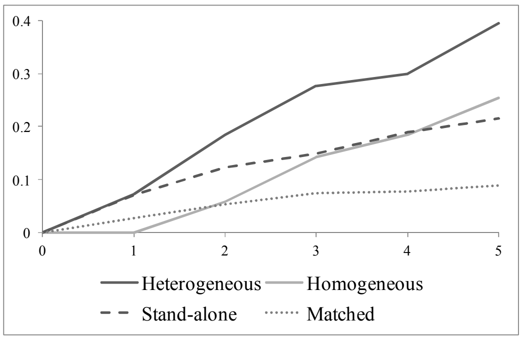
Panel B

Syndicate and stand-alone investments



Panel C

Homogeneous and 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 in equation (2). The horizontal axis represents the years since the first venture capital investment, τ=1,…,5.

APPENDIX 1: MATCHING

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 independent and governmental VCs to follow different selection criteria and re-estimate the model for independent and governmental VCs separately. The results, presented in Columns 2 and 3 in Table A.1, show that independent 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	Independent VC	Governmental VC
Patent stock	0.916***	0.958***	0.769***
	(0.172)	(0.173)	(0.218)
Employees	-1.305***	-1.591***	-0.984***
	(0.270)	(0.379)	(0.347)
Seed	2.810***	2.482***	3.758***
	(0.389)	(0.465)	(0.741)
Constant	-8.318***	-9.663***	-9.392***
	(0.531)	(1.010)	(0.822)
Country dummies	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes
N observations	7,451	7,785	7,889
N companies	834	834	834

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 an independent 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 *log (1+patent stock*$_{t-1}$*)*. *Employees* is *log(1+employees*$_{t-1}$*)*. *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.

APPENDIX 2: SYNDICATE LEADERSHIP

The VICO dataset contains information about the lead investor in the first round of investment for 107 (85.6%) of the 128 companies in our sample. This information is obtained by combining information provided by commercial databases (e.g. VentureXpert, Zephyr, Library house), EVCA yearbooks, national VC associations, and national specific databases (e.g. the RITA dataset in Italy, and WebCapitalRiesgo in Spain). For the remaining 21 companies we identify the lead investor using a hierarchical approach. First, if information about the amount invested by each syndicate partner is available, we identify as lead investor the one with the highest invested amount; this allows us to identify 7 (5.5%) lead VCs. If the information about the amount invested is unavailable, we identify as lead investor the one with the largest stake for the round; this allows us to identify 3 (2.3%) lead VCs. For the 11 (8.6%) residual cases we assign the leadership to the VC that is most closely located to the company (for each VC and company address, we find the respective latitude and longitude; in the next step we calculate geographical distance between each VC and the company based on the Vincenty's (1975) formula). Our results are robust towards excluding the companies for which the lead VC information was missing in VICO dataset.

APPENDIX 3: GOVERNMENTAL VCs

Governmental VCs are funds and investment vehicles set up by public entities, investing young high-tech companies, whose governance structure does not ensure the separation between the management company and the public entity setting up the fund. Often governmental VCs operate at a national or a local level with the objective to foster innovation. Examples of this type of governmental VC in our sample are: SITRA (Finland), Scottish Enterprise (UK), the Sociedades Para el Desarrollo Industrial (Spain), SRIB (Belgium), and Piemontech (Italy). SITRA is a public fund with the duty to promote stable and balanced development in Finland. Its investment objectives clearly reflect a political intent and it operates directly under the supervision of the Finnish Parliament. Similarly, Scottish Enterprise operates within the objectives of the economic strategy set by the Scottish Government, and the members of its board, with the exception of the Chief Executive, are directly appointed by the Scottish Ministers. Spain has established several Sociedades Para el Desarrollo Industrial, with the objective of sustaining entrepreneurship and innovation in different regions. The Sociedades Para el Desarrollo generally set up one or more holding companies, which may also be open to other investors (most of the times other public agencies, but sometimes also to private companies). The shareholders in the holding company elect its board of directors which oversees the investment committee, with no real separation between investors and the management company. A similar structure characterizes local investment agencies in Italy such as Piemontech (which invests in the Piedmont region), in Belgium such as the Societe Regionale d'Investissement de Bruxelles (which invests in the Brussels area) and in Germany such as Brandenburg Capital (which invests in the Brandenburg region).

Finally, some governmental VCs are created with the special aim of supporting the creation and development of academic spin-offs. This is the case, for instance of Uninvest (Spain), which has been funded by the Spanish agency for innovation of the Ministry of Industry, a dozen public universities and a public business incubator.

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FORSCHUNGSZENTRUM FZID

Universität Hohenheim
Forschungszentrum
Innovation und Dienstleistung
Fruwirthstr. 12
D-70593 Stuttgart
Phone +49 (0)711 / 459-22476
Fax +49 (0)711 / 459-23360
Internet www.fzid.uni-hohenheim.de