Venture capital and the investment curve of young high-tech companies☆

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ABSTRACT

We explore how and when venture capital (VC) alleviates the financial constraints of portfolio companies. Using a sample comprising 128 VC-backed companies and 233 non-VC-backed companies identified by propensity score matching, we estimate an error-correction model by accounting for the fact that the investment curve may be U shaped because of capital market imperfections. Our findings show that VC leads the investment curve to flatten in portfolio compa-nies, which indicates an alleviation of financial constraints. This effect, however, is economically and statistically significant only after companies receive a follow-on round of VC financing. Because follow-on rounds, on average, do not involve larger amounts invested but have stronger informative content than initial rounds of investment, we interpret this result to indicate the importance of VC certification for the alleviation of financial constraints in portfolio companies. Evidence regarding the access to credit by VC-backed companies confirms this interpretation of the results.

1. Introduction

In this study, we explore how and when venture capital (VC) alleviates the financial constraints of young high-tech portfolio companies. These companies typically have a limited availability of internally generated cash flow and are also severely exposed to frictions in capital markets that inhibit the access to other forms of external financing (Berger and Udell, 1998). Accordingly, young high-tech companies are exposed to financial constraints that restrain their growth and investment (Carpenter and Petersen, 2002a,b).

Several works in the literature have studied whether VC alleviates the financial constraints of portfolio companies. Overall, the empirical evidence indicates that VC reduces young high-tech companies' financial constraints (Bertoni et al., 2010, 2013; Engel and Stiebale, 2014). However, the literature is silent about how and when these financial constraints are eased. Accordingly, we aim to shed light on these issues.

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With respect to *how* VC may alleviate the financial constraints of portfolio companies, two channels must be considered. The first, and most obvious, is the injection of capital into the company. Companies receive substantial financial resources from VC investors (the average capital injection per round of financing in our sample is 4.484 million Euro), and this money can be used to exploit in-vestment opportunities regardless of the availability of external capital. The second channel is more subtle but is no less important: VC certification. Because of their screening capabilities, VC investors certify their portfolio companies by conveying a signal about their quality to capital markets (Hsu, 2004; Lee and Wahal, 2004; Megginson and Weiss, 1991; Nahata, 2008). Companies that receive VC certification should have easier access to capital markets and thus less exposure to financial constraints. The literature has not ex-plored which of these two channels is most important for VC-backed companies, a limitation that we aim to overcome with this paper.

A related research question is, *when* does VC alleviate the financial constraints of portfolio companies? In this work, we distinguish between initial and follow-on VC investment rounds. While initial and follow-on rounds differ only marginally in terms of the amount of capital injected,[1] they differ dramatically in terms of certification. VC investors decide whether to participate in a follow-on round based on information about the entrepreneur and the investment opportunity that is richer than the information available in the first round (Bergemann and Hege, 1998; Gompers, 1995). Being based on more complete information, a follow-on round is much more informative about the quality of a company than an initial round. Accordingly, differences in the effect of VC on financial constraints across rounds of investment are driven more by certification than by capital injection.

To study how and when VC relaxes the financial constraints of young high-tech companies, we analyze how and when VC changes the shape of their investment curve (IC), which is the relationship between capital investment and the availability of internal capital. Cleary et al. (2007) show that the IC is U-shaped and that its convexity is proportional to the severity of financial constraints deriving from capital market imperfections. Accordingly, by comparing the convexity of the IC between VC-backed and non-VC-backed com-panies, we may infer the extent to which VC relaxes the financing constraints of portfolio companies.

We estimate an error-correction model (ECM) for capital investment in which we allow the IC to be convex, and allow its shape to differ between VC-backed and non-VC-backed companies. In an augmented version of the model, we also distinguishing between companies in their initial round of VC and companies that have received follow-on rounds of financing. Our sample comprises 128 companies that received VC from independent VC firms, and 233 non-VC-backed companies that are identified by using propensity score matching. The sample companies, which are extracted from the VICO database (Bertoni and Martí Pellón, 2011), are based in six European countries (Belgium, Finland, France, Italy, Spain, and the UK), are independent at founding, operate in high-tech sectors, and were younger than 10 years at their first round of VC.

We summarize our findings as follows. First, when pooling initial and follow-on rounds of financing, we find weak evidence that the IC of VC-backed companies is less convex than the IC of non-VC-backed companies. However, when we distinguish between rounds of financing, we find that the effect of VC is statistically significant once invested companies receive a follow-on round. Moreover, our findings indicate that the amount injected has limited impact on the level of investment in VC-backed companies. Collectively, our results suggest that the effect of VC on the financial constraints of portfolio companies is mostly driven by certification.

The results are robust to changes in the specification, changes in the estimation methodology, and the inclusion of additional controls for growth opportunities. We also rule out two alternative explanations for our results: (i) that companies use capital injections to build a cash buffer that shelters them against shocks in cash flow and (ii) that age is a confounding factor driving the lower convexity of the IC in follow-on rounds. Finally, we show that VC-backed companies have better access to other forms of external financing (notably, long-term financial debt) after they receive VC, particularly after these firms receive a follow-on round of financing. This evidence is consistent with the notion that VC certification is important in reducing financial constraints.

In summary, we contribute to the literature in three ways. First, we show that, contrary to the implicit assumption in the extant literature (e.g., Manigart et al., 2003; Bertoni et al., 2010, 2013; Engel and Stiebale, 2014), the effect of VC on the financial constraints of portfolio companies is not immediate and is economically and statistically significant only after a company receives a follow-on round. Second, we show that certification drives the effect of VC on financial constraints and that capital injections, by contrast, have a limited impact on investment. Third, we overcome another important limitation in the extant literature on the impact of VC on the investments of portfolio companies, which typically assumes that the IC is linear. We show that the linear specification of the IC is misspecified in our sample, because of the substantial fraction of companies with negative cash flows. Our results indicate that the IC of young high-tech companies is U-shaped, suggesting that studies on the financial constraints of such companies should refrain from using a linear specification.

The paper proceeds as follows. In Section 2, we outline our theoretical framework. In Section 3, we illustrate the methodology that is used in the empirical analysis. In Section 4 we describe the sample and provide some descriptive evidence regarding ICs and VC financing for the sample companies. In Section 5, we report the results of the econometric models and provide robustness tests and additional evidence to support our interpretation. Finally, in Section 6, we summarize our main findings and suggest avenues for future research.

2. Theoretical framework

2.1. Financial constraints and corporate investment

If capital markets were frictionless, the distinction between internal capital and external capital would be irrelevant, and all sources of financing would have the same cost. When frictions are introduced into capital markets, internal and external capital

[1] Initial and follow-on rounds do not substantially differ in terms of the absolute capital injection (in our sample, on average, 4.276 million Euro are invested in initial rounds, and 4.694 million Euro are invested in follow-on rounds) and, relative to the size of the company, the capital injection is actually smaller in follow-on rounds.

cease to be perfect substitutes (Gertner et al., 1994). Information asymmetries between founders and external investors render the marginal cost of external capital higher than that of internal capital and lead investors to miss some investment opportunities that would be financed in a frictionless world, resulting in under-investment. This phenomenon is particularly severe in young high-tech companies (Carpenter and Petersen, 2002a; Hall, 2002).

In their seminal paper, Fazzari et al. (1988) argue that whereas the marginal opportunity cost of internal capital is constant, the marginal cost of external capital is upward sloped, and its steepness increases as a company's exposure to frictions in capital markets increases. Under these circumstances, one would expect the investments of companies with a steep capital supply curve (i.e., more financially constrained companies) to be more sensitive to cash flow (as a proxy for internal capital) than the investments of compa-nies with a less steep capital supply curve (i.e., less financially constrained companies). According to Fazzari et al. (1988), the invest-ment cash-flow sensitivity (ICFS) should then be a tool to gauge the severity of a company' s financial constraints. This paradigm has been adopted in numerous studies from various countries and for different types of companies (Hubbard, 1998).

However, the idea that higher financial constraints lead to higher ICFS is too simplistic. This argument was first made by Kaplan and Zingales (1997), who critiqued the work of Fazzari et al. (1988) by showing theoretically and empirically that companies that are extremely financially constrained can have a lower, not higher, ICFS than companies that are less financially constrained. Several more sophisticated empirical works have proved that Kaplan and Zingales' (1997) critiques are indeed well posed (e.g., Cleary, 1999, 2006; Hovakimian, 2009; Kadapakkam et al., 1998). As noted by Allayannis and Mozumdar (2004), the results in Kaplan and Zingales (1997) are largely caused by companies in distress with negative cash flows. When these observations are excluded from the sample, the estimated ICFS for financially constrained companies is much higher, and in line with Fazzari et al. (1988). Using the terminology of Guariglia (2008),studiesthatsupporttheFazzari et al. (1988) approach typically classify companies based on their external financial constraints (i.e., the capital market imperfections that they face), whereas studies that support the Kaplan and Zingales (1997) approach typically classify companies based on their internal financial constraints (i.e., their inability to produce sufficient internal capital).

Cleary et al. (2007) develop a theoretical model of debt-financed investment that helps explain the relationship between internal and external financial constraints. The model is developed under four main assumptions: that external capital is costlier than internal capital; that the cost of external capital is determined endogenously (depending on the company's financial situation and investment opportunities); that investment is scalable; and that liquidation is costly. Cleary et al. (2007) show that under these assumptions the IC is U-shaped in the presence of external financial constraints, as shown in Fig. 1.

When external financial constraints are present but internal financial constraints are weak (i.e., the cash flow is insufficient to fund the company's optimal investment level but is sufficient to keep the company out of distress), a marginal increase in cash flow deter-mines a marginal increase in investment (i.e., the ICFS is positive). However, when internal financial constraints are strong, the ICFS is negative and a marginal decrease in cash flow translates into an increase in investment.

The convexity of the IC is proportional to the magnitude of the external financial constraints (see Cleary et al., 2007, Section IV.D). Thus, the alleviation of external financial constraints will lead to a reduction in the convexity of the IC. In Fig. 1, if the external financial constraints are reduced a company moves from a steep (solid line) to a shallow (dotted line) IC, and accordingly, the ICFS corresponding to any level of cash flow is reduced in absolute terms. In other words, the alleviation of external financial constraints leads to a change in the IC that converges, as external financial constraints vanish, toward the first-best investment level (I^*).

The empirical evidence supports the view that the IC is non-monotonic with respect to the availability of internal funds in the presence of capital market imperfections. Consistent with the prediction of their model, Cleary et al. (2007) empirically document a negative ICFS for the sub-sample of negative cash flow observations and positive ICFS for the sub-sample of positive cash flow observations. Further, Bhagat et al. (2005) document negative ICFS for distressed companies with operating losses and explain this result by demonstrating that the increase in the investment in financially distressed companies is funded by equity claimants that

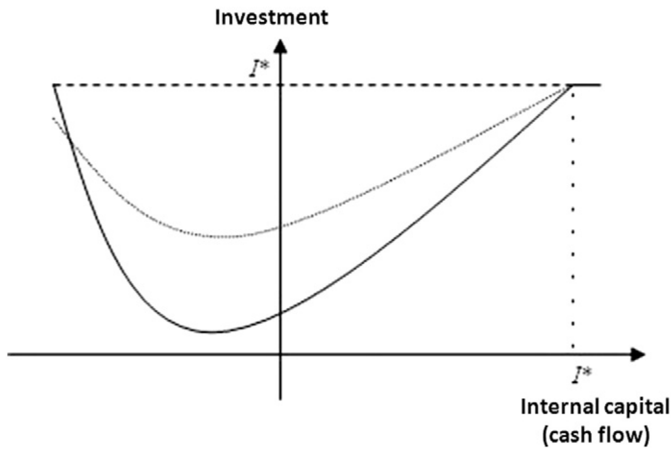

Fig. 1. The investment curve corresponding to the different levels of external financial constraints. The figure depicts the IC corresponding to two different levels of external financial constraints. The horizontal axis measures the extent of the internal capital (cash flow). The vertical axis is the level of investment. The horizontal dashed line represents the first-best level of investment. The solid curve is associated to a higher level of the external financial constraints than the dotted curve.

gamble on the company' s resurrection. Hence, with respect to Cleary et al. (2007), the authors find an additional explanation for the U-shaped IC. Using a panel of 24,184 UK companies for the 1993–2003 period, Guariglia (2008) studies the extent to which the ICFS differs among companies facing different degrees of internal and external financial constraints. The results suggest that when the sample is split on the basis of the internal capital available to the companies, the IC is U-shaped. By contrast, the ICFS tends to increase monotonically with the degree of the external financial constraints faced by the companies. Combining the internal with the external financial constraints, Guariglia (2008) finds that the ICFS is strongest for externally financially constrained companies that have a relatively high level of internal capital. Hovakimian (2009) finds that ICFS is non-monotonic with respect to internal funds and to a set of company characteristics that are associated with external financial constraints (size, asset tangibility, financial slack, and credit rating). Moreover, companies with negative ICFS appear to be the most financially constrained companies.

2.2. Venture capital and the financial constraints of young high-tech companies

Young high-tech companies are severely exposed to financial market frictions (Denis, 2004). First, their technology-intensive nature requires outlays that often exceed the founders resources (Berger and Udell, 1998). Second, the internally generated cash flow is limited and often negative for the first few years after founding (Brown et al., 2009). Third, the most typical contractual mechanisms to circumvent information asymmetries are weakened by the intangibility of young high-tech companies' assets (Gugler, 2003). According to the terminology introduced in the previous section: both the internal and the external financial constraints are substantial for young high-tech companies.

The ideal candidate to alleviate the financial constraints of young high-tech companies is VC. Because of their scouting and monitoring capabilities, VC investors are able to effectively address the information asymmetries in young high-tech companies (Kaplan and Stromberg, 2001). In addition, the governance structure of VC investors gives them explicit (Sahlman, 1990) and implicit (Gompers, 1996) incentives to boost the performance of their portfolio companies, allowing the companies to realize their hidden potential as quickly as possible. Moreover, VC conveys a signal to other, uninformed, parties, certifying the company's quality (Lee and Wahal, 2004; Megginson and Weiss, 1991; Stuart et al., 1999) and facilitating its access to additional finance in the form of financial debt, operational debt, or external equity (Vanacker et al., 2011).

VC can be reasonably expected to reduce the financial constraints of portfolio companies. In the extant literature, this hypothesis is tested empirically under the assumption that the IC for both non-VC-backed and VC-backed companies is linear, and that the ICFS is increasing with the degree of external financial constraints. If we limit the scope of VC to investments in early stage deals in high-tech companies made by independent VC investors, the literature is unanimous in showing that the positive ICFS is reduced after VC invest-ment. For instance, using a sample of 379 Italian young high-tech companies, Bertoni et al. (2010) find that ICFS ceases to be statisti-cally significant once these companies are backed by an independent VC investor. Specifically, they show that non-VC-backed companies exhibit positive ICFS. VC financing increases the investment rate, and when companies receive VC financing from an inde-pendent VC investor, ICFS disappears. A similar result is obtained by Engel and Stiebale (2014), who estimate a dynamic version of a sales accelerator model on a sample of companies in the UK and France. Consistent with the view that small and medium-sized enterprises (SMEs) are mostly affected by financial constraints, the authors show that expansion financing is associated with higher investment and lower ICFS for these companies. Using a sample of Spanish companies, Bertoni et al. (2013) confirm the significant reduction in ICFS in SMEs at the expansion stage after they receive VC. However, these studies also show that the type of investor, the characteristics of the company, and the type of investment play an important moderating role in the effect of VC on financial constraints. Bertoni et al. (2010) show that corporate VC investors, contrarily to independent VC investors, do not exhibit any ability to relax a firm's financial constraints. Moreover, Bertoni et al. (2013), Engel and Stiebale (2014) and Ughetto (forthcoming) show that ICFS increases substantially when the deal is a buyout, rather than an early stage VC investment, especially for companies in medium-tech or low-tech sectors.[2]

The extant literature on the impact of VC on the IC of portfolio companies suffers from two limitations, which we aim to overcome in this paper. First, because both internal and external financial constraints are substantial for young high-tech companies, the IC of these companies is likely to be non-monotonic. However all the studies in the literature on the impact of VC on financial constraints assume that the IC is linear, implying that these studies are based on an econometric specification that is potentially misspecified. The risk of misspecification is proportional to the fraction of companies with negative cash flows in the sample (Allayannis and Mozumdar, 2004), which means that studies on early stage VC investments in young companies are particularly at risk. In this paper, by allowing the IC to be U-shaped, we do not suffer from this limitation.

Second, little is known about when VC relaxes the external financial constraints of portfolio companies. The literature (e.g., Bertoni et al., 2010, 2013; Engel and Stiebale, 2014; Manigart et al., 2003) implicitly assumed that the effect of VC on financial constraints should be immediate and that the alleviation of financial constraints should be visible after the initial round of investment and remain constant thereafter. In this work, we study if the effect of VC on the IC of portfolio companies differs between the initial and the follow-on rounds.

Distinguishing the impact of initial and follow-on VC investment rounds also allows us to shed light on how VC relaxes the financial constraints of its portfolio companies. Apart from direct capital injections, VC can alleviate the financial constraints of portfolio companies through certification. If VC conveys a signal to the capital market about a firm's quality, a company certified by VC could be subject to fewer external financial constraints and should have easier access to additional external financing. The initial

[2] Manigart et al. (2003) first analyzed how ICFS is moderated by VC. Their findings show that ICFS is, on average, positive and significant before VC investment but that it is still positive and significant, and even higher, after VC investment. A possible explanation for this puzzling result is that the study by Manigart et al. (2003) pools together types of VC investments that are extremely different in their mode and objectives and, accordingly, in their impact on ICFS.

round and the follow-on rounds differ substantially in terms of VC certification. We argue that the effect of VC certification on financial constraints is particularly significant after companies receive a second round of financing. The entrepreneurial finance literature stressed the importance of staged capital injections in limiting problems associated with information asymmetries. Staging creates an option to abandon a disappointing project (Sahlman, 1990). As noted by Bergemann and Hege (1998), a VC investor decides whether to participate in a follow-on round of financing based on all of the information it acquired over time about the entrepreneur and the company. If, after the initial round of financing, negative information about future returns is observed, a second round of financing becomes less likely. Accordingly, a second round of financing can be much more informative about the "quality" of a company than the initial round such that, more rounds of financing increase the likelihood of a successful exit. Indeed, Gompers (1995) finds that the most successful companies receive more total financing and a greater number of rounds than less successful companies. To this extent, with respect to the initial round of financing, the follow-on rounds convey an additional signal about the future profitability of a company to capital markets. Consequently, to the extent to which certification plays a role in alleviating financial constraints, we would expect VC-backed companies that receive follow-on rounds of financing to exhibit a flatter IC.

3. Empirical methodology

3.1. Econometric model

Recent works propose the use of ECM for capital investment (Bond et al., 2003; Guariglia, 2008). The ECM is a reduced-form model of the firm's demand for capital in which the long-run desired level of the capital stock is modeled as a log-linear function of the output and the user cost of capital. The speed of adjustment of the capital stock to its desired level is derived from the data rather than imposed a priori. Further, the ECM assumes a general auto-regressive distributed-lag model that allows the relevant short-run investment dynamics to be empirically determined (Bond et al., 2003). The main strength of the ECM is therefore its flexibility, because it does not impose restrictions on short-run dynamics associated with particular adjustment cost specifications, in sharp contrast to structural models such as the Euler equation.[3] Furthermore, contrary to other rival models of capital investment (e.g., Tobin's Q model), the ECM does not require stock market information about a company, which would be unavailable for a sample of unlisted companies such as ours.[4]

In estimates of models on capital investment, particular care should be given to the potential endogeneity of cash flows, because the results could be biased if cash flows are correlated to investment opportunities. To determine whether endogeneity of cash flows is an issue in our sample, we follow the procedure suggested by Bond et al. (2003). The logic is as follows: investment opportunities are correlated with expected growth opportunities. Although expected growth opportunities are not observable, actual growth is. Thus, the endogeneity of cash flows can be inferred by determining the extent to which cash flows predict future observed growth. Following Bond et al. (2003), we estimate a VAR(2) model in which sales growth is regressed against past sales growth, investments and cash flows. We also include a full set of industry, country and time dummies in the model. We estimate the model on the full sample and on various sub-samples, such as non-VC-backed companies only; all companies, but excluding VC-backed companies after they receive VC; and all company and years, but introducing a moderating effect of VC on the cash flow coefficients. Overall, our results show that, as expected, past investments predict future growth (i.e., companies anticipate future growth opportunities and calibrate their invest-ments accordingly). However, the coefficients of the cash flow variables are never significantly different from zero at conventional con-fidence levels (10% and below). These results reassure us about the validity of the assumptions of the ECM.

3.2. Specification

We use a quadratic form for the investment equation, which allows us to test the presence of a non-monotonic IC for the compa-nies in our sample.[5] Our baseline ECM specification is as follows:

$$\begin{aligned}\frac{I_{i,t}}{K_{i,t-1}} &= \lambda_1 \frac{I_{i,t-1}}{K_{i,t-2}} + \lambda_2 \Delta y_{i,t} + \lambda_3 \Delta y_{i,t-1} + \lambda_4 \left(k_{i,t-2} - y_{i,t-2}\right) + \\ &+ \lambda_5 \frac{CF_{i,t}}{K_{i,t-1}} + \lambda_6 \left(\frac{CF_{i,t}}{K_{i,t-1}}\right)^2 + \xi D_i + \phi Z_t + \varepsilon_{i,t}.\end{aligned} \quad (1)$$

In Eq. (1), $I_{i,t}$ is the capital investment of company i in period t, measured by the increase in the book value of the tangible and intangible assets before depreciation; $K_{i,t}$ is the end-of-period t book value of company i's total assets, and $k_{i,t}$ is its logarithm; $CF_{i,t}$ is company i's cash flow in period t after taxes but before dividends; and $y_{i,t}$ is the logarithm of company i's sales during period t. Regarding the control variables, D_i is the company fixed effect and Z_t is a vector of year fixed effects. Finally, $\varepsilon_{i,t}$ is an error term. We expect

[3] The Euler equation approach is based on a structural model that is explicitly derived from a dynamic optimization problem that captures the influence of the current expectations of the future profitability on current investment decisions (Abel, 1980; Bond and Meghir, 1994). However, this model assumes a symmetric, quadratic structure of adjustment costs that is very restrictive. In fact, the estimates of these structural models often have the wrong signs for the key explanatory variables or imply implausibly slow speeds of adjustment (Bond et al., 2003).

[4] In the early literature, Tobin's Q is used to capture investment opportunities. Nevertheless, dissatisfaction with the empirical performance of Tobin's Q and the impossibility of using it in samples comprising unlisted companies have led to an interest in models such as the ECM and the Euler equation (Bond and Van Reenen, 2007).

[5] It is worth pointing out that Cleary et al. (2007) predict that the relation between investment and cash flow is quasi-convex, but not necessarily quadratic. In Section 5.2 we compare the results from the quadratic specification with the results obtained using a piecewise linear specification.

$\lambda_6 > 0$, indicating that the IC is convex. Eq. (1) is a useful means to validate the extent to which the model by Cleary et al. (2007) is well suited for the sample that is used in this work. Since we aim to understand whether, absent VC, young high-tech companies in our sample have a U-shaped IC, we estimate Eq. (1) on a subsample that includes only firm-year observations in which a VC investor is not present (i.e., non-VC-backed companies, and VC-backed companies before VC investment).

To detect the effect of VC financing on the IC of the sample companies, we estimate an augmented version of Eq. (1) in which we introduce a series of moderating effects of VC on the firm's investment for the full sample. The specification is as follows:

$$\begin{aligned}\frac{I_{i,t}}{K_{i,t-1}} = {} & \lambda_1 \frac{I_{i,t-1}}{K_{i,t-2}} + \lambda_2 \Delta y_{i,t} + \lambda_3 \Delta y_{i,t-1} + \lambda_4 \left(k_{i,t-2} - y_{i,t-2}\right) + \\ & + \lambda_5 \frac{CF_{i,t}}{K_{i,t-1}} + \lambda_6 \left(\frac{CF_{i,t}}{K_{i,t-1}}\right)^2 + \xi D_i + \phi Z_t + \\ & + \theta_1 \frac{A_{i,t}}{K_{i,t-1}} + \theta_2 VC_{i,t} + \theta_3 VC_{i,t} \frac{CF_{i,t}}{K_{i,t-1}} + \theta_4 VC_{i,t} \left(\frac{CF_{i,t}}{K_{i,t-1}}\right)^2 + \varepsilon_{i,t}.\end{aligned} \quad (2)$$

Eq. (2) allows us to assess the potential effect of VC financing discussed in Section 2.2. First, we include the amount of the capital injection received in year t by company i from VC investors ($A_{i,t}$). A capital injection $A_{i,t}$ increases the firm's availability of capital, which could affect its investment. The extent to which the amount invested by VC translates into a change in investment is captured by the coefficient θ_1.

Second, the coefficients θ_2, θ_3 and θ_4 capture the extent to which VC alters the shape of the IC: θ_2 captures the vertical shift in the investment level of VC-backed companies; the parameters θ_3 and θ_4 measure changes in the shape of the IC attributable to the presence of VC. As mentioned in Section 2.2, VC financing should reduce information asymmetries between a company and the capital markets, thus lowering the company's external financial constraints. Therefore, lower information asymmetry should be associated with a reduction in the convexity of the IC, $\theta_4 \leq 0$ If VC completely alleviates external financial constraints, the IC would become flat and we should expect: $\lambda_5 + \theta_3 = 0$ and $\lambda_6 + \theta_4 = 0$.

In Section 2, we argued that the allegedly beneficial effects of VC financing in alleviating external financial constraints should be more pronounced in the follow-on rounds, owing to their higher information content. To disentangle the mechanism underlying the more pronounced effect in the follow-on rounds, we estimate Eq. (3), which distinguishes the effect of VC after the initial round and after the follow-on rounds of financing:

$$\begin{aligned}\frac{I_{i,t}}{K_{i,t-1}} = {} & \lambda_1 \frac{I_{i,t-1}}{K_{i,t-2}} + \lambda_2 \Delta y_{i,t} + \lambda_3 \Delta y_{i,t-1} + \lambda_4 \left(k_{i,t-2} - y_{i,t-2}\right) + \\ & + \lambda_5 \frac{CF_{i,t}}{K_{i,t-1}} + \lambda_6 \left(\frac{CF_{i,t}}{K_{i,t-1}}\right)^2 + \xi D_i + \phi Z_t + \\ & + \theta_1 \frac{A_{i,t}}{K_{i,t-1}} + \sum_{r=I,F} \left(\theta_2^r VC_{i,t}^r + \theta_3^r VC_{i,t}^r \frac{CF_{i,t}}{K_{i,t-1}} + \theta_4^r VC_{i,t}^r \left(\frac{CF_{i,t}}{K_{i,t-1}}\right)^2\right) + \varepsilon_{i,t}.\end{aligned} \quad (3)$$

Eq. (3) highlights whether the effect of VC depends on the investment round. The superscript r distinguishes between the initial and the follow-on rounds: $VC_{i,t}^I$ is a dummy variable that is equal to one between the year of the initial investment and the year of first follow-on round of financing. $VC_{i,t}^F$. is a dummy variable that is equal to one after the company receives a follow-on round of financing. Accordingly, the coefficients θ_2^I and θ_2^F measure the vertical shifts in investment after the initial round of VC financing (until the company receives a follow-on round) and after follow-on rounds, respectively. The coefficients θ_3^I, θ_4^I, θ_3^F and θ_3^F capture the changes in the IC after the initial round (superscript I) and a follow-on (superscript F) round. Again, we test whether VC financing flattens the IC by performing the following linear tests: $\lambda_5 + \theta_3^I = 0$ and $\lambda_6 + \theta_4^I = 0$ after the initial round of financing and $\lambda_5 + \theta_3^F = 0$ and $\lambda_6 + \theta_4^F = 0$ after the follow-on rounds.

3.3. Estimation methodology

Eqs. (1), (2) and (3) include the lagged dependent variable among the covariates. Accordingly, pooled ordinary least squares and fixed-effects estimations yield, respectively, upwardly and downwardly biased estimates of λ_1 and unpredictably biased estimates of all of other parameters (see Bond and Meghir, 1994; Bond and Van Reenen, 2007; Bond et al., 1999). To solve this problem, we resort to the generalized method of moments (GMM) estimation. Specifically, in this work we adopt a two-step SYS-GMM estimation (Arellano and Bover, 1995; Blundell and Bond, 1998) with finite-sample correction (Windmeijer, 2005). The SYS-GMM estimator uses the lagged differences of the endogenous variables as instruments for levels equations, in addition to the lagged levels of the endogenous variables as instruments for first-differences equations (for an application in the context of an ECM specification, see Bond and Lombardi, 2006).

The actual set of instruments that is used in the GMM estimation depends on the assumptions about the nature of the endogeneity that affects each variable in the model. We follow the most conservative assumption that all the covariates are potentially endogenous with the exception of the time, industry, and country dummies, which are all assumed to be exogenous. More important, treating the VC-related variables as potentially endogenous allows us to control for biases arising from potential correlation between VC investments and unobservable factors that may influence a firm's investment. To reduce the number of moment conditions of the model and to avoid excessive over-identification, we limit the time span of the instruments to *t*-4. We test the validity of the over-identifying restrictions using Hansen tests.

Some transformations must be performed on accounting ratios before a meaningful parametric model can be estimated. All of the ratios that are included in Eqs. (1), (2) and (3) are normalized by the beginning-of-period stock of fixed and intangible assets. Because the companies in our sample are relatively young and small, this value is sometimes very small, producing extremely skewed and leptokurtic distributions of the variables. Since the presence of these outliers could severely bias our results, we winsorized all of the variables with a 2% cut-off for each tail (Dixon, 1960). This approach is useful because it reduces the impact of the outliers and allows us to use a larger number of observations than would be possible if the outliers were deleted. Furthermore, this approach is commonly used in studies on ICs (e.g., Bertoni et al., 2010; Cleary, 1999, 2006).

4. Sample

The sample that is used in this work is extracted from the VICO database. This database has been developed by nine European research centers through a project funded by the European Commission within the 7th Framework Program. The database includes two strata of companies: the first stratum is a sample of VC-backed companies and the second is a control group of non-VC-backed companies. The database includes detailed information about 8370 companies (759 of which are VC-backed) operating in seven European countries: Belgium, Finland, France, Germany, Italy, Spain, and the United Kingdom. The data are collected by local teams from each country (using a variety of commercial and proprietary sources) and checked for reliability and consistency by a centralized data collection unit. All of the companies that are included in the database are young (i.e., less than 20 years of age), and they operate in a high-tech industry (i.e., Biotech & pharmaceutical, ICT manufacturing, Internet, Software, TLC services, Other high-tech manufacturing, and R&D services). A detailed description of the sampling process can be found in BertoniandMartíPellón(2011).

The VICO database also includes investments made by VC firms with different organizational forms (independent VC, corporate VC, bank-affiliated VC, governmental VC, and university VC funds). As discussed in Section 2.2, different types of VC are likely to have different impacts on the IC of their portfolio companies. While the variety of organizational forms for VC firms is clearly a promising subject for future research, in this paper we decided to focus on the largest (and, to some extent, the most important) category of VC investors: independent VC firms, which are characterized by a management company (general partner) that gathers money from investors that act as limited partners (Sahlman, 1990).[6] Accordingly, we extract from the VICO database all companies for which the relevant accounting data are available and in which an independent VC investor has been involved either as a standalone investor or as the leader of a syndicate of investors.[7] As a result of this extraction, we obtain a sample of 128 VC-backed companies.

Second, we extract from the VICO database the full population of the 6411 non-VC-backed companies for which accounting data are available. From this sample, we build a matched sample that is comparable to the sample of VC-backed companies (for a similar procedure in the VC literature see Engel and Keilbach, 2007; Megginson and Weiss, 1991). The matched sample is identified by using propensity-score matching. The aim is to find, for each VC-backed company that received an initial round of VC financing in year *t*, the non-VC-backed companies that, in the same year, had the most similar probability (i.e., propensity score) of receiving an initial round of VC financing. The propensity scores are obtained by estimating, for each year, a probit model in which the dependent variable is the occurrence of the initial round of VC investment and the independent variables include: age, size (measured by the end-of-period book value of the firm's total assets), sales to total assets, investment to total assets, cash flow to total assets, industry dummies and a variable reflecting the availability of VC, which is measured by the amount of VC fundraising (source: VentureXpert) to GDP in the previous year for the country of the company. For each VC-backed company, we select (with replacement) the two nearest-neighbor non-VC-backed peers. Our final sample comprises 128 VC-backed companies and 233 non-VC-backed companies, operating in six European countries (Belgium, Finland, France, Italy, Spain, and the United Kingdom).[8]

66 VC-backed companies in our sample (i.e., 51.56% of the VC-backed sample) receive only one round of VC financing, while the remaining VC-backed companies receive one or more follow-on rounds (up to 7 rounds of financing). On average, the VC-backed companies in our sample receive 1.99 rounds of financing.

The distribution of sample companies by country, industry and founding period is reported in Table 1.
The matched sample has a very similar distribution to the sample of VC-backed companies, as confirmed by Chi-squared tests ($\chi^2[5] = 1.17$, $\chi^2[5] = 2.69$ and $\chi^2[2] = 2.55$ for country, industry and founding period, respectively). These results confirm the va-lidity of the matching process, where age, country and industry dummies are included in the calculation of propensity scores.

Table 2 reports mean values and standard deviations of the variables that are used in the regression models. The sample includes 2180 firm-year observations (i.e., an average of 6.04 observations per company). Table 2 reports descriptive statistics for the variables

[6] Several recent studies based on the VICO database have analyzed the differences across VC types in the patterns of investment (Bertoni et al., 2015), and impact on growth (Grilli and Murtinu, 2014), productivity (Cumming et al., forthcoming), exit (Bertoni and Groh, 2014), and innovation (Bertoni and Tykvová, 2015).

[7] To identify the lead investor in the 1397 investment rounds in the VICO database, we use the following hierarchical process. First, an investor is considered to be the lead investor every time it invested alone in a round of financing (891 of 1397 investment rounds, 63.8%). Second, when the round involves a syndicate, in most cases, the secondary information included in the VICO database (collected e.g., by VentureXpert) explicitly identifies one investor as the lead (216 of the 506 remaining investment rounds, and 15.5% of the total). When a lead investor is not explicitly identified, the lead investor is identified as (i) the investor that invested the highest amount in the round (79 of the 211 remaining cases, 5.7% of the total); (ii) the investor that acquired the highest equity interest in the round (13 of 198 remaining cases, 1% of the total); (iii) the investor that was closest to the headquarter of the focal company (the remaining 198 cases, 14.2% of the total).

[8] German companies are excluded from the sample because the accounting variables that are needed for this study are not available in the VICO dataset for German companies. This omission is due to the fact that, before 2009, only large companies were required to file their financial statements to the public registry in Germany.

Table 1
Sample distribution by country, industry and founding period.
The table reports the distribution of the sample by country, industry and founding period. The matched sample is obtained by using propensity score matching. The propensity scores are obtained by estimating, for each year, a probit model in which the dependent variable is the occurrence of the initial round of VC investment and the independent variables include age, size (measured by the end-of-period book value of a firm's total assets), sales to total assets, investment to total assets, cash flow to total assets, industry dummies, and a variable reflecting the availability of VC that is measured by the amount of VC fundraising to GDP in the previous year for the country of the company. For each VC-backed company, the two nearest-neighbors non-VC-backed peers are included in the matched sample (with replacement).

	VC-backed		Matched sample		Total	
	N	%	N	%	N	%
Belgium	14	10.94	29	12.45	43	11.91
Finland	7	5.47	12	5.15	19	5.26
France	11	8.59	17	7.30	28	7.76
Italy	34	26.56	66	28.33	100	27.70
Spain	28	21.88	45	19.31	73	20.22
UK	34	26.56	64	27.47	98	27.15
Internet	38	29.69	66	28.33	104	28.81
TLC services	8	6.25	15	6.44	23	6.37
Software	40	31.25	67	28.76	107	29.64
ICT manufacturing	19	14.84	45	19.31	64	17.73
Biotech & Pharmaceutical	19	14.84	29	12.45	48	13.30
Other high-tech	4	3.13	11	4.72	15	4.16
Funded before 1995	22	17.18	30	12.89	52	14.41
Funded 1995–1999	54	42.19	110	47.21	164	45.43
Funded 2000–2004	52	40.62	93	39.91	145	40.16
Total	128	100	233	100	361	100

that are included in the analysis. We also report, for reference, the descriptive statistics for the non-winsorized variables. As expected, winsorizing the variables substantially reduces the standard deviation of the accounting ratios.

The mean investment rate in our sample is 0.118. This value is consistent with the value reported by Guariglia (2008) and is similar to the median investment rate reported by Bertoni et al. (2010). The cash flow to total assets is, on average, negative (−0.007), which is consistent with the idea that the availability of internal funds is limited in these companies. The fact that more than half of the firm-year observations in our sample have negative cash flows highlights the risk of misspecification from using a linear specification for the IC and, accordingly, the importance of allowing the IC to be U-shaped.

In Panel B of Table 2, we report the average capital injection by VC in our sample companies. On average, the VC-backed companies receive 4.484 million Euro per financing round, with little difference between the initial round (4.276 million Euro) and the follow-on rounds (4.694 million Euro). The average ratio of cash injection to a firm's pre-money fixed capital is 1.950, and this ratio is substan-tially larger in the initial round (2.678) than in follow-on rounds (1.215) because of the larger fixed capital of portfolio companies at the time of the follow-on round.

We can obtain preliminary descriptive evidence regarding the shape of the IC by computing the average level of investment that corresponds to the different deciles of cash flow. The results are reported in Table 3.

The first column in Table 3 reports the average value of $CF_{i,t}/K_{i,t-1}$ in each decile. The cash flow ratio for the companies in our sample varies considerably, ranging from an average of −0.908 of total assets in the bottom decile to an average of 0.682 of total as-sets in the top decile. Corresponding to each decile, we compute the average level of investment. The IC appears to be U-shaped: the investment-to-capital ratio reaches a minimum when the cash flow to capital ratio is intermediate (fifth decile). When the cash flow is small, the level of investment appears to be higher with lower cash flow, whereas when the cash flow is high, the level of investment increases with cash flow.

Table 3 also elucidates whether the IC differs between VC-backed companies and non-VC-backed companies, as we would expect if financial constraints were reduced by VC. We compute the average investment corresponding to each cash flow decile for both VC-backed companies (after the initial round of financing) and non-VC-backed companies. The IC seems to be less U-shaped in VC-backed companies than in non-VC-backed companies: on the leftmost part of the curve the average investment decreases between the first and second deciles, increases in the third decile, and then decreases again between the fourth and the sixth deciles; on the right-most part of the curve, the average investment increases in the seventh, ninth, and tenth deciles, but decreases in the eighth decile. The decreasing and increasing portions of the curve also appear to be less steep for VC-backed companies than for non-VC-backed companies. At a merely descriptive level, this evidence suggests that the external financial constraints of VC-backed companies could be relaxing.

5. Results

5.1. Main econometric results

Table 4 reports our main estimates. The first column of Table 4 reports the estimates obtained with a linear specification for the IC. The following columns report the estimates for Eqs. (1), (2) and (3). We estimate the reduced models in the first two columns (in which we ignore the impact of VC on the IC) using only non-VC-backed firm-year observations.

Table 2
Descriptive statistics of the variables in the error-correction model.
The table reports the descriptive statistics of the key variables used in the ECM model. All of the monetary amounts are deflated using the country-level Consumer Price Index (2005 is used as reference year). Panel A reports descriptive statistics of the variables included in the baseline ECM Model in Eq. (3). The figures in the *Winsorized* column are winsorized at the 2% threshold. $I_{i,t}$ is the level of investment of company *i* in period *t*, measured as the increase in the book value of the tangible and intangible assets net of depreciation; $K_{i,t}$ is the end-of-period *t* book value of company *i*'s total assets, and $k_{i,t}$ is its logarithm; $CF_{i,t}$ is company *i*'s cash flow in period *t* after taxes but before dividends; $y_{i,t}$ is the logarithm of company *i*'s sales during period *t*. In Panel B, mean values of capital injections in absolute value (million Euro) and normalized by beginning-of-period total assets (winsorized at the 2% threshold). The standard deviations are reported in round brackets.

Panel A: investment, sales growth, error-correction term and cash flows

			Winsorized		Non-winsorized	
Variable	Observations	Median	Mean	Std. dev.	Mean	Std. dev.
$I_{i,t}/K_{i,t-1}$	2180	0.037	0.118	0.209	0.187	1.540
$\Delta y_{i,t}$	2180	0.084	0.102	0.597	0.111	0.944
$(k_{i,t-2} - y_{i,t-2})$	2180	−0.084	0.200	1.261	0.222	1.420
$CF_{i,t}/K_{i,t-1}$	2180	0.051	−0.007	0.414	−0.060	1.063

Panel B: capital injection by VC

Rounds	Capital injection (EUR million) ($A_{i,t}$)	Capital injection to assets ($A_{i,t}/K_{i,t-1}$)
All	4.484	1.950
	(6.880)	(3.179)
Initial	4.276	2.678
	(6.579)	(3.798)
Follow-on	4.694	1.215
	(7.191)	(2.180)

The validity of the over-identifying restrictions is never rejected by the Hansen test. The AR(1) and AR(2) tests always behave as required for the consistency of the estimates: AR(1) is always statistically significant, and AR(2) is never statistically significant. We also report an adjusted goodness-of-fitmeasure.[9] For all quadratic specifications of the IC, the coefficient of the error-correction term is negative and significant, as required by the ECM specification, indicating that an above-average level of investment is associated with lower future investments. The size of the error-correction term (and, hence, the estimated speed of adjustment) is similar to that reported in previous studies (e.g., Guariglia, 2008). As expected, in all of the estimates, investment is positively correlated with sales growth; further, both current growth and lagged growth are positive and statistically significant in all specifications.

Our analysis indicates that the linear specification for the IC is misspecified in our sample. First, the error-correction term is not statistically significant, as required for the validity of the ECM. Second, the estimated ICFS is negative and significant, which is not reconcilable with the assumptions of a linear IC (i.e., that the ICFS is positive or, at the limit, null). This result is most likely driven by the large proportion of negative cash-flow observations in our sample, for which the U-shaped IC is negatively sloped.

Consistent with the preliminary evidence shown in Table 3, non-VC-backed companies do exhibit a U-shaped IC. The estimates of Eq. (1) show that the coefficient associated with the quadratic term of cash flows is positive and statistically significant.[10] Following the discussion in Section 2.1, we interpret the shape of the IC as confirmatory evidence that young high-tech companies in Europe are exposed to external financial constraints.

Once the baseline model is validated, we can focus on the effect of VC on the IC of portfolio companies. In Table 5, we report the linear and quadratic terms of the IC for non-VC-backed companies, VC-backed companies, and VC-backed companies after the first and the follow-on round. These terms are obtained as linear combinations of the parameters reported in Table 4, as explained in Section 3.2.

The first interesting result in Table 5 is that the quadratic term of cash flow is still positive and significant for VC-backed companies (0.064, p-value < 10%) in Eq. (2). This result indicates that the IC of VC-backed companies, with all rounds of investment pooled together, is still U-shaped. The difference in convexity between VC-backed and non-VC-backed companies, reported in Table 4, is negative ($\theta_4 = -0.044$) but not statistically significant at conventional confidence levels. In other words, the results do not provide statistically robust evidence that VC-backed companies are, in general, less exposed to external financial constraints than non-VC-backed companies.

When examining the results for Eq. (3), we observe that the quadratic term of cash flow is still positive and significant after the initial round of VC financing ($\lambda_6 + \theta_4^I = 0.129$, p-value < 10%) but that it is not significantly different from zero after a follow-on round ($\lambda_6 + \theta_4^F = -0.016$). The reduction in the convexity of the IC for VC-backed companies after the second round of VC is highly statistically significant, as reported in Table 4 ($\theta_4^F = -0.128$, p-value < 1%).

These results are in line with the certification effect of VC. The alleviation of external financial constraints is greater when the signal that is conveyed by VC is stronger, as for follow-on rounds relative to first rounds of financing. Note that the effect of VC on the IC is not driven by capital injections. The control for the amount of capital injection in Eqs. (2) and (3) is positive but not significant, which

[9] The adjusted goodness-of-fit measure is calculated as follows: we compute the squared correlation coefficient between actual and predicted levels of the dependent variable as in Bloom et al. (2007) and adjust the result by accounting for the number of explanatory variables in the model relative to the number of observations Greene (2003).

[10] Note that while the turning point of the IC corresponds to a positive level of cash flows according to our estimates, Cleary et al. (2007) estimate the turning point to correspond to a negative level cash flow. This difference is driven by the fact that the linear coefficient of cash-flow in Table 4 is negative, while it is positive in Cleary et al. (2007). Presumably, this discrepancy is due to the specific nature of companies in our sample, compared to the broader-based sample that is used by Cleary et al. (2007). Specifically, the difference might be driven by the higher proportion of negative cash-flow observations in our sample, corresponding to which the linear coefficient of the cash flow coefficient is, indeed, negative, as shown in Table 6.

Table 3
Descriptive evidence on the shape of the investment curve.
The table reports the mean values of $CF_{i,t}/K_{i,t-1}$ and $I_{i,t}/K_{i,t-1}$ across deciles of $CF_{i,t}/K_{i,t-1}$. $I_{i,t}$ is the level of investment of company i in period t, measured by the increase in the book value of the tangible and intangible assets net of depreciation; $K_{i,t}$ is the end-of-period t book value of company i's total assets; $CF_{i,t}$ is company i's cash flow in period t after taxes but before dividends. The figures in column *VC-backed* refer to VC-backed companies after they receive the initial round by VC. The figures in the column *Non-VC-backed* are computed on all of the non-VC-backed observations, including both the matched sample and the VC-backed companies before they received the initial round of VC. All of the ratios are winsorized at the 2% threshold. All of the monetary amounts are deflated using the country-level consumer price index (2005 used as reference year).

$CF_{i,t}/K_{i,t-1}$ decile	Mean $CF_{i,t}/K_{i,t-1}$	Mean $I_{i,t}/K_{i,t-1}$		
		Total sample	VC-backed	Non-VC-backed
1	−0.908	0.191	0.119	0.254
2	−0.323	0.083	0.069	0.097
3	−0.110	0.092	0.112	0.079
4	−0.009	0.088	0.108	0.076
5	0.037	0.070	0.077	0.067
6	0.068	0.083	0.075	0.087
7	0.104	0.100	0.104	0.098
8	0.152	0.130	0.090	0.142
9	0.235	0.159	0.128	0.170
10	0.682	0.186	0.204	0.181

suggests that the presence of VC affects the level of investment in portfolio companies beyond the mere injection of money. Moreover, capital injection alone would not be able to explain the differences observed across rounds of investment because, as shown in Panel B of Table 2, the capital injected relative to capital invested is comparable between the first round and the follow-on rounds.

5.2. Robustness of the results

Following Cleary et al. (2007), we repeat all of the estimates by using a piecewise linear specification for the cash flow variables. Specifically, we eliminate the quadratic term of cash flow and set the cash flow variable to interact with two dummy variables indicating whether the cash flow is positive ($d_{i,t}^{+}$) or negative ($d_{i,t}^{-}$). The results of estimates obtained by using the piecewise linear specification for the cash flow variables are reported in Appendix A (Table A.11). Note that the goodness of fit is similar between the piecewise linear specification and the quadratic specification. Table 6 reports the results of the linear tests of the coefficients to evaluate the ICFS for VC-backed and non-VC-backed companies.

The main results are confirmed. The IC is indeed convex for non-VC-backed companies: the ICFS is negative and significant (p-value < 5%) for a company with negative cash flow and positive and significant (p-value < 5%) for a company with positive cash flow. Further, the magnitude (in absolute value) of the positive coefficient of cash flow for a company with positive cash flow is comparable to the magnitude of the negative coefficient of cash flow for a company with negative cash flow.[11] Finally, and more important, only after the second round of financing is the ICFS of VC-backed companies not different from zero for both companies with negative cash flow and companies with positive cash flow.

Furthermore, we perform a number of additional estimates to verify the robustness of our results. In this section, we provide only a brief overview of the robustness tests that we performed, which are described in detail in Appendix A. First, we estimate all of the models by using a DIF-GMM approach, instead of the SYS-GMM approach. This model is based on only difference equations with instruments in levels and is thus based on a more parsimonious set of moment conditions than the SYS-GMM model. A difference-in-Hansen test (Bond, 2002) does not reject the hypothesis that the additional instruments used by the SYS-GMM model are valid ($\chi^2[145] = 35.3$), which normally leads to favoring a SYS-GMM model over DIF-GMM model. However, all our results are confirmed if we use a DIF-GMM model instead.

Second, we implement a further classic test of endogeneity for the follow-on rounds. In Eq. (3), we introduce a placebo-lead for the $VC_{i,t}^{F}$ variable (for a similar approach, see Bartel and Harrison, 2005; Bertoni et al., 2011). This term, which is equal to one for companies that will receive a follow-on round of financing *after* year t, should capture reverse causality and residual endogeneity in our estimates. The results are again confirmed, and the placebo-lead variable is not statistically significant, suggesting that reverse causality and endogeneity are not driving our results.

Third, we include additional controls for growth opportunities in Eq. (3). Specifically, we consider company size (defined as the logarithm of firm's total assets), company asset tangibility (calculated by dividing the book value of a company's tangible assets net of depreciation over the company's total assets), and the median firm's industry sales growth. The coefficients of asset tangibility and industry sales growth are both positive and significant. Conversely, the coefficient of size is not significant. All our main results are thus confirmed.

[11] We also use spline regressions by dividing the sample in terciles and quintiles of $\frac{CF_{i,t}}{K_{i,t-1}}$, as in Cleary et al. (2007). For non-VC-backed companies, the coefficients for the bottom quantiles are negative, while they are positive for the top quantiles.

Table 4

Venture capital effect on firm's investment curve.

The table reports the estimates of a linear ECM model and of non-linear ECM specifications in Eqs. (1), (2) and (3). $I_{i,t}$ is the level of investment of company i in period t, measured as the increase in the book value of the tangible and intangible assets net of depreciation; $K_{i,t}$ is the end-of-period t book value of company i's total assets, and $k_{i,t}$ is its logarithm; $CF_{i,t}$ is company i's cash flow in period t after taxes but before dividends; $\Delta y_{i,t}$ is the growth of company i's sales during period t; $VC_{i,t}$ equals 1 if company i received VC in or before period t; $A_{i,t}$ is the capital injection by VC in company i in period t. Superscript I and F refer to initial and follow-on rounds respectively. Country, industry and time dummies are included in the estimates but omitted from the table for readability. The estimates are derived from two-step SYS-GMM estimation with finite sample correction. The robust standard errors are reported in round brackets. The degrees of freedom are reported in square brackets. ***, ** and * indicate, respectively, significance level <1%, <5% and <10%.

Coeff.	Variable	Linear ECM	Eq. (1)	Eq. (2)	Eq. (3)
λ_1	$I_{i,t-1}/K_{i,t-2}$	0.095***	0.082**	0.104***	0.120***
		(0.036)	(0.034)	(0.032)	(0.029)
λ_2	$\Delta y_{i,t}$	0.077***	0.084***	0.062***	0.061***
		(0.025)	(0.024)	(0.016)	(0.015)
λ_3	$\Delta y_{i,t-1}$	0.028***	0.035***	0.038***	0.034***
		(0.013)	(0.013)	(0.010)	(0.010)
λ_4	$(k_{i,t-2} - y_{i,t-2})$	−0.012	−0.020*	0.020**	−0.015**
		(0.011)	(0.011)	(0.008)	(0.007)
λ_5	$CF_{i,t}/K_{i,t-1}$	−0.070**	−0.059**	0.046*	−0.044**
		(0.031)	(0.029)	(0.028)	(0.028)
λ_6	$(CF_{i,t}/K_{i,t-1})^2$		−0.104***	0.108***	−0.111***
			(0.029)	(0.031)	(0.032)
θ_1	$A_{i,t}/K_{i,t-1}$			0.020	−0.009
				(0.015)	(0.032)
θ_2	$VC_{i,t}$			−0.007	
				(0.018)	
θ_2^I	$VC_{i,t}^I$				−0.015
					(0.023)
θ_2^F	$VC_{i,t}^F$				−0.024
					(0.023)
θ_3	$VC_{i,t} \times CF_{i,t}/K_{i,t-1}$			0.056	
				(0.041)	
θ_3^I	$VC_{i,t}^I \times CF_{i,t}/K_{i,t-1}$				0.055
					(0.052)
θ_3^F	$VC_{i,t}^F \times CF_{i,t}/K_{i,t-1}$				0.073
					(0.044)
θ_4	$VC_{i,t} \times (CF_{i,t}/K_{i,t-1})^2$			−0.044	
				(0.049)	
θ_4^I	$VC_{i,t}^I \times (CF_{i,t}/K_{i,t-1})^2$				−0.017*
					(0.073)
θ_4^F	$VC_{i,t}^F \times (CF_{i,t}/K_{i,t-1})^2$				−0.128***
					(0.038)
Observation		1445	1445	2180	2180
companies		262	262	361	361
Hansen		193.34	229.3	325.8	323.17
		[227]	[280]	[445]	[508]
AR (1)		−6.30***	−6.31***	−7.09***	−7.15***
AR (2)		−0.29	−0.33	0.27	0.30
Adjusted goodness of fit measure		0.15	0.17	0.18	0.18

Table 5

Impact of venture capital on the shape of the investment curve.

The table reports the estimates of the IC parameters depending on the VC status obtained from the linear combination of the parameters in Table 4. The robust standard errors are reported in round brackets. * indicates significance level <10%.

Rounds	Coeff.	Variable	Eq. (2)	Eq. (3)
All	$\lambda_5 + \theta_3$	CF/K	0.009	
			(0.031)	
	$\lambda_6 + \theta_4$	$(CF/K)^2$	0.064*	
			(0.038)	
Initial	$\lambda_5 + \theta_3^I$	CF/K		0.011
				(0.047)
	$\lambda_6 + \theta_4^I$	$(CF/K)^2$		0.129*
				(0.069)
Follow-on	$\lambda_5 + \theta_3^F$	CF/K		0.029
				(0.033)
	$\lambda_6 + \theta_4^F$	$(CF/K)^2$		−0.016
				(0.020)

Table 6
Impact of venture capital on the shape of the investment curve: piecewise linear specification.
The table reports the estimates of the ICFS depending on the VC status obtained from the linear combination of parameters from a piecewise linear specification of the IC. The robust standard errors are reported in round brackets. ***, ** and * indicate, respectively, significance level <1%, <5% and <10%.

VC status	Variable.	Piecewise linear specification version of Eq. (1)	Piecewise linear specification version of Eq. (2)	Piecewise linear specification version of Eq. (3)
No VC	$d^- \cdot CF/K$	−0.126**	−0.151***	−0.163***
		(0.055)	(0.050)	(0.052)
	$d^+ \cdot CF/K$	0.125***	0.146**	0.160**
		(0.048)	(0.062)	(0.065)
All rounds	$d^- \cdot CF/K$		−0.026	
			(0.043)	
	$d^+ \cdot CF/K$		0.132*	
			(0.074)	
Initial round	$d^- \cdot CF/K$			−0.095
				(0.061)
	$d^+ \cdot CF/K$			0.191*
				(0.109)
Follow-on round (negative cash flow)	$d^-_{i,t} \cdot CF/K$			0.060
				(0.045)
Follow-on round (positive cash flow)	$d^+ \cdot CF/K$			0.058
				(0.063)

5.3. Alternative interpretations and additional evidence

To further support our interpretation that the effect of VC on financial constraints is driven by VC certification, in this section, we explore two alternative explanations for our results and provide some additional evidence. The first alternative explanation that we consider is that the difference that we observe between the initial round and the follow-on rounds does not arise because of the certification role of VC but, rather, simply arises because companies are older when receiving follow-on rounds. In fact, to the extent that external financial constraints decrease as a company matures (Hovakimian, 2009), age could be a confounding factor for our estimates. To rule out this alternative explanation, we estimate a version of Eq. (3) in which we add an interaction between age and the linear and quadratic terms of cash flow. The coefficients of interaction terms between the VC dummy and both cash flow and its squared have the same sign and the same level of statistical significance as those shown in Table 4. Moreover, both the coef-ficient of the interaction between age and both cash flow and its squared term are not significant, and a joint test does not reject the null hypothesis that both interaction terms are zero. These results reassure us that age does not influence the IC in our sample of young companies, and does not affect our interpretation of the results.

For completeness, in Table 7 we also report the estimated linear and quadratic terms of the IC corresponding to different levels of age (1st quartile, median, 3rd quartile) for non-VC-backed and VC-backed companies, distinguishing between initial and follow-on rounds. As Table 7 shows, the parameter of the squared cash flow variable is positive and significant for non-VC-backed companies within each of the three age quartiles. The same result is obtained for VC-backed companies after the initial round of financing: the quadratic term is positive and significant with a p-value < 5% for the first 2 age quartiles, and positive and significant with a p-value < 10% for the last age quartile. These findings, again, confirm that financial constraints are not relaxed after the initial round of financing independent of the age of the company. The quadratic term for VC-backed companies that received a follow-on round of financing is, instead, non-significant for each of the three age quartiles. The effect of VC certification in reducing a company's ICFS is thus related to follow-on rounds, independent of the age of the company. Hence, the impact of VC on a firm's IC is significantly larger for companies that receive a follow-on round of financing expressly because of VC certification, even when we control for differences in age.

The second alternative explanation that we explore is as follows: companies may delay the use of a VC capital injection to build a long-term capital buffer in order to safeguard themselves from future potential shocks in cash flows. In this case, we would observe a flattening of a firm's IC not because of VC certification but rather because of a prolonged effect of VC capital injection associated with the company's tendency to build a long-term capital buffer. We test this capital buffer hypothesis by analyzing the effect of VC financing on the cash holdings ratio (i.e., the ratio between cash holdings and capital stock). If companies build a capital buffer to finance future investments, we should expect them to exhibit a long-term increase in their level of cash holdings after they obtain VC. We test the capital buffer hypothesis by using the following model specification:

$$\frac{CASH_{i,t}}{K_{i,t-1}} = \tau_1 \frac{CASH_{i,t-1}}{K_{i,t-2}} + \tau_2 \Delta y_{i,t} + \tau_3 \Delta y_{i,t-1} + \tau_4 \frac{A_{i,t}}{K_{i,t-1}} + \\ + \tau_5 VC^I_{i,t} + \tau_6 VC^F_{i,t} + \xi D_i + \phi Z_t + \varepsilon_{i,t}. \tag{4}$$

Where $CASH_{i,t}$ is the level of cash holdings of company $\boldsymbol{i}$ in period $\boldsymbol{t}$. If the capital buffer hypothesis holds, we should expect each capital injection to create a long-term capital buffer after the initial round of financing ($\tau_5 > 0$) or after the follow-on rounds ($\tau_6 > 0$). The results of the estimation of Eq. (4) are shown in the first column of Table 8. The estimates of Eq. (4) reveal that, as expected, τ_4, representing the effect of VC capital injection on a firm's cash holdings, is positive and significant, indicating that financing obtained increases the level of a

Table 7
Impact of venture capital on the shape of the investment curve: additional control for age.
Estimates of the IC parameters depending on the VC status and age obtained from the linear combination of the parameters in an version of Eq. (3) in which age is interacted with both cash flow and its squared term. The robust standard errors are reported in round brackets. Degrees of freedom are reported in square brackets. ***, ** and * indicate, respectively, significance level <1%, <5% and <10%.

VC status	Variable	1st quartile (4 years)	Age Median (6 years)	3rd quartile (9 years)
No VC	*CF/K*	−0.024	−0.029	−0.037
		(0.038)	(0.032)	(0.034)
	$(CF/K)^2$	0.136***	0.119***	0.095**
		(0.044)	(0.039)	(0.038)
Initial Round	*CF/K*	0.029	0.024	0.016
		(0.050)	(0.050)	(0.058)
	$(CF/K)^2$	0.158**	0.142**	0.117*
		(0.074)	(0.071)	(0.069)
Follow-on	*CF/K*	0.056	0.051	0.043
		(0.038)	(0.033)	(0.037)
	$(CF/K)^2$	0.0249	0.0086	−0.0158
		(0.034)	(0.027)	(0.026)

firm's available cash holdings. However, the level of cash holdings of VC-backed companies is not significantly different from that of non-VC-backed companies in the years after the initial or the follow-on rounds (τ_5 and τ_6 are not significantly different from zero at the conventional significance levels). Thus, companies do not appear to use VC to build a long-term buffer to shelter them from future shocks in cash flow; therefore, we can dismiss this alternative interpretation of the changes in the IC.

Finally, we test a prediction derived from our interpretation of the results. If VC financing conveys a credible signal to capital markets, we would expect creditors to be more willing to lend money to VC-backed companies, especially after they receive a follow-on round of financing. If this interpretation holds, we should observe a long-term increase in leverage in VC-backed companies. To test this hypothesis, we estimate the following model based on the debt ratio (i.e., the ratio of long-term financial debt to capital stock):

$$\frac{D_{i,t}}{K_{i,t-1}} = \rho_1 \frac{D_{i,t-1}}{K_{i,t-2}} + \rho_2 \Delta y_{i,t} + \rho_3 \Delta y_{i,t-1} + \rho_4 \frac{A_{i,t}}{K_{i,t-1}} + \\ + \rho_5 VC^I_{i,t} + \rho_6 VC^F_{i,t} + \xi D_i + \phi Z_t + \varepsilon_{i,t}; \quad (5)$$

Table 8
Estimates on the level of cash holdings and long-term financial debt after VC financing.
The table reports the estimates of Eqs. (4) and (5). $CASH_{i,t}$ is the level of firm's *i* cash and equivalent at the end of period *t*; $D_{i,t}$ is the level of long term financial debt of company *i*' at the end of period *t*; $K_{i,t}$ is the end-of-period *t* book value of company *i* s total assets; $\Delta y_{i,t}$ is the growth of company *i*'s sales during period *t*; $VC_{i,t}$ equals 1 if company *i* received VC in or before period *t*; $A_{i,t}$ is the capital injection by VC in company *i* in period *t*. Superscript *I* and *F* refer to initial and follow-on rounds respectively. Country, industry, and time dummies are included in the estimates but omitted from the table. All ratios are winsorized at the 2% threshold. The estimates are derived from the two-step SYS-GMM estimation with finite sample correction. The robust standard errors are reported in round brackets. The degrees of freedom are in square brackets. ***, ** and * indicate, respectively, significance level <1%, <5% and <10%.

Variable	Cash holdings Eq. (4)	LT financial debt Eq. (5)
$CASH_{i,t-1}/K_{i,t-2}$	0.118***	
	(0.034)	
$D_{i,t-1}/K_{i,t-2}$		0.395***
		(0.064)
$\Delta y_{i,t}$	0.057*	0.043
	(0.034)	(0.034)
$\Delta y_{i,t-1}$	0.025	−0.020
	(0.019)	(0.022)
$A_{i,t}/K_{i,t-1}$	0.247***	−0.022
	(0.087)	(0.042)
$VC^I_{i,t}$	−0.069	−0.042
	(0.050)	(0.062)
$VC^F_{i,t}$	0.088	0.252**
	(0.074)	(0.116)
Observations	2103	1641
companies	359	293
Hansen	225.9	195.7
	[233]	[230]
AR(1)	−4.550***	−4.200***
AR(2)	−0.490	0.630

where $D_{i,t}$ is the level of long-term financial debt of company *i* in period *t*. If certification is driving the effect of VC on financial constraints, we would expect a firm's financial debt level to increase after the first round ($\rho_5 > 0$) and, especially, after a follow-on round ($\rho_6 > 0$) of VC. The estimation of Eq. (5) is reported in the second column of Table 8. The results confirm that VC-backed companies have easier access to long-term debt financing than non-VC-backed companies. Interestingly and consistent with our interpretation of the findings reported in Table 4, a significant effect is found only after a follow-on round of VC financing.

6. Conclusions

In this work, we study how and when VC alleviates the financial constraints of portfolio companies by using a sample of young high-tech companies located in six European countries. Building upon the theoretical model proposed by Cleary et al. (2007), we use the convexity of the IC as a proxy for the intensity of financial constraints.

Our results show that the IC of young high-tech companies is indeed U-shaped. This finding suggests that the models that are used in the extant literature to describe the effect of VC on financial constraints, which assume that the IC is linear, are misspecified as they do not take into account the influence of negative cash flow observations. Even assuming that the bias associated to this misspecification problem is limited (because of a low proportion of negative cash flow observations), results of prior studies cannot be generalized to companies with limited available internal capital, i.e., companies that are exposed to substantial internal financial constraints. Furthermore, compared to findings reported in the extant literature, our results regarding the role of VC in alleviating the financial constraints of portfolio companies are more nuanced. If we pool all investment rounds, we do not find robust evidence of an alleviation of financial constraints in VC-backed companies. However, when we distinguish between initial and follow-on rounds of financing, our findings show that financial constraints disappear only after companies receive a follow-on round of financing. Note that slightly more than half (51.56%) of the VC-backed companies in our sample receive only an initial round of financing. In other words, the alleviation of financial constraints occurs for less than half of the VC-backed companies in our sample.

Our finding that the effect of VC is only significant after a follow-on round of investment, coupled with our finding of a non significant relationship between capital injection and capital investment, leads us to conclude that the most important channel through which VC alleviates financial constraints is certification. We observe a stronger effect of VC in follow-on rounds because, even though these rounds do not involve a larger capital injection, they provide stronger informative content. Consistent with this interpretation, we observe an increase in long-term debt for VC-backed companies only after they receive a follow-on round of financing.

Our analysis provides the foundation for additional research on this topic. First, a natural continuation of this work would be to test how VC reputation contributes to flattening the IC of VC-backed companies. To the extent that certification drives the relaxation of financial constraints, we may expect reputation to play an important role in this process. Second, our results are based on independent VC investors only, but other organizational forms deserve specific attention. Captive VC investors may differ from independent VC in-vestors in terms of both the timing and the intensity of their certification (because of their screening skills). Third, it would be inter-esting to study the extent to which the effectiveness of VC certification is mediated by the development of financial markets in the country (or geographic area) where a company operates. Other things being equal, a signal will be more effective when the economic agents that receive it are more numerous.

Appendix A. Robustness tests

As outlined in Section 5.2, we estimate several alternative models to test the robustness of our results. We report in Table A.9 the estimates of Eq. (A.3), obtained by using a more parsimonious set of the moment conditions (DIF-GMM model instead of the SYS-GMM model) and a placebo lead for follow-on rounds ($VC^F_{i,t}(lead)$). Table A.10 reports the linear combinations of the coefficients that characterize the IC.

Table A.9
Venture capital effect on firm's investment curve: DIF-GMM and placebo lead estimates.
The table reports the estimates of the ECM specifications in Eq. (3) using alternative estimation techniques from those in Table 4. $I_{i,t}$ is the level of investment of company *i* in period *t*, measured as the increase in the book value of the tangible and intangible assets net of depreciation; $K_{i,t}$ is the end-of-period *t* book value of company *i*'s total assets, and $k_{i,t}$ is its logarithm; $CF_{i,t}$ is company *i*'s cash flow in period *t* after taxes but before dividends; $\Delta y_{i,t}$ is the growth of company *i*'s sales during period *t*; $VC_{i,t}$ equals 1 if company *i* received VC in or before period *t*; $A_{i,t}$ is the capital injection by VC in company *i* in period *t*. Superscript *I* and *F* refer to initial and follow-on rounds re-spectively. $VC^F_{i,t}(lead)$ is a placebo lead dummy equal to one for companies that will eventually receive a follow-on round of financing. Country, industry, time dummies and constant term are omitted from the table but included in estimates. The robust standard errors are reported in round brackets. The degrees of freedom in square brackets. ***, ** and * indicate, respectively, significance level <1%, <5% and <10%.

Coeff.	Variable	DIF-GMM		Placebo-lead	
λ_1	$I_{i,t-1}/K_{i,t-2}$	0.056	(0.038)	0.121	(0.029)***
λ_2	$\Delta y_{i,t}$	0.056	(0.017)***	0.062	(0.015)***
λ_3	$\Delta y_{i,t-1}$	0.039	(0.014)***	0.034	(0.010)***
λ_4	$(k_{i,t-2} - y_{i,t-2})$	−0.023	(0.012)**	−0.015	(0.007)**
λ_5	$CF_{i,t}/K_{i,t-1}$	−0.052	(0.038)	−0.043	(0.029)

Table A.9 *(continued)*

Coeff.	Variable	DIF-GMM		Placebo-lead	
λ_6	$(CF_{i,t}/K_{i,t-1})^2$	0.165	(0.047)***	0.108	(0.031)***
θ_1	$A_{i,t}/K_{i,t-1}$	0.025	(0.015)*	0.009	(0.012)
θ_2^I	$VC_{i,t}^I$	−0.160	(0.086)*	−0.017	(0.022)
θ_2^F	$VC_{i,t}^F$	−0.186	(0.123)	0.023	(0.024)
θ_3^I	$VC_{i,t}^I \times CF_{i,t}/K_{i,t-1}$	0.051	(0.066)	0.056	(0.052)
θ_3^F	$VC_{i,t}^F \times CF_{i,t}/K_{i,t-1}$	0.039	(0.048)	0.071	(0.044)
θ_4^I	$VC_{i,t}^I \times (CF_{i,t}/K_{i,t-1})^2$	0.023	(0.099)	0.020	(0.070)
θ_4^F	$VC_{i,t}^F \times (CF_{i,t}/K_{i,t-1})^2$	−0.153	(0.052)***	−0.125	(0.031)***
	$VC_{i,t}^F(lead)$			0.108	(0.031)
Observations		1792		2180	
Companies		319		361	
Hansen		290.1		321.2	
		[360]		[507]	
AR(1)		−6.665***		−7.152***	
AR(2)		−0.100		0.311	

All of the main results of our analysis are confirmed in these alternative models. The investment curve is U-shaped for non-VC-backed companies, VC has a significant effect in flattening the IC, especially after a follow-on round. Moreover, the placebo lead variable, $VC_{i,t}^F(lead)$, is not statistically significant, confirming that residual endogeneity is not driving our results.

We also re-estimate all of the models using a linear specification for the cash flow variables. Specifically, we eliminate the quadratic term of cash flow and we interact the cash flow variable with a dummy indicating whether the company has a positive or a negative cash flow in each year. Following Cleary et al. (2007) we estimate the following model:

$$\begin{aligned}\frac{I_{i,t}}{K_{i,t-1}} &= \alpha_1\frac{I_{i,t-1}}{K_{i,t-2}} + \alpha_2\Delta y_{i,t} + \alpha_3\Delta y_{i,t-1} + \alpha_4\left(k_{i,t-2} - y_{i,t-2}\right) + \\ &+\alpha_5 d_{i,t}^{+} + \sum_{z\in\Theta}\left(\alpha_6^z d_{i,t}^z\frac{CF_{i,t}}{K_{i,t-1}}\right) + \xi D_i + \phi T_t + \varepsilon_{i,t};\end{aligned} \tag{A.1}$$

with $z\in\Theta = \{+,-\}$. The dummy variables $d_{i,t}^{+}$ and $d_{i,t}^{-}$ indicate whether the company has positive ($d_{i,t}^{+}=1$) or negative ($d_{i,t}^{-}=1$) cash flow in year *t*. We expect $\alpha_6^{+}>0$ and $\alpha_6^{-}<0$, which indicate that ICFS is positive (negative) for a company with positive (negative) cash flow.

Along the lines of what done in Section 3.1 we augment the Eq. (A.1) including the VC variables:

$$\begin{aligned}\frac{I_{i,t}}{K_{i,t-1}} &= \alpha_1\frac{I_{i,t-1}}{K_{i,t-2}} + \alpha_2\Delta y_{i,t} + \alpha_3\Delta y_{i,t-1} + \alpha_4\left(k_{i,t-2} - y_{i,t-2}\right) + \\ &+\alpha_5 d_{i,t}^{+} + \sum_{z\in\Theta}\left(\alpha_6^z d_{i,t}^z\frac{CF_{i,t}}{K_{i,t-1}}\right) + \xi D_i + \phi T_t + \\ &+\beta_1\frac{A_{i,t}}{K_{i,t-1}} + \beta_2 VC_{i,t} + \sum_{z\in\Theta}\left(\beta_3^z d_{i,t}^z VC_{i,t}\frac{CF_{i,t}}{K_{i,t-1}}\right) + \varepsilon_{i,t}.\end{aligned} \tag{A.2}$$

Table A.10
Impact of venture capital on the shape of the investment curve: DIF-GMM and placebo lead estimates.
The table reports the estimates of the IC parameter depending on the VC status as obtained from the linear combination of the parameters in Table A.9. The robust standard errors are reported in round brackets. ***, ** and * indicate, respectively, significance level <1%, <5% and <10%.

VC status	Coeff.	DIF-GMM	Placebo-lead
No VC	$^{CF}/_{K}$	−0.052	−0.043
		(0.038)	(0.029)
	$(^{CF}/_{K})^2$	0.165***	0.108***
		(0.047)	(0.031)
Initial round	$^{CF}/_{K}$	−0.001	0.013
		(0.060)	(0.047)
	$(^{CF}/_{K})^2$	0.188**	0.128*
		(0.091)	(0.066)
Follow-on round	$^{CF}/_{K}$	−0.014	0.029
		(0.031)	(0.032)
	$(^{CF}/_{K})^2$	0.011	−0.018
		(0.024)	(0.020)

The parameters β_3^+ and β_3^- measure changes in the ICFS due to the presence of VC. If VC financing makes the ICFS disappear we expect that: $\alpha_6^+ + \beta_3^+ = 0$ and $\alpha_6^+ + \beta_3^- = 0$. Finally, we distinguish between the initial and the follow-on rounds through the following specification:

$$\frac{I_{i,t}}{K_{i,t-1}} = \alpha_1 \frac{I_{i,t-1}}{K_{i,t-2}} + \alpha_2 \Delta y_{i,t} + \alpha_3 \Delta y_{i,t-1} + \alpha_4 \left(k_{i,t-2} - y_{i,t-2}\right) + \\ + \alpha_5 d_{i,t}^+ + \sum_{z\in\Theta} \left. \alpha_6^z d_{i,t}^z \frac{CF_{i,t}}{K_{i,t-1}} \right) + \xi D_i + \phi T_t + \varepsilon_{i,t} + \\ + \beta_1 \frac{A_{i,t}}{K_{i,t-1}} + \sum_{r\in\Omega} \beta_2^r VC_{i,t}^r + \sum_{z\in\Theta} \left. \beta_3^{z,r} d_{i,t}^z VC_{i,t}^r \frac{CF_{i,t}}{K_{i,t-1}} \right). \tag{A.3}$$

The coefficients $\beta_3^{+,I}$, $\beta_3^{-,I}$, $\beta_3^{+,F}$ and $\beta_3^{-,F}$ capture the changes in the ICFS. Again, we evaluate whether ICFS is alleviated in VC-backed companies by performing the following linear tests: $\alpha_6^+ + \beta_3^{+,I} = 0$ and $\alpha_6^- + \beta_3^{+,I} = 0$ after the initial round of financing, and $\alpha_6^+ + \beta_3^{+,F} = 0$ and $\alpha_6^- + \beta_3^{+,F} = 0$ after the follow-on rounds.

The results of these estimates are reported in Table A.11.

Finally, we include in Eq. (3) additional controls for growth opportunities and external financial constraints. More in details, we consider two firm-level variables and one industry-level variable. The two firm-level variables are size (defined as the logarithm of firm's total assets) and asset tangibility (calculated by dividing the book value of company's tangible assets net of depreciation over company's total assets). According to Hovakimian (2009), smaller companies are expected to face higher external financial constraints and higher growth opportunities while companies with higher asset tangibility are expected to face lower external financial constraints due to the higher collateral value of their assets. The industry-level control for growth opportunities is the median industry sales growth in each period (for a discussion on the use of industry-level variables to control for growth opportunities, see D'Espallier and Guariglia, 2015). In Table A.12 we report the parameters of the IC for VC-backed and non VC-backed companies, together with the estimated coefficients of these additional controls (the coefficient of the control for growth opportunities is indicated as γ in Table A.12).

The results in Table A.12 are similar to those reported in third column of Table 5. In all estimates, the quadratic term of cash flow is not significant after follow-on rounds, while it is still positive and significant after receipt of the first round of financing (with the

Table A.11

Venture capital effect on firm's investment curve: piecewise linear specification.

The table reports the estimates of ECM specifications in Eqs. (A.1)-(A.3). $I_{i,t}$ is the level of investment of company i in period t, measured as the increase in the book value of the tangible and intangible assets net of depreciation; $K_{i,t}$ is the end-of-period t book value of company i's total assets, and $k_{i,t}$ is its logarithm; $CF_{i,t}$ is company i's cash flow in period t after taxes but before dividends; $y_{i,t}$ is the logarithm of company i's sales during period t; $d_{i,t}^z$ is a dummy variable that indicates whether cash flow of company i in period t has the same or the opposite sign as $z \in \Theta = \{+,-\}$; $VC_{i,t}$ equals 1 if company i received VC in or before period t; $A_{i,t}$ is the capital injection by VC in company i in period t. Superscript I and F refer to initial and follow-on rounds respectively. All rations are winsorized at the 2% threshold. Country, industry, time dummies and constant term are omitted from the table but included in the estimates. The estimates are derived from the two-step SYS-GMM estimation with finite sample correction. The robust standard errors are reported in round brackets; degrees of freedom are in square brackets. ***, ** and * indicate, respectively, significance level <1%, <5% and <10%.

Coeff.	Variable	Eq. (A.1)		Eq. (A.2)		Eq. (A.3)	
α_1	$I_{i,t-1}/K_{i,t-2}$	0.082	(0.032)**	0.098	(0.030)***	0.116	(0.030)***
α_2	$\Delta y_{i,t}$	0.095	(0.022)***	0.075	(0.015)***	0.070	(0.014)***
α_3	$\Delta y_{i,t-1}$	0.035	(0.012)***	0.039	(0.010)***	0.034	(0.010)***
α_4	$(k_{i,t-2} - y_{i,t-2})$	−0.020	(0.011)*	−0.022	(0.008)***	−0.016	(0.008)**
α_5	$d_{i,t}^+$	−0.061	(0.029)**	−0.038	(0.025)	−0.034	(0.024)
α_6^+	$d_{i,t}^+ \times CF_{i,t}/K_{i,t-1}$	0.125	(0.048)***	0.146	(0.062)**	0.160	(0.065)**
α_6^-	$d_{i,t}^- \times CF_{i,t}/K_{i,t-1}$	−0.126	(0.055)**	−0.151	(0.050)***	−0.163	(0.052)***
β_1	$A_{i,t}/K_{i,t-1}$			0.028	(0.016)*	0.016	(0.013)
β_2	$VC_{i,t}$			0.003	(0.023)		
β_2^I	$VC_{i,t}^I$					−0.009	(0.029)
β_2^F	$VC_{i,t}^F$					0.040	(0.026)
β_3^+	$d_{i,t}^+ \times VC_{i,t} \times CF_{i,t}/K_{i,t-1}$			−0.014	(0.098)		
$\beta_3^{+,I}$	$d_{i,t}^+ \times VC_{i,t}^I \times CF_{i,t}/K_{i,t-1}$					0.031	(0.124)
$\beta_3^{+,F}$	$d_{i,t}^+ \times VC_{i,t}^F \times CF_{i,t}/K_{i,t-1}$					−0.103	(0.092)
β_3^-	$d_{i,t}^- \times VC_{i,t} \times CF_{i,t}/K_{i,t-1}$			0.125	(0.056)**		
$\beta_3^{-,I}$	$d_{i,t}^- \times VC_{i,t}^I \times CF_{i,t}/K_{i,t-1}$					0.067	(0.068)
$\beta_3^{-,F}$	$d_{i,t}^- \times VC_{i,t}^F \times CF_{i,t}K_{i,t-1}$					0.223	(0.065)***
Observations		1455		2180		2180	
Companies		262		361		361	
Hansen		27.9		320.6		332.7	
		[332]		[478]		[559]	
AR(1)		−6.331***		−7.078***		−7.087***	
AR(2)		−0.541		0.036		0.058	
Adjusted goodness of fit measure		0.17		0.18		0.18	

Table A.12
Impact of venture capital on the shape of the investment curve: additional controls for growth opportunities.
The table reports the estimates of the IC parameter depending on the VC status based on a version of Eq. (A.3) in which we add a control for growth opportunities. Controls for growth opportunities are Size Asset Tangibility and Median Industry Sales Growth. The robust standard errors are reported in round brackets. ***, ** and * indicate, respectively, significance level <1%, <5% and <10%.

VC status	Coeff.	Variable	Asset tangibility	Size	Industry sales growth
No VC	λ_5	*CF/K*	−0.033	−0.034	−0.034
			(0.026)	(0.027)	(0.027)
	λ_6	$(CF/K)^2$	0.112***	0.114***	0.106***
			(0.031)	(0.033)	(0.030)
Initial round	$\lambda_5 + \theta_3^I$	*CF/K*	−0.010	0.027	0.017
			(0.038)	(0.049)	(0.046)
	$\lambda_6 + \theta_4^I$	$(CF/K)^2$	0.100*	0.157*	0.137*
			(0.058)	(0.069)	(0.074)
Follow-on	$\lambda_5 + \theta_3^F$	*CF/K*	0.021	0.036	0.030
			(0.030)	(0.032)	(0.033)
	$\lambda_6 + \theta_4^F$	$(CF/K)^2$	−0.009	−0.011	−0.012
			(0.020)	(0.023)	(0.020)
All companies	γ	Growth opp.	0.448***	0.005	0.156**
			(0.065)	(0.006)	(0.064)

exception of first column). As expected the coefficient of asset tangibility and industry level control are both positive and significant.

Conversely, the coefficient of size is not significant. This latter result derives from the presence of two opposite effects: on the one hand smaller companies allegedly have higher growth opportunities (which leads to a higher investment rate); on the other hand, smaller companies are exposed to higher external financial constraints (which leads to a lower investment rate).

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