

ORIGINAL ARTICLE OPEN ACCESS

# Dynamics of High-Growth Young Firms and the Role of Venture Capitalists

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**Correspondence:** Yoshiki Ando ([yando@smu.edu.sg](mailto:yando@smu.edu.sg))**Received:** 17 February 2025 | **Revised:** 3 November 2025 | **Accepted:** 4 November 2025**Keywords:** defaultable debt | endogenous sorting | firm dynamics | innovation | upfront investment | venture capital

## ABSTRACT

Motivated by the substantial growth and upfront investments of venture capital (VC)-backed firms observed in administrative US Census data, this study develops a life-cycle firm dynamics model. In the model, startups choose the source of financing from VC, angel investors, or banks, depending on their growth potential, and invest in innovation. The calibrated model explains the life-cycle dynamics of firms with different sources of financing and suggests that venture capitalists' managerial advice accounts for around 22% of the growth in VC-backed firms. A counterfactual economy without VC financing would experience an aggregate consumption loss of around 0.46%.

**JEL Classification:** D22, D25, E22, G24, G30, O32

## 1 | Introduction

Young firms are important drivers of job creation, innovation, and economic growth. In particular, a small fraction of high-growth firms disproportionately contributes to economic dynamism (cf. Decker et al. 2014; Haltiwanger et al. 2016; Acemoglu et al. 2022). However, startup founders with an intention to grow their business often lack the financial resources and management skills to execute their business ideas. Venture capital (VC) is a prominent example of external financing for high-growth firms, backing more than 30% of firms with an initial public offering (IPO) since 1980, and is known for its equity investment in early-stage startups and mentorship.<sup>1</sup> This study examines the role that external financing, particularly VC financing, plays in capitalizing young firms and fostering high-growth firms.

This study documents motivational facts using administrative US Census data and proprietary VC data sets: VC-backed firms achieve substantial employment and payroll growth relative to firms financed by other sources, while they require significant

upfront investments. A quantitative life-cycle firm dynamics model is developed to explore the factors driving these outcomes, where firms are endowed with heterogeneous growth potential, choose the source of financing, and invest in innovation. The model implies that high-potential firms self-select into VC financing to benefit from equity-based funding and managerial advice. Microlevel counterfactual simulation suggests that advice from venture capitalists (VCs) accounts for around 22% of the growth of VC-backed firms, relative to angel financing (i.e., non-VC equity financing).<sup>2</sup> In the steady state, a counterfactual economy without VC financing would suffer aggregate output and consumption losses of around 0.22% and 0.46%, respectively.

The empirical analysis is based on the US Census Bureau's Longitudinal Business Database (LBD). The data are merged with the proprietary VC data sets via name and address matching. This data set facilitates a comprehensive study of VC-backed firms in the US economy. At the macrolevel, VC-backed firms contributed to 10.6% of net employment growth and 15.8% of net payroll growth from 1990 to 2019. This occurred even though only

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around 0.2% of all firms in the economy secured VC financing, indicating the disproportionate importance of VC-backed firms in the economy.

At the microlevel, 22% of VC-backed firms established from 1980 to 2010 became high-growth firms, whereas less than 1% of all firms achieved high growth. High-growth firms, so-called Gazelles, are defined as firms whose annual average employment growth rate exceeds 20% in the first 5 years and whose employment level exceeds 100 within 20 years.<sup>3</sup> In the Gazelles sample, the growth of VC-backed firms is exceptional. The average firm size of VC-backed Gazelles at age 15 is more than five times larger than that of non-VC-backed Gazelles.

Furthermore, the data show substantial upfront investments by VC-backed firms and highlight the cost of VC financing. At age 0, VC-backed firms typically raise more than 10 times their revenue, as opposed to angel-backed firms raising 3.4 times their revenue, where angel investors are high-net-worth individuals who directly invest in early-stage companies. The R&D intensity of VC-backed firms, measured by R&D expenditures over firm revenue, is 14% higher than that of non-VC-backed firms and declines over firm age. These two facts indicate that, compared with non-VC-backed firms, VC-backed firms raise significantly more funding relative to their revenue and invest more heavily in innovation during the initial stages. Finally, VC investors acquire 3.3% extra equity stakes than angel investors in observationally comparable financing deals. This disparity can be interpreted as compensation for VCs' managerial advice. Prior studies also document that, while some angel investors do offer mentorship, most are relatively unsophisticated and less active than VCs in monitoring and advising firms (cf. Fenn et al. 1997; Hochberg 2012). Overall, microlevel evidence indicates that the life-cycle dynamics of VC-backed firms differ significantly from those of non-VC-backed firms.

This study develops a quantitative firm dynamics model with three key elements based on descriptive evidence. First, unlike a firm dynamics model with an exogenous productivity process, firms invest in innovation to realize their heterogeneous growth potential. In other words, the firm's potential does not materialize without investment in innovation. Second, startups choose a financing source from VC, angel investors, and banks. Financial frictions arise from bank default costs and costs of raising equity. Because high-potential firms invest intensively in innovation and would have a higher chance of defaulting on bank loans, they choose equity financing over bank financing. Third, VCs provide managerial advice to enhance the chance of successful innovation.<sup>4</sup> Because VC financing requires management fees paid in the form of an extra equity stake, startups seek such financing only if the benefits of the VCs' advice outweigh the cost of losing an additional equity stake. The value-adding effect is calibrated to match the extra equity stake that VCs obtain relative to that of angel investors. To the best of the author's knowledge, this paper provides the first quantitative framework for explaining firm growth over the life cycle that embeds the three interconnected factors: innovation, financing choice, and the role of VCs. As a result, the life-cycle dynamics of VC-, angel-, and bank-backed firms are captured. The importance of the source of financing for firm growth is quantified by counterfactual exercises.

In the model, firms are endowed with heterogeneous growth potential and invest in innovation to move up inherent productivity ladders. Firms earn zero revenue at age zero, but they must pay for labor, capital, and innovation expenditures, implying the need for external financing. Firms choose VC, angel investors, or bank financing, depending on their inherent growth potential. While the model assumes complete information on growth potential, firm growth is subject to stochastic innovation outcomes and ex-post productivity shocks.

In bank financing, firms raise defaultable short-term debt each period and roll over the debt if necessary. The bank loan rate is endogenously determined to satisfy banks' zero expected profit condition based on the probability of debt being repaid and potential default costs. In equity (VC or angel) financing, firms raise funds sequentially in exchange for financiers' ownership stakes. The investors' equity stake is determined by a ratio of the money invested to the firm's overall value.

VC financing differs from angel financing in that VCs provide managerial advice and improve the probability of moving up the productivity ladder, while the economy has a limited supply of VCs. In exchange for their advice, VCs demand an extra equity stake. Their compensation is determined in equilibrium such that firms at the threshold are indifferent to VC and angel financing. The additional 3.3% equity stake that VCs demand reflects their value-adding effect, as VC-backed firms may choose to raise angel financing instead if the compensation is higher than the perceived benefit of managerial advice.

The model results in a monotonic relationship between a firm's potential and financing mode. Most firms borrow from banks because their default rate is relatively low, and the fixed costs of equity financing outweigh the benefits. However, for higher-potential firms, large innovation expenditures and uncertain innovation outcomes make bank financing less suitable. As borrowing increases, the probability of bankruptcy and associated costs increase, making equity financing more suitable. The highest potential firms, which represent the top 0.2% of newly established firms, raise VC financing, as they benefit the most from VCs' advice given the high return associated with successful innovation.

The calibration targets the salient features of firm dynamics, such as the average firm size over the life cycle, and identifies the innovation function, in which innovation expenditures and other firm characteristics determine the probability of successful innovation. In practice, VC-backed firms typically seek to raise funds through multiple rounds, and reaching a subsequent round indicates successful business performance. Hence, the model targets the probability of raising subsequent VC rounds observed in the data, which is informative regarding the success rate of innovation. This approach identifies the innovation function without relying on R&D expenditure or patent filing data, which take positive values for only a small fraction of all firms.<sup>5</sup>

The calibrated model explains the substantial growth of VC-backed firms and their upfront investments as untargeted moments. Furthermore, without explicitly targeting them in calibration, the model reasonably matches the evolution of equity

stakes owned by investors and the total money raised by VC- and angel-backed firms over the life cycle.

The calibrated model quantifies VCs' role at the micro and macrolevels. The counterfactual growth paths of VC-backed firms are simulated at the microlevel under alternative financing sources. The counterfactual simulation implies that VCs' advice enhances the expected firm size of VC-backed firms at age 10 by 22% relative to angel financing. Conversely, the expected firm size of VC-backed firms would decline by 52% with bank financing relative to that with angel financing, demonstrating the importance of equity financing for high-growth firms.

At the macrolevel, the role of VCs in the economy is quantified by simulating an economy without VC financing. The counterfactual experiment predicts a decline in aggregate output and consumption in the steady state by approximately 0.22% and 0.46%, respectively. The findings indicate that the impact of VC financing on the economy is sizable but not as large as that estimated by previous studies.<sup>6</sup> Furthermore, doubling the number of VCs in the economy, assuming that they provide the same quality of managerial advice, enhances aggregate output and consumption by 0.26% and 0.33%, respectively, as more firms receive VCs' advice while paying lower compensation. Finally, a transition analysis, approximated by a sequence of steady states, suggests that the increase in VC financing over the past 40 years has contributed to around 27% of the rise in firm concentration.

**Related Literature.** This study contributes to four strands of the literature. First, this paper is closely related to recent studies of VC in the macroeconomy. For instance, Jovanovic and Szentes (2013), Akcigit et al. (2022), and Greenwood et al. (2022a) examine how VC-backed firms outperform other firms in the macroeconomy. Compared to their work, this study embeds VC financing within a firm dynamics model and explains VC-backed firms' growth trajectories over the life cycle. Furthermore, this study models the endogenous choice of securing financing from VC, angel, and bank financing and quantifies the importance of external sources of financing for firm growth.<sup>7</sup>

Second, the quantitative model builds on a substantial body of literature on firm dynamics in the style of Hopenhayn (1992). The analysis echoes three themes in the literature: (i) firm dynamics over the life cycle (e.g., Sterk et al. 2021), (ii) financial frictions due to the costs of defaulting on bank loans and raising equity (e.g., Cooley and Quadrini 2001),<sup>8</sup> and (iii) the productivity ladder (Cole et al. 2016). Compared with Sterk et al. (2021), this study tracks the life-cycle dynamics of firms with various financing sources. Compared with Cooley and Quadrini (2001), this analysis allows for a synergistic effect between VCs and entrepreneurs. In addition, unlike Cole et al. (2016), the probability of moving up the ladder is endogenous and is affected by the source of financing.

Third, this study builds on the empirical VC financing literature. The treatment effect of VC has been estimated in several studies (e.g., Kortum and Lerner 2000; Sørensen 2007; Bernstein et al. 2016). This study quantifies the value-adding effect of VCs relative to angel investors using a new calibration strategy based on the extra equity stake of VC investors compared to angel investors.<sup>9</sup> Furthermore, this study measures the growth of

VC-backed firms in employment and payroll, which are relevant to household welfare.

Finally, this study contributes to the empirical literature on firm dynamics that analyzes US Census data (e.g., Haltiwanger et al. 2013; Pugsley and Şahin 2019; Salgado et al. 2019; Ma 2022). Puri and Zarutskie (2012) were among the first to document the growth of VC-backed firms using US Census data. Compared with their study, this study documents the substantial growth of VC-backed firms, even among high-growth firms, and the significant upfront investments by VCs. Moreover, this study provides the first evidence of the contribution of VC-backed firms to the net aggregate growth of employment and payroll and the high R&D intensity of VC-backed firms along with its decline with firm age. This finding adds to the understanding of VC-backed firms in the sample of all employer businesses in the United States.

## 2 | Descriptive Evidence

This section presents three sets of descriptive evidence: VC-backed firms exhibit high growth in employment and payroll, VC-backed firms make large upfront investments in their early life, and VC investors acquire more equity stakes than angel investors in observationally comparable financial deals. Comparisons between VC-backed and non-VC-equity (angel-)backed firms are particularly novel, as little information on angel-backed firms has been documented in the literature. The facts presented here motivate the quantitative firm dynamics model with VC financing and innovation.

### 2.1 | Data

The LBD is the primary source of firm-level microdata, which are collected and organized by the US Census Bureau. The LBD covers virtually the entire population of employer firms and contains information on employment, payroll, revenue, firm age, industry (NAICS code), and firm death. The sample spans from 1980 to 2019 in this study. Firm size is primarily measured in employment and payroll. Since 1997, revenue data have been added to the LBD. The LBD is linked to the Census Bureau's Business Register, which contains all establishments' names and addresses.

The 2007 Survey of Business Owners (SBO) supplements the information on the source of financing. More than one million businesses in the United States were surveyed about their sources of capital, such as early-stage equity investments and business loans.<sup>10</sup> The data on R&D expenditures are drawn from the Survey of Industrial Research and Development (SIRD) for the period 1980–2007 and from the Business R&D and Innovation Survey (BRDIS) for the period 2008–2019. These data sets are part of the Census Bureau's restricted-use database and are linked to the LBD with census identifiers.

This study implemented name and address matching between the Business Register and four external VC data sets: Crunchbase, PitchBook, Preqin, and Refinitiv's VentureXpert. VC data sets provide information on the size and timing of most VC deals in the sample and investors' equity share for a subset of VC deals.

**TABLE 1** | Contribution of VC-backed firms and Gazelles to net aggregate growth.

|                 | Fraction (%) | Growth in employment (%) | Growth in payroll (%) |
|-----------------|--------------|--------------------------|-----------------------|
| VC-backed firms | 0.2          | 10.6                     | 15.8                  |
| Gazelles        | 0.8          | 65.2                     | 51.3                  |

Note: Employment Gazelles are firms with an average annual growth rate above 20% in the first 5 years and employment of 100 or more by the age of 20. Payroll Gazelles are defined similarly. The fractions of employment and payroll Gazelles are 0.793% and 0.788%, respectively, both of which are approximately 0.8%. The fraction of firms is computed for the period from 1980 to 2019. The contribution to aggregate growth is for 1990–2019. Data: LBD (1980–2019) and VC data sets. FSRDC Project Number 2633 (CBDRB-FY23-P2633-R10843).

Crunchbase and PitchBook contain information on some angel deals, enabling comparisons between VC and angel deals.<sup>11</sup> In addition, two data sets, the SDC New Issues and Ritter's IPO data set, are merged to supplement the VC-backing status of firms that eventually went public. Appendix B.1 describes each data set in more detail.

## 2.2 | Growth Accounting

This subsection conducts an accounting exercise to measure the contribution of VC-backed firms and high-growth firms to net aggregate growth, exploiting the sample of essentially all firms in the US economy.<sup>12</sup>

High-growth firms, which are often called “Gazelles” in the literature, are defined based on the firm's employment or payroll. Employment Gazelles are firms whose average annual employment growth rate is above 20% in the first 5 years and whose employment exceeds 100 by the age of 20. Payroll Gazelles are defined likewise.<sup>13</sup> VC-backed firms are those that are perceived to raise VC financing in the VC data sets and are linked to firms in the LBD. For the period from 1980 to 2019, around 0.2% of all firms are VC-backed, and around 0.8% of all firms are Gazelles, as shown in Table 1.

Contributions of VC-backed firms and Gazelles to net aggregate growth are computed in several steps. The mathematical definitions are provided in Appendix B.2. First, the growth rate of all firms is computed as a weighted sum of the growth rates of establishments belonging to the firms in the next period, following Davis et al. (1996) (hereafter, DHS). The advantage of this approach is that it measures the organic expansion of firms, which is not affected by ownership changes. The growth rate of a group of firms (i.e., VC-backed firms or Gazelles) is computed as a weighted sum of the firm growth rates within the group based on the DHS firm growth rates. Then, each year, the contribution of the group of firms to aggregate growth is computed. Finally, the contribution of the groups of firms from 1990 to 2019 is computed based on the geometric mean of the growth rates.

Table 1 summarizes the results of the growth accounting. Despite their small fraction in the economy, VC-backed firms account for 10.6% of net employment growth and 15.8% of net payroll growth from 1990 to 2019.<sup>14</sup> Gazelles account for 65.2% of net employment growth and 51.3% of net payroll growth, demonstrating their disproportionate contributions. In terms of payroll growth, VC-backed and Gazelle firms contribute approximately 80 and 65 times more to aggregate growth than typical firms in the economy,

respectively. VC-backed firms account for a higher share of payroll growth than that of employment growth, implying that VC-backed firms create more high-paying jobs.

## 2.3 | High Growth of VC-Backed Firms

This subsection examines firm growth at the microlevel in a sample of firms established from 1980 to 2010. Table 2 presents the number of newly established firms in each category. Of the approximately 18.2 million firms created during this period, 27,500 are identified as VC-backed, representing about 0.15% of newborn firms.<sup>15</sup> While employment Gazelles and payroll Gazelles account for only 0.86% and 0.88% of all new firms, respectively, 21.8% and 36% of VC-backed firms become employment and payroll Gazelles, respectively. Therefore, the odds of becoming a Gazelle are around 25 to 40 times higher for VC-backed firms compared with typical firms in the economy.

Next, in the sample of Gazelles, the growth trajectories of the VC-backed and non-VC-backed Gazelles are compared. The left panel in Figure 1 shows the average firm size of VC-backed and non-VC-backed Gazelles from age 0 to 15, measured in terms of payroll. VC-backed Gazelles sustain higher growth than non-VC-backed Gazelles. The average firm size of VC-backed Gazelles at the age of 15 is around \$60 million, more than five times that of non-VC-backed Gazelles. The raw sample mean of firm size is documented here. The Deaton–Paxson regression (Figure A4) in Appendix B.3 shows that the difference in growth trajectories is not mainly driven by year or industry effects.<sup>16</sup>

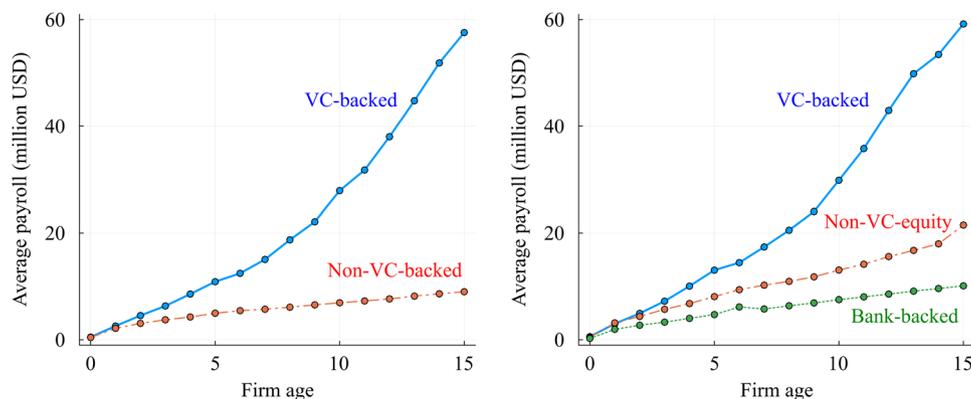
The right panel compares the growth trajectories of VC-financed, non-VC-equity-financed, and bank-financed Gazelles in the sample of firms that appear both in the LBD and SBO. The information on the source of capital is drawn from the SBO. The average growth of VC-backed Gazelles is higher than that of non-VC-equity-backed Gazelles, followed by that of bank-backed Gazelles. This monotonic relationship between the source of financing and the average growth of the Gazelles will be explained using a quantitative model.

Descriptive evidence of the high growth of VC-backed firms is documented here without showing a causal relationship. However, the quantitative model with several channels explains the high growth of VC-backed firms. The model is also used to predict the growth path of firms with an alternative source of financing. Note that Ando et al. (2025) suggest a positive treatment effect of VC financing on firm size using a difference-in-differences approach with matched control samples. Bernstein

**TABLE 2** | Number of newly established firms from 1980 to 2010.

|                 | Any firm   | Employment Gazelles | Payroll Gazelles |
|-----------------|------------|---------------------|------------------|
| All firms       | 18,150,000 | 156,000 (0.86%)     | 160,000 (0.88%)  |
| VC-backed firms | 27,500     | 6000 (21.8%)        | 9900 (36%)       |

Note: The sample consists of firms established between 1980 and 2010. Employment Gazelles are firms with an average annual growth rate above 20% in the first 5 years and employment of 100 or more by the age of 20. Payroll Gazelles are defined similarly. The percentages in parentheses indicate the fraction of Gazelles. The number of firms is properly rounded following the disclosure avoidance rules of the US Census Bureau. Data: LBD (1980–2019) and VC data sets. FSRDC Project Number 2633 (CBDRB-FY23-P2633-R10186).

**FIGURE 1** | Growth trajectory of VC-backed and non-VC-backed Gazelles.

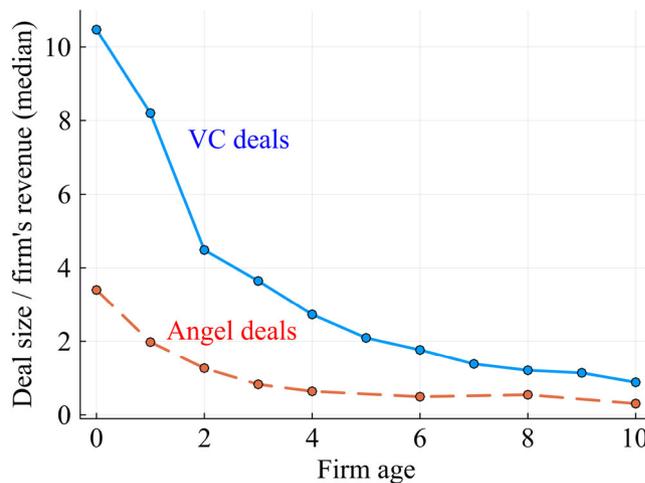
Notes: The left panel compares VC- and non-VC-backed firms in the sample of payroll Gazelle firms established from 1980 to 2010. The right panel compares VC-, non-VC-equity-, and bank-backed firms, using a subset of firms in the left panel that reported the source of capital in the SBO (2007). Payroll is denominated in 2009 US dollars based on GDP deflators. Data: LBD (1980–2019), SBO(2007), and VC data sets. FSRDC Project Number 2633 (CBDRB-FY23-P2633-R10186).

et al. (2016) show that VCs' on-site involvement has a positive impact on firm outcomes, exploiting the introduction of new airline routes as a source of variation.

## 2.4 | Upfront Investment

This subsection demonstrates upfront investments of VC-backed firms. The first measure of upfront investments is the ratio of the size of VC or angel funding raised to the firm's revenue. Figure 2 shows the median ratio in the sample of VC-backed and angel-backed firms from the age of 0 to 10. The plot demonstrates that at age 0, VC-backed firms typically raise more than 10 times their revenue. The funding size of VC deals consistently exceeds the firm's revenue until age 9. Angel-backed firms raise funding larger than their revenue at age 0, but the ratio is smaller than one after age 3. Therefore, VC-backed firms make significant upfront investments compared to angel-backed firms in their early life. Note that such large upfront investments cannot be explained using a standard firm dynamics model that does not consider innovation activities.

Furthermore, this study documents upfront investments by VC-backed firms using data on R&D expenditures, which is a commonly used measure of innovation inputs. The R&D data are drawn from the US Census SIRD/BRDIS data sets. The two data

**FIGURE 2** | Upfront investment of VC- and angel-backed firms.

Notes: The amount raised (i.e., deal size) is drawn from the VC data sets. Angel-backed firms are defined as firms that raised angel financing but have not raised VC financing, according to PitchBook and Crunchbase. Revenue data are from the LBD (1997–2019). The pseudo median, defined as the mean of a subset of observations around the median, is reported to protect confidentiality, following the Census Bureau's guidelines. In the sample of angel-backed firms, observations at ages 4–5, 6–7, 8–9, and 10–11 are pooled to ensure a reasonable sample size. FSRDC Project Number 2633 (CBDRB-FY23-P2633-R10843).

**TABLE 3** | R&D/revenue of VC-backed and non-VC-backed firms.

|                       | <b>Dependent: R&amp;D/revenue (%)</b> |                         |
|-----------------------|---------------------------------------|-------------------------|
|                       | <b>(1)</b>                            | <b>(2)</b>              |
|                       | <b>All firms</b>                      | <b>Payroll Gazelles</b> |
| VC-backed dummy       | 14.5***<br>(0.743)                    | 14.2***<br>(0.882)      |
| Firm age              | -0.0629***<br>(0.0137)                | -0.0788***<br>(0.0204)  |
| VC dummy × firm age   | -0.347***<br>(0.0391)                 | -0.306***<br>(0.0459)   |
| log(employment)       | -1.46***<br>(0.0684)                  | -1.24***<br>(0.121)     |
| Year fixed effects    | Yes                                   | Yes                     |
| NAICS (four digits)   | Yes                                   | Yes                     |
| <i>N</i>              | 241,000                               | 80,000                  |
| <i>R</i> <sup>2</sup> | 0.329                                 | 0.436                   |

Note: Robust standard errors in parentheses. \* $p < 0.05$ , \*\* $p < 0.01$ , \*\*\* $p < 0.001$ . The sample in column (1) comprises firms with positive R&D activity. The sample in column (2) comprises payroll Gazelles with positive R&D. Data on R&D expenditures are taken from the SIRD (1980–2007) and BRDIS (2008–2019) data sets. Revenue data are drawn from the LBD. If it is unavailable, sales in the SIRD and BRDIS are used. R&D/firm revenue is winsorized at 5%. Observations are weighted using the survey weights in the SIRD and BRDIS. The number of observations is rounded to protect confidentiality. The sample period is from 1980 to 2019. FSRDC Project Number 2633 (CBDRB-FY23-P2633-R10843).

sets cover a large sample of firms (approximately 25,000–40,000 firms each year) and contain young firms that are not publicly traded. R&D intensity is defined as R&D expenditures divided by firm revenue. Table 3 shows the regression results comparing the R&D intensity of VC-backed and non-VC-backed firms, based on the following regression equation:

$$y_{it} = \beta_1 \mathbf{1}\{\text{VC-backed}_i\} + \beta_2 \text{age}_{it} + \beta_3 \mathbf{1}\{\text{VC-backed}_i\} \times \text{age}_{it} + \text{controls}_{it} + \epsilon_{it},$$

where  $y_{it}$  is an R&D/firm revenue ratio of firm  $i$  in year  $t$ , and  $\epsilon_{it}$  is an error term. Here, firms with positive R&D expenditures are analyzed. The table shows that VC-backed firms typically have a higher R&D intensity by approximately 14 percentage points relative to non-VC-backed firms and that the intensity declines with firm age. A similar pattern is observed in the Gazelle sample in column (2). These results show that VC-backed firms intensively invest in innovation, particularly in their early life. To the author's knowledge, the evidence of upfront investments of VC-backed firms, measured by the money raised over firm revenue or R&D expenditures over firm revenue, is new to this study.

## 2.5 | Equity Share in VC Financing

This subsection documents the difference in equity stakes obtained by VC investors and angel investors. Table 4 shows the

results of the regression analysis that compares the characteristics of VC deals and angel deals conditional on firm characteristics observed in the LBD, such as log(employment), firm age, and industry:

$$y_{it} = \beta_1 \mathbf{1}\{\text{VC-backed}_i\} + \text{controls}_{it} + \epsilon_{it},$$

where  $y_{it}$  is log(deal size), equity stakes acquired by the investors, and deal size/firm revenue in columns (1)–(3), respectively. Column (1) shows that VC deals are typically larger than angel deals. Column (2) shows that VC investors acquire approximately 3.3% extra equity stakes conditional on observable firm characteristics. Column (3) confirms the evidence on upfront investments documented in Figure 2: VC-backed firms raise larger financial capital relative to their revenue than angel-backed firms, and the ratio declines with firm age. All regressions control for year, deal number, initial year, and industry (four-digit NAICS code). The evidence of extra equity stakes in column (2) can be interpreted based on the revealed preference argument that VCs' advice is valuable from the startup's perspective.<sup>17</sup> Figure A5 in Appendix B.3 shows the robustness of the extra equity stakes in VC deals with descriptive statistics.

**Firm Age at the Time of the First VC Deal.** Table 5 reports the firm age at the first VC financing. Firm age is defined in the LBD, where firm age is zero in the year when the firm's oldest establishment reports positive payroll for the first time. Almost half of the VC-backed firms obtain their first VC deal by age zero, and approximately three-fourths of VC-backed firms raise VC funding by age two. This evidence shows that VC-backed firms raise financing early in their life and motivates the model's assumption that all firms choose their source of financing at birth.

## 3 | Model

This study explains the life-cycle dynamics of firms with different financing sources by developing a firm dynamics model that incorporates ex ante heterogeneity, innovation, and external financing. Newly established firms are endowed with heterogeneous growth potential and choose their source of external financing at birth.<sup>18</sup> External financing is crucial to pay for labor, capital, and innovation expenditures, where successful innovation enhances the firm's productivity. Once a firm achieves its full growth potential, its productivity depends only on exogenous productivity shocks, as in Hopenhayn (1992), after which external financing plays a minimal role. The model assumes complete information and abstracts from informational issues, such as incomplete and asymmetric information.<sup>19</sup> The economy is studied in general equilibrium.

### 3.1 | Production

Each firm has an inherent growth potential, which can be considered the quality of its business idea. An ambitious idea may allow for high growth, but this potential is realized only through investment in innovation. The potential is represented by a sequence of productivities  $\{\hat{\theta}_1, \dots, \hat{\theta}_N\}$ , referred to as a productivity ladder. Examples of such ladders are shown in Figure 3. Every firm is endowed with a ladder and begins in the

**TABLE 4** | Comparison between VC and angel deals.

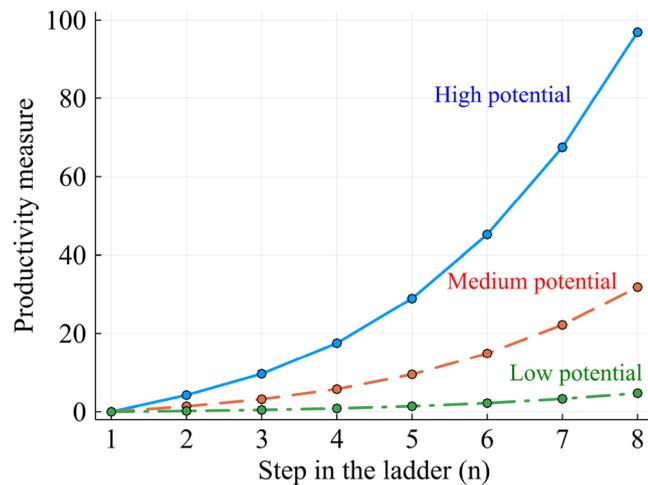
|                       | Dependent variable:   |                         |                          |
|-----------------------|-----------------------|-------------------------|--------------------------|
|                       | (1)<br>log(deal size) | (2)<br>Equity share (%) | (3)<br>Deal size/revenue |
| VC deal dummy         | 1.448***<br>(0.0271)  | 3.285***<br>(0.529)     | 7.232***<br>(0.587)      |
| log(employment)       | 0.502***<br>(0.00748) | -3.873***<br>(0.117)    |                          |
| log(deal size)        |                       | 5.731***<br>(0.102)     |                          |
| Firm age              |                       |                         | -0.994***<br>(0.102)     |
| Year fixed effects    | Yes                   | Yes                     | Yes                      |
| Age fixed effects     | Yes                   | Yes                     | No                       |
| Deal number           | Yes                   | Yes                     | Yes                      |
| Initial year          | Yes                   | Yes                     | Yes                      |
| NAICS (four digits)   | Yes                   | Yes                     | Yes                      |
| <i>N</i>              | 37,500                | 22,500                  | 37,500                   |
| <i>R</i> <sup>2</sup> | 0.398                 | 0.241                   | 0.079                    |

Note: Robust standard errors in parentheses. \*  $p < 0.05$ , \*\*  $p < 0.01$ , \*\*\*  $p < 0.001$ . The deal number represents the number of rounds in VC or angel deals. The initial year is the year when the firm's oldest establishment reports positive payroll for the first time. The deal size/revenue ratio is winsorized at 5%. Data: LBD (1997–2019) and the VC data sets. The number of observations is rounded to protect confidentiality. FSRDC Project Number 2633 (CBDRB-FY25-P2633-R12481).

**TABLE 5** | Firm age at the time of the first VC deal.

|             | Fraction (%) | Cumulative fraction (%) |
|-------------|--------------|-------------------------|
| Age ≤ 0     | 46.77        | 46.77                   |
| 1 ≤ Age ≤ 2 | 27.45        | 74.22                   |
| 3 ≤ Age ≤ 5 | 14.05        | 88.27                   |
| Age > 5     | 11.73        | 100                     |

Note: Firm age is zero in the year when the firm's oldest establishment reports positive payroll for the first time. Data: LBD (1980–2019) and VC data sets. FSRDC Project Number 2633 (CBDRB-FY23-P2633-R10843).



**FIGURE 3** | Examples of the productivity ladder.

first step, reaching its full potential upon attaining the last step. The probability of moving up the ladder (i.e., achieving successful innovation) is endogenously determined by the firm's innovation expenditures, VCs' advice, and other firm characteristics.

The model is now formalized as follows. Firms are risk-neutral and maximize the discounted sum of expected future profits. Firms produce goods with decreasing-returns-to-scale technology by hiring workers and renting capital. The production function is as follows:

$$y_t = \underbrace{(\hat{\theta}_{n_t} + \epsilon_t)^{1-\eta}}_{\text{productivity}} \underbrace{(k_t^\alpha \ell_t^{1-\alpha})^\eta}_{\text{production inputs}}, \quad (1)$$

where  $k_t$  and  $\ell_t$  denote capital and labor, respectively. Capital and labor are static inputs and purchased at prices  $R$  and  $w$ , respectively. Costs are paid one period in advance before production yields revenue. The span-of-control parameter is given by  $\eta < 1$ .

A firm's productivity is the sum of two elements,  $\hat{\theta}_{n_t}$  and  $\epsilon_t$ . The first element  $\hat{\theta}_{n_t}$  is determined by the firm's potential and innovation outcome. All firms start with the first step of their productivity ladder,  $n = 1$ , with  $\hat{\theta}_1 = 0$ . If their innovation is successful with probability  $\zeta$ , they move on to the next step. Otherwise, firms stay at the same step of the ladder in the next period. This is formalized in the following equation:

$$n_{t+1} = \begin{cases} n_t + 1 & \text{with prob. } \zeta_{t+1} \\ n_t & \text{with prob. } 1 - \zeta_{t+1}, \end{cases} \quad (2)$$

where  $n_t \in \{1, \dots, N\}$  denotes a position on the ladder at time  $t$ . The probability of moving up the ladder  $\zeta_t$  is endogenously determined by the innovation expenditures. The second element  $\epsilon_t$  follows an exogenous AR(1) process:

$$\log(\epsilon_t) = \rho \log(\epsilon_{t-1}) + \sigma_v v_t \text{ with } v_t \sim \text{Normal}(0, 1), \quad (3)$$

where  $\rho$  is the persistence of the exogenous productivity shocks, and  $\sigma_v$  is the volatility of the shocks.

The probability of moving up the ladder  $\zeta_{t+1} \in (0, 1)$  is determined by the following logistic function:

$$\underbrace{\zeta_{t+1}}_{\text{success rate}} = \frac{\exp(x_t)}{1 + \exp(x_t)}, \quad (4)$$

$$\underbrace{x_t}_{\text{factor of success}} = \underbrace{\gamma_0}_{(+)} + \underbrace{\gamma_1 \log(I_t)}_{\text{innovation expnd}} + \underbrace{\gamma_2 \log(1 + \hat{\theta}_N)}_{(-) \text{ firm's potential}} + \underbrace{\gamma_3 \mathbf{1}\{\text{fail}_t\}}_{(-)} + \underbrace{\gamma_4 \mathbf{1}\{\text{VC}\}}_{(+)} + \underbrace{\gamma_5 \log(n_t)}_{\text{step in the ladder}}, \quad (5)$$

where the success rate  $\zeta_{t+1}$  increases with the factor of success  $x_t$ . The factor of success ( $x_t$ ) is assumed to depend on the six terms in Equation (5) to match the empirical moments discussed in Section 4.1.<sup>20</sup> The second term indicates that the success probability is increasing in innovation expenditure  $I_t$ . The third to sixth terms in Equation (5) are other firm characteristics relevant to the success rate. A negative coefficient  $\gamma_2$  means that more ambitious ideas with higher potential  $\hat{\theta}_N$  are harder to materialize. A negative  $\gamma_3$  implies that if a firm fails in innovation in the last period, the probability of success declines in the following period. In practice, startups that are not growing will have a hard time maintaining their momentum.<sup>21</sup> A coefficient  $\gamma_4$  measures the value-adding effect of VCs. If VCs provide managerial advice, firms have a higher chance of successful innovation. Finally, a coefficient  $\gamma_5$  captures the relation between the success probability of innovation and the position on the ladder. All six coefficients are estimated in the calibration. Appendix A.1 discusses the plausibility of the functional form and provides additional empirical evidence.

The timeline of each period is as follows. Following Cooley and Quadrini (2001), a key assumption is that firms obtain revenue from production only in the next period and thus need to raise external funding if their cash flow falls short of labor, capital, and innovation expenditures. In practice, a critical task of startup founders is to avoid running out of cash, which is a serious concern, especially for firms pursuing high growth and rapid scale-up (cf. Feld and Mendelson 2019). The timing of expenditure and revenue in the model captures this practical aspect. Because of this assumption, the source of financing can be important for firm growth.

Figure 4 shows the timeline. Firms are endowed with growth potential  $\hat{\theta} := \{\hat{\theta}_n\}_{n=1, \dots, N}$ , initial exogenous productivity  $\epsilon_0$ , and initial assets  $\mathbf{o}_0$ . Given their initial state variables, firms decide the source of funding: VC, angel, or bank financing. Then, they raise funding and pay for labor, capital, and innovation expenditures. In the first period, at age 0, firms do not collect revenue from their production.

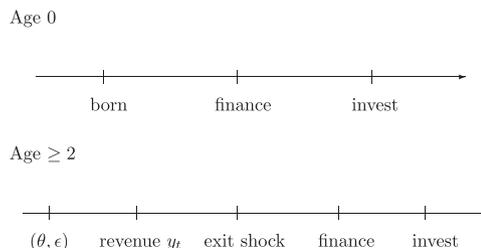


FIGURE 4 | Timeline.

At the beginning of period  $t$ , productivity  $(\hat{\theta}_n, \epsilon_t)$  is realized. Given the labor and capital inputs  $(\ell_t, k_t)$  chosen in the previous period, the firm earns revenue according to the production function (1). After the realization of revenue, firms may be hit by an exogenous exit shock with probability  $\varphi$ . In this case, firms cannot continue their business and exit the market. Otherwise, firms may raise additional external funding and pay for labor, capital, and innovation expenditures. If the business is insufficiently profitable to operate, the firm may endogenously exit the market. This may happen because firms need to pay for operational fixed costs  $c_f$  every period. One period is set to be 2 years in the model, as the duration between VC deals is typically around 1.5–2 years. The following subsections discuss the details of the firm’s decisions, separately for equity (VC and angel) financing and bank financing.

### 3.2 | Equity (VC or Angel) Financing

In equity financing, firms raise funding from investors in exchange for an equity stake in the company. Since investors own a part of the firm, they will receive dividends once the business profits materialize in the future. Firms pay a fixed cost  $c_{e,0}$  every period to operate as equity-backed firms.<sup>22</sup> In addition, raising one unit of funding costs  $c_{e,1}$  as flotation costs. These two costs are distortions in equity financing.

VCS provide managerial advice that enhances the probability of moving up the productivity ladder. In return, firms pay management fees  $(\bar{\pi}_{vc})$  each period.<sup>23</sup> These management fees are determined in equilibrium since the supply of VCS is fixed, reflecting a shortage of human capital as in Jovanovic and Szentes (2013).<sup>24</sup> Compensation  $(\bar{\pi}_{vc})$  is reflected in extra equity stakes, as VC-backed firms generally lack sufficient cash flow to cover the fees. In contrast, angel investors do not require management fees, as they operate in a competitive market and earn zero expected profits. Aside from advice and compensation, VC and angel financing have the same structure in the model.

Equity investors acquire the equity stake of the firm ( $s_t$ ) based on the value of the financial investment relative to the firm’s overall value. Firms may raise funding in several stages, and the investor’s share from earlier rounds is diluted in subsequent rounds of equity financing. Taking this into account, the total equity share of investors  $s_{t+1}$  evolves according to the following formula:

$$\underbrace{s_{t+1}}_{\text{total stakes}} = \underbrace{s_t}_{\text{previous stakes}} + (1 - s_t) \frac{(1 + c_{e,1})(-d_t)}{V_t(n_t, \epsilon_t, \mathbf{o}_t, \text{fail}_t; \hat{\theta}) + (1 + c_{e,1})(-d_t)}, \quad (7)$$

newly acquired stakes

where  $(-d_t)$  denotes the amount of funding raised in this period, and  $V_t(n_t, \epsilon_t, \mathbf{o}_t, \text{fail}_t; \hat{\theta})$  denotes the firm's value before raising money. The derivations are presented in Appendix C.1.

A value function of equity-backed firms,  $V_t(n_t, \epsilon_t, \mathbf{o}_t, \text{fail}_t; \hat{\theta})$ , is now formulated. The four state variables include the position of the ladder ( $n_t$ ), exogenous productivity shock ( $\epsilon_t$ ), cash flow at the beginning of the period ( $\mathbf{o}_t$ ), and the most recent innovation outcome ( $\text{fail}_t \in \{0, 1\}$ ). Given the state variables, firms decide whether to continue their business and, if so, choose labor and capital inputs and innovation expenditures. The revenue minus the sum of all expenditures is distributed as dividends.

Firms exit the market if the continuation value is less than their cash flow. Hence, the firm's value is the maximum of the continuation value and its cash flow:

$$V_t^j(n_t, \epsilon_t, \mathbf{o}_t, \text{fail}_t; \hat{\theta}) = \max\left\{ \underbrace{V_t^{j,C}(n_t, \epsilon_t, \mathbf{o}_t, \text{fail}_t; \hat{\theta})}_{\text{continue}}, \underbrace{\mathbf{o}_t}_{\text{cash flow}} \right\} \text{ for } j \in \{\text{VC}, \text{Angel}\}. \quad (8)$$

If the firm continues the business operation, the continuation value is as follows:

$$V_t^{j,C}(n_t, \epsilon_t, \mathbf{o}_t, \text{fail}_t; \hat{\theta}) = \max_{\epsilon_{t+1}, k_{t+1}, I_t, d_t} \left\{ \underbrace{d_t}_{\text{dividend}(+) \text{ or deal size}(-)} - \underbrace{\mathbf{1}\{(-d_t) > 0\}(-d_t, c_{e,1})}_{\text{cost of raising equity}} \right. \\ \left. + \frac{1}{1+r} \left\{ (1-\varphi) \mathbb{E} \left[ \underbrace{V_{t+1}^j(n_{t+1}, \epsilon_{t+1}, \mathbf{o}_{t+1}, \text{fail}_{t+1}; \hat{\theta})}_{\text{no exit shock}} \middle| \zeta_{t+1} \right] + \varphi \mathbb{E}[\mathbf{o}_{t+1} | \zeta_{t+1}] \right\} \right. \quad (9) \\ \left. \text{s.t. } \underbrace{d_t + Rk_{t+1} + w\ell_{t+1} + I_t + c_f + c_{e,0} + \mathbf{1}\{j = \text{VC}\}\bar{\pi}_{\text{vc}}}_{\text{expenditures}} = \underbrace{(\hat{\theta} n_t + \epsilon_t)^{1-\eta} (k_t^\alpha \ell_t^{1-\alpha})^\eta}_{=: \mathbf{o}_t(\text{cash flow})} \right. \quad (10)$$

where  $d_t$  is the value of the dividend if it is positive, and  $(-d_t)$  is the amount of money raised if  $d_t$  is negative. If the firm is hit by an exogenous exit shock in the next period with probability  $\varphi$ , the firm must exit the market with its cash flow  $\mathbf{o}_{t+1}$ . Otherwise, the firm value is given by Equation (8). In Equation (10),  $R$  is the rental rate of capital,  $w$  is the wage of workers,  $I_t$  is the innovation expenditure,  $c_f$  is the fixed operational costs, and  $c_{e,0}$  is the additional fixed cost for equity-backed firms. In VC financing, firms pay management fees  $\bar{\pi}_{\text{vc}}$  to VCs every period. Cash flow ( $\mathbf{o}_t$ ) is equal to the firm's revenue except for the initial period, where the initial cash flow is exogenously given. If the sum of all expenditures is greater than the revenue, firms rely on external financing  $(-d_t)$ .

Management fees to VCs ( $\bar{\pi}_{\text{vc}}$ ) is determined in equilibrium. Since the supply of VCs is limited, only a fixed fraction of all startups can be funded by VCs. Hence, startups need to compensate for the advice of VCs. While newborn firms are heterogeneous in their potential, VCs are homogeneous. Thus, all VCs receive the same compensation. In equilibrium, all VC-backed firms compensate  $\bar{\pi}_{\text{vc}}$  for VCs' advice so that the threshold firm is indifferent between VC financing and angel financing.<sup>25</sup> Appendix A.2 extends the model and introduces two types of VCs, reputable and nonreputable VCs, to examine its quantitative implications.

The equity share of investors is calculated using Equation (7). The above maximization problem does not involve the equity share of investors. Intuitively, since both firms and investors are risk-

neutral, the objective of both agents is to maximize the expected firm value. Appendix C.1 shows that the above maximization problem is equivalent to maximizing the founder's value, which is given by the founder's equity share multiplied by the firm's postmoney valuation. The compensation for VCs is reflected in the extra equity stakes, as  $\bar{\pi}_{\text{vc}}$  increases the amount of money raised  $(-d_t)$  in Equation (10), resulting in higher equity stakes in Equation (7).

### 3.3 | Bank Financing

Bank-backed firms raise defaultable short-term debt instead of raising equity. The default procedure incurs costs, and banks can seize only part of the firm's value. Banks take into account the possibility of default and these costs, and charge a loan rate such that the expected return equals the risk-free rate.

A firm raises debt  $b_{t+1}$  with price  $q_t(b_{t+1}, k_{t+1}, I_t; n_t, \epsilon_t, \mathbf{o}_t, \text{fail}_t, \hat{\theta})$  at time  $t$  and pays back  $b_{t+1}$  in the next period. The price of debt satisfies  $q_t < 1$  and is a function of control variables ( $b_{t+1}$ : size of debt,  $k_{t+1}$ : capital input,  $I_t$ : innovation expenditures) and state variables of the firm. The bank loan rate is given by the inverse of the price  $1/q_t$  and is equal to the risk-free rate,  $1+r$ , if the probability of default in the next period is zero.

In bank financing, the firm's cash flow is revenue minus the debt repayment:

$$\mathbf{o}_t = y_t - b_t. \quad (11)$$

If the cash flow is negative, the firm either defaults on debt, in which case the firm loses all revenue and shuts down its business (i.e., Chapter 7 bankruptcy), or borrows additional money and rolls over the debt. The decision to default, denoted by  $\Delta_{t+1} = 1$ , is given by

$$\Delta_{t+1} = \mathbf{1}\{\mathbf{o}_{t+1} < 0 \text{ and } (V_{t+1} < 0 \text{ or exogenous exit shock})\}. \quad (12)$$

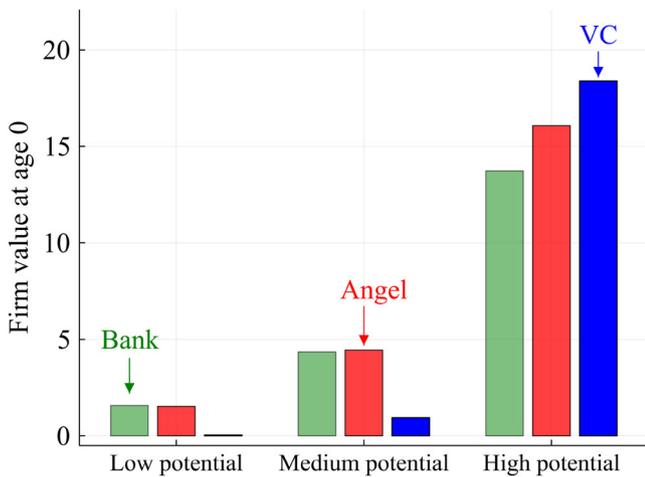
The firm defaults on the debt if the outstanding debt exceeds revenue and the firm does not operate in the next period, either because of the firm's negative present value or because of an exogenous exit shock.

Banks operate in a competitive market and charge a bank loan rate that satisfies the following zero-expected-profit condition:

$$q_t(\cdot) = \frac{1}{1+r} \mathbb{E}_t \left[ \underbrace{\mathbf{1}\{\Delta_{t+1} = 0\}}_{\text{no default}} + \underbrace{\mathbf{1}\{\Delta_{t+1} = 1\}}_{\text{default}} \left( \frac{y_{t+1}}{b_{t+1}} - c_d \right) \right]. \quad (13)$$

If a firm does not default on debt ( $\Delta_{t+1} = 0$ ), a bank receives full repayment on the debt. In the case of default ( $\Delta_{t+1} = 1$ ), a return on debt for the bank is given by  $(y_{t+1}/b_{t+1} - c_d)$ . This is because the firm transfers all revenue ( $y_{t+1}$ ) to the bank upon default, but the default incurs costs that are proportional to the size of the debt.

The value function of a bank-backed firm is now formulated. At the beginning of each period, the firm chooses whether to continue, repay its debt and exit, or default and exit. Accordingly,



**FIGURE 5** | Choice of financing source at age 0.

the firm's value is the maximum of the continuation value, the cash flow, and the default value, which is zero from the business owner's perspective:

$$V_t^{\text{Bank}}(n_t, \epsilon_t, \mathbf{o}_t, \text{fail}_t; \hat{\theta}) = \max \left\{ \underbrace{V_t^{\text{Bank,C}}(n_t, \epsilon_t, \mathbf{o}_t, \text{fail}_t; \hat{\theta})}_{\text{continue}}, \underbrace{\mathbf{o}_t}_{\text{exit}}, \underbrace{0}_{\text{default}} \right\}.$$

The continuation value is given as follows:

$$V_t^{\text{Bank,C}}(n_t, \epsilon_t, \mathbf{o}_t, \text{fail}_t; \hat{\theta}) = \max_{d_t \geq 0, k_{t+1}, b_{t+1}, I_{t+1}} d_t + \frac{1}{1+r} \left\{ (1-\varphi) \underbrace{\mathbb{E} \left[ V_{t+1}^{\text{Bank}}(n_{t+1}, \epsilon_{t+1}, \mathbf{o}_{t+1}, \text{fail}_{t+1}; \hat{\theta}) \right]}_{\text{no exit shock}} + \varphi \underbrace{\mathbb{E} \left[ \max \{0, \mathbf{o}_{t+1}\} \right]}_{\text{exogenous exit}} \right\} \quad (14)$$

$$s.t. \underbrace{d_t + Rk_{t+1} + w\ell_{t+1} + I_t + c_f}_{\text{expenditures}} = \underbrace{(\hat{\theta}_{n_t} + \epsilon_t)^{1-\alpha} (k_t^\alpha \ell_t^{1-\alpha})^\alpha}_{=: \mathbf{o}_t \text{ (cash flow)}} - b_t + \underbrace{q_t (b_{t+1}, k_{t+1}, I_t) b_{t+1}}_{\text{new debt}}$$

where the price of debt  $q_t$  and the default decision  $\Delta_{t+1}$  are given by Equations (12) and (13), respectively. The probability of moving up the ladder  $\zeta_{t+1}$  is determined by innovation functions (4) and (5). If the cash flow exceeds the total expenditures, the firm distributes the business surplus as a dividend. Otherwise, firms borrow money from a bank. Appendix C.2.3 describes the optimality conditions and numerical algorithms used to compute the value function.

### 3.4 | Choice of Financing Source

Firms with heterogeneous initial characteristics choose the financing source that maximizes the firm's present discounted value:

$$V_0(n_0, \epsilon_0, \mathbf{o}_0, \hat{\theta}) = \max \left\{ V_0^{\text{VC}}(n_0, \epsilon_0, \mathbf{o}_0, \hat{\theta}), V_0^{\text{Angel}}(n_0, \epsilon_0, \mathbf{o}_0, \hat{\theta}), V_0^{\text{Bank}}(n_0, \epsilon_0, \mathbf{o}_0, \hat{\theta}) \right\}.$$

Figure 5 shows an example of the firm's value in the model depending on growth potential. In the figure, high-potential firms attain the highest value if they choose VC financing. In contrast, low-potential firms obtain the highest value from bank financing. Intuitively, high-potential firms benefit the most from the advice of VCs because the gain from successful innovation is exceptionally high.<sup>26</sup> Low-potential firms do not heavily invest

in innovation; thus, the probability of default and the associated default costs in bank financing are low, as shown in Figure A6 in Appendix C.3.1. Medium-potential firms choose angel financing because equity financing is more suitable than bank financing to finance innovation, as failure in innovation may lead to costly bankruptcy in bank financing, but the compensation for VCs is too expensive. This results in a monotonic relationship between a firm's potential and the mode of financing.

Firms are born with three initial characteristics  $(\hat{\theta}, \epsilon_0, \mathbf{o}_0)$ . The growth potential  $\hat{\theta} = \{\hat{\theta}_n\}_{n=1, \dots, N}$  is summarized by a single number  $\hat{\theta}_N$ , which is the productivity at the last step of the ladder. Productivity levels in other rungs of the ladder  $\{\hat{\theta}_n\}_{n=1, \dots, N}$  are determined by the following parametric function of  $\hat{\theta}_N$  and  $n$ :

$$\hat{\theta}_n = \hat{\theta}_N \left[ (1-\xi) \left( \frac{n-1}{N-1} \right) + \xi \left( \frac{n-1}{N-1} \right)^3 \right]. \quad (15)$$

This functional form satisfies  $\hat{\theta}_{n=1} = 0$  and  $\hat{\theta}_{n=N} = \hat{\theta}_N$ . If  $\xi = 0$ , the firm's productivity increases linearly along the ladder. If  $\xi > 0$ , the ladder has a convex shape. The curvature of the ladder  $\xi$  is calibrated in Section 4.1 to match the average firm growth in the data.<sup>27</sup> The growth potential  $\hat{\theta}_N$  follows a log-normal distribution:<sup>28</sup>

$$\hat{\theta}_N \sim \text{LogNormal}(\mu_\theta, \sigma_\theta). \quad (16)$$

The initial exogenous productivity  $\epsilon_0$  also follows a log-normal distribution:<sup>29</sup>

$$\epsilon_0 \sim \text{LogNormal}(\mu_{\epsilon_0}, \sigma_{\epsilon_0}). \quad (17)$$

The initial assets  $\mathbf{o}_0$  are assumed to be the same for all firms.<sup>30</sup>

**Free-Entry Condition.** Entrants are ex ante identical. The growth potential  $\hat{\theta}$  and exogenous productivity  $\epsilon_0$  are drawn upon entry. The free-entry condition ensures that the ex ante value of the entry is equal to the cost of entry, denoted by  $f^e$ :

$$\text{Value of Entry} := \sum_{\epsilon_0, \hat{\theta}} \underbrace{V_0(n_0, \epsilon_0, \mathbf{o}_0, \text{fail}_0 = 0; \hat{\theta})}_{\text{firm value given an initial state}} \Phi(\epsilon_0, \hat{\theta}) = \underbrace{f^e}_{\text{cost of entry}}, \quad (18)$$

where the growth potential  $\hat{\theta}$  and initial exogenous productivity  $\epsilon_0$  follow distributions (16) and (17).  $\Phi(\epsilon_0, \hat{\theta})$  denotes the probability mass of firms with initial states  $(\epsilon_0, \hat{\theta})$ , where  $\sum_{\epsilon_0, \hat{\theta}} \Phi(\epsilon_0, \hat{\theta}) = 1$ . All firms start from an initial step of the ladder ( $n_0 = 1$ ) and with initial assets  $\mathbf{o}_0$ . Newly established firms have not failed in innovation; thus, their failure status starts with  $\text{fail}_0 = 0$ .

### 3.5 | Aggregation

This subsection describes a representative household and capital renters. The economy is closed with market clearing conditions.

**Representative Household.** The representative household supplies a fixed amount of labor  $\bar{L}$  every period. All profits from heterogeneous firms and VCs are returned to the household, denoted by  $\Pi_t$ .<sup>31</sup> The infinitely lived household maximizes the

lifetime utility subject to a budget constraint:

$$\max_{\{c_t, a_{t+1}\}_{t \geq 0}} \sum_{t=0}^{\infty} \beta^t u(c_t) \text{ s.t. } c_t + a_{t+1} = w_t \bar{L} + (1+r)a_t + \Pi_t,$$

where profits  $\Pi_t$  are given by  $\sum_i [\pi_{it} + \mathbf{1}\{\text{VC}_i\} \bar{\pi}_{\text{vc}}]$ . Each firm is indexed by  $i$ . The household's saving  $a_t$  returns a risk-free rate,  $1+r$ . The flow utility is assumed to be CRRA (constant relative risk aversion). The household chooses consumption and savings according to the Euler equation:

$$u'(c_t) = \beta(1+r)u'(c_{t+1}).$$

In the steady state, the Euler equation implies

$$1+r = \frac{1}{\beta}. \quad (19)$$

Hence, the steady-state risk-free rate is given by the inverse of the discount factor  $\beta$ .

**Capital Renters.** Capital renters collect savings from the representative household and rent capital to firms at a rental rate  $R$ . Since capital depreciates with rate  $\delta$ , the rental rate of capital  $R$  is given by

$$R = r + \delta. \quad (20)$$

The capital rental market is competitive, and capital renters make zero profits.

**Market Clearing Conditions.** The labor, capital, and final goods markets clear in equilibrium. First, the aggregate labor demand by heterogeneous firms equals the household's exogenous labor supply:

$$\sum_i \ell_{it} = \bar{L}. \quad (21)$$

Second, the aggregate capital rented by capital owners to heterogeneous firms is equal to the household's savings:

$$\sum_i k_{i,t+1} = a_{t+1}.$$

Finally, the total output produced plus the undepreciated capital is equal to the sum of all expenditures, household consumption, and capital in the next period:

$$Y_t + (1-\delta)K_t = \underbrace{\sum_i [I_{it} + c_f + f^e \mathbf{1}\{\text{age}_i = 0\} + \mathbf{1}\{\text{equity}_i\}(c_{e,0} + c_{e,1}(-d_{it})) + \Delta_{it} c_d b_{it}]}_{\text{all expenditures (= EXPND}_t\text{)}} + C_t + K_{t+1},$$

where  $Y_t := \sum_i y_{it}$  and  $K_t := \sum_i k_{it}$  denote the aggregate output and capital, respectively. In the steady state, capital in the economy is invariant over time. Therefore, household consumption in the steady state is given by

$$C = Y - \text{EXPND} - \delta K.$$

The distribution of heterogeneous firms with state variables  $(n_i, \varepsilon_i, \mathbf{o}_i, \text{fail}_i; \hat{\theta}_i)$  is stationary in the steady state.<sup>32</sup> Wages are set to clear the free-entry condition (18). In the steady state, the rental price of capital  $R$  is determined by the discount rate of the household and the depreciation rate, as shown in Equations (19) and (20). The price of final goods is normalized to one. The measure of entrants in the steady state is given by  $M^e$ .

## 4 | Quantitative Analysis

The model is calibrated to capture the salient features of firm dynamics and explains the substantial growth and upfront investments of VC-backed firms as untargeted moments. The calibrated model is used to quantify the importance of VC financing at the micro and macrolevels.

### 4.1 | Calibration

The model features the 23 parameters listed in Table 6. Nine of these parameters are fixed exogenously, while the remaining 14 parameters are calibrated internally to minimize the distance between the model-implied and targeted data moments. Figure 6 and Table 7 show the targeted moments.

**Exogenous Parameters.** The model period is 2 years, and the risk-free rate is set to  $r = 0.08$ . Capital depreciates at rate  $\delta = 0.2$  biannually. The capital coefficient in the production function (1) is  $\alpha = 0.33$ . The span-of-control parameter is  $\eta = 0.85$  (e.g., Midrigan and Xu 2014). The exogenous biannual exit rate is set to  $\varphi = 0.08$ .<sup>33</sup> The persistence parameter in the exogenous productivity process (3) is chosen to be  $\rho = 0.8$ .<sup>34</sup> The standard deviation of the exogenous productivity shocks  $\sigma_v$  is set to unity. The unit cost of raising capital is set equal to  $c_{e,1} = 0.04$ , within a range of values reported in the literature (e.g., Gomes 2001 and Hennessy and Whited 2007). Finally, startups launch their businesses with initial assets  $\mathbf{o}_0$ , which are equal to the wage of one worker.<sup>35</sup>

**Fitted Parameters.** The remaining parameters are calibrated to match the empirical moments. The set of parameters  $(\gamma_0, \gamma_1, \gamma_2, \gamma_3, \gamma_4, \gamma_5)$  in the innovation function (5) is distinctive to this study. Estimating innovation functions is generally challenging because innovation inputs and outputs are not directly observable.<sup>36</sup> Here, the coefficients are calibrated using VC and angel deals data.

In practice, VC-backed firms raise money in multiple rounds, allowing firms and VCs to assess their performance before raising additional capital. Thus, subsequent VC rounds can be viewed as an indicator of satisfactory performance. Motivated by this, the parameters are chosen such that the model-implied probabilities of raising the second and fifth rounds match their empirical counterparts (48.4% and 11.8%, respectively). Figure 6 (left panel) shows that the model and data align well in this dimension. These moments help identify the coefficients  $\gamma_0$  (intercept) and  $\gamma_5$  (coefficient on  $\log(n_t)$ ) in the innovation function, which governs the innovation success rates at the initial and upper steps of the ladder conditional on innovation expenditures.

TABLE 6 | Model parameters.

| Parameters                       | Values | Description                        | Identification                        |
|----------------------------------|--------|------------------------------------|---------------------------------------|
| <i>Innovation function</i>       |        |                                    |                                       |
| $\gamma_0$                       | 5.42   | intercept                          | Pr(second VC round)                   |
| $\gamma_1$                       | 0.46   | coef on $\log(I)$                  | equity share of VC (at age 0)         |
| $\gamma_2$                       | -0.93  | coef on $\log(1 + \hat{\theta}_N)$ | equity share of angel (at age 0)      |
| $\gamma_3$                       | -4.50  | coef on failure                    | average firm size over the life cycle |
| $\gamma_4$                       | 0.16   | coef on VC                         | VCs' extra equity share (3.3%)        |
| $\gamma_5$                       | 0.09   | coef on $\log(n)$                  | Pr(fifth VC round)                    |
| <i>Productivity distribution</i> |        |                                    |                                       |
| $\mu_\theta$                     | -4.34  | mean of $\log(\hat{\theta}_N)$     | fraction of Gazelles                  |
| $\sigma_\theta$                  | 3.89   | std of $\log(\hat{\theta}_N)$      | Pareto tail                           |
| $\mu_{\epsilon_0}$               | 1.64   | mean of $\log(\epsilon_0)$         | average firm size over the life cycle |
| $\sigma_{\epsilon_0}$            | 4.04   | std of $\log(\epsilon_0)$          | average firm size over the life cycle |
| $\rho$                           | 0.8    | persistence                        | exogenous                             |
| $\sigma_\nu$                     | 1      | std of the AR(1) shocks            | exogenous                             |
| <i>Financial frictions</i>       |        |                                    |                                       |
| $c_{e,0}$                        | 0.26   | fixed cost of equity               | top 2% choose equity                  |
| $c_{e,1}$                        | 0.04   | unit cost of equity                | exogenous                             |
| $c_d$                            | 0.42   | default costs                      | loan recovery rate                    |
| $\mathfrak{a}_0$                 | 0.41   | initial assets                     | wage of one worker                    |
| <i>Other parameters</i>          |        |                                    |                                       |
| $r$                              | 0.08   | risk-free rate                     | standard value (2 years)              |
| $\delta$                         | 0.2    | capital depreciation               | standard value (2 years)              |
| $\alpha$                         | 0.33   | capital share                      | standard value                        |
| $\eta$                           | 0.85   | span-of-control                    | standard value                        |
| $\varphi$                        | 0.08   | exit shock                         | exogenous (2 years)                   |
| $\xi$                            | 0.71   | convex ladder                      | average firm size over the life cycle |
| $c_f$                            | 0.37   | operating costs                    | exit rate                             |

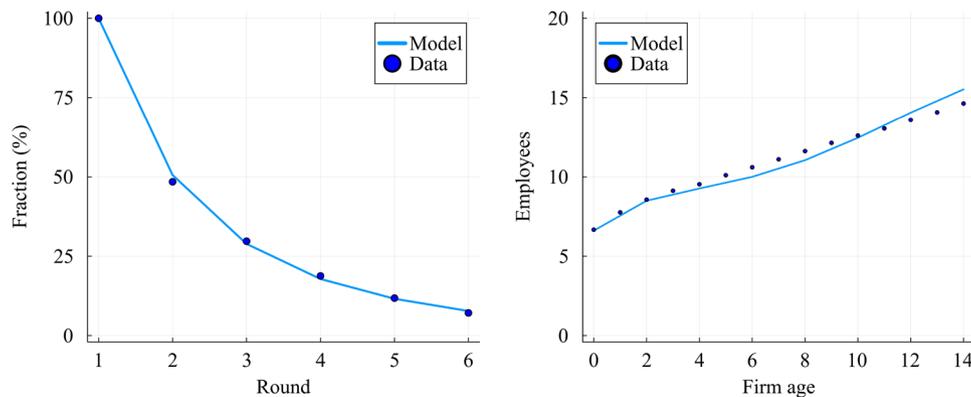


FIGURE 6 | Probability of subsequent VC deals and average firm size.

Notes: The left panel shows the fraction of VC-backed firms that raised the  $n$ th VC round ( $n = 1, \dots, 6$ ). The right panel shows the average size of all firms in the economy from age 0 to 14. The data are from Crunchbase (1980–2022) and the replication file of Sterk et al. (2021), respectively.

TABLE 7 | Remaining target moments.

| Description                         | Target | Model |
|-------------------------------------|--------|-------|
| Fraction of “Gazelles”              | 0.87%  | 0.89% |
| Pareto tail                         | 1.06   | 1.08  |
| Average VC equity share at age 0    | 33.4%  | 34.0% |
| Average angel equity share at age 0 | 23.2%  | 22.7% |
| Exit rate (annual) at age 0–20      | 9.4%   | 7.7%  |
| Loan recovery rate                  | 54%    | 53%   |
| The fraction of VC-backed firms     | 0.2%   | 0.2%  |
| The fraction of equity-backed firms | 2%     | 2%    |
| Extra equity share of VC investors  | 3.3%   | 3.3%  |

Note: The data moments on the fraction of Gazelles, the fraction of VC-backed firms, and the extra equity share of VC investors are taken from the descriptive evidence in Section 2. Gazelles are firms with an average annual growth rate above 20% in the first 5 years and employment of 100 or above by age 20. The Pareto tail of firm size distribution, the average equity share of VCs and angel investors, exit rate, and loan recovery rate are taken from Luttmer (2010), PitchBook (1980–2022), BDS (2000–2019), and Ottonello and Winberry (2020), respectively. The fraction of equity-backed firms is set to be 10 times the fraction of VC-backed firms.

The parameter  $\gamma_3 < 0$  measures the negative impact of innovation failure on future innovation. If the magnitude of  $\gamma_3$  is large enough, VC-backed firms will not raise the next VC round in case of innovation failure. This parameter also affects the average growth of all firms, which helps to pin down its value.

The elasticity of the probability of successful innovation to innovation expenditures ( $\gamma_1$ ; the coefficient of  $\log(I_t)$ ) is pinned down based on the equity stakes of VC investors at firm age 0. The idea is that since VC-backed firms raise money to invest primarily in innovation and the investor's equity share is approximately equal to the money injected divided by the firm value, the equity share contains information about the size of innovation expenditures relative to firm value.<sup>37</sup>

The parameter  $\gamma_2$  (the coefficient on  $\log(1 + \hat{\theta}_N)$ ) determines the relationship between the firm's potential and innovation success rate. This parameter is pinned down by targeting the angel investors' average equity stake in the first deal. This moment is informative about the intensity of the innovation activities of angel-backed firms.<sup>38</sup>

The value-adding effect of VCs, denoted by  $\gamma_4$ , is identified by the extra equity stake of VCs documented in the empirical section. The idea is to measure the perceived value-adding effect of VCs from the startup founder's perspective. The parameter  $\gamma_4$  is jointly determined with the VCs' management fees  $\bar{\pi}_{vc}$ . Firms at the 99.8th percentile (top 0.2%) are at the threshold and indifferent between VC and angel financing. While VC financing boosts the probability of successful innovation, VCs require 3.3% of extra equity stake. The parameter  $\gamma_4$  and VCs' management fees  $\bar{\pi}_{vc}$  are set such that the benefit and cost balance out for firms at the top 0.2% threshold.

The next set of parameters ( $\mu_\theta, \sigma_\theta, \mu_{\epsilon_0}, \sigma_{\epsilon_0}$ ) govern the productivity distribution. The distribution of growth potential  $\hat{\theta}_N$ , given

by  $\text{LogNormal}(\mu_\theta, \sigma_\theta)$ , is set to match the fraction of Gazelles among all startups, 0.87%, taken from Table 2, and the Pareto tail of the firm-size distribution, 1.06, among firms with more than 100 employees, as reported by Luttmer (2010). The distribution of initial productivity  $\epsilon_0$ , given by  $\text{LogNormal}(\mu_{\epsilon_0}, \sigma_{\epsilon_0})$ , regulates the average firm size in early years.

The curvature of the productivity ladders ( $\xi$ ) and the wage ( $w$ ) also govern the evolution of the average firm size. Higher wage  $w$  lowers the average firm size, whereas the curvature of the ladder  $\xi$  forms the growth trajectory of the average firm size. The average size of all firms from age 0 to 14 is targeted, as depicted in the right panel of Figure 6. The model fits the average firm size over the life cycle reasonably well. The coefficient  $c_f$  is chosen to match the exit rate because higher operating costs  $c_f$  induce more firms to exit.<sup>39</sup>

Finally, the two parameters ( $c_{e,0}, c_d$ ) related to financial frictions are set such that 2% of all firms choose equity financing (VC or angel) and that banks recover 54% of defaulting loans in case of bankruptcy, a value taken from Ottonello and Winberry (2020) and Gomes and Sarkisyan (2023).<sup>40</sup> Parameter  $c_d = 0.42$  implies that defaulting on bank loans incurs costs equivalent to 42% of outstanding debt.

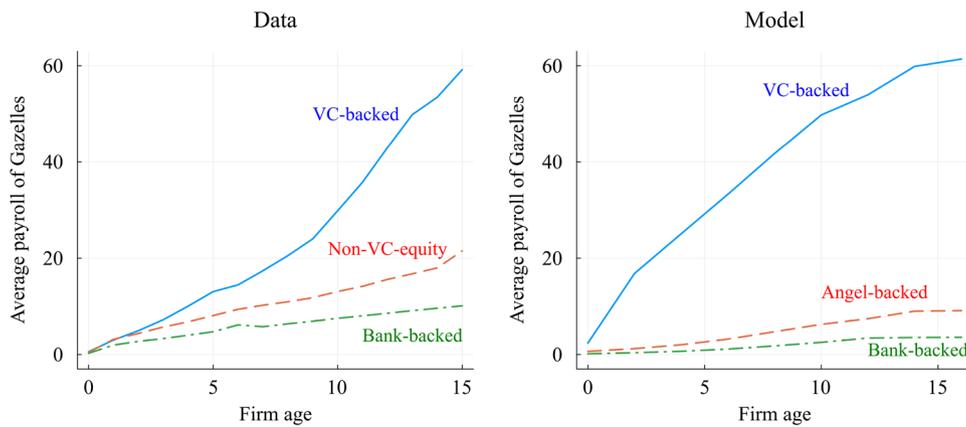
Overall, 19 moments are targeted to set 14 parameter values and two endogenous prices ( $w$  and  $\bar{\pi}_{vc}$ ) in the model.<sup>41</sup> The calibrated parameters minimize the sum of squared distances between the targets and the model-implied moments.<sup>42</sup>

## 4.2 | Model Fit

The calibrated model explains the substantial growth and upfront investments of VC-backed firms, as documented in Section 2. Furthermore, the model's prediction on the evolution of equity shares and the average total money raised in VC and angel financing are compared with the data. All these moments are untargeted and reasonably match their empirical counterparts.

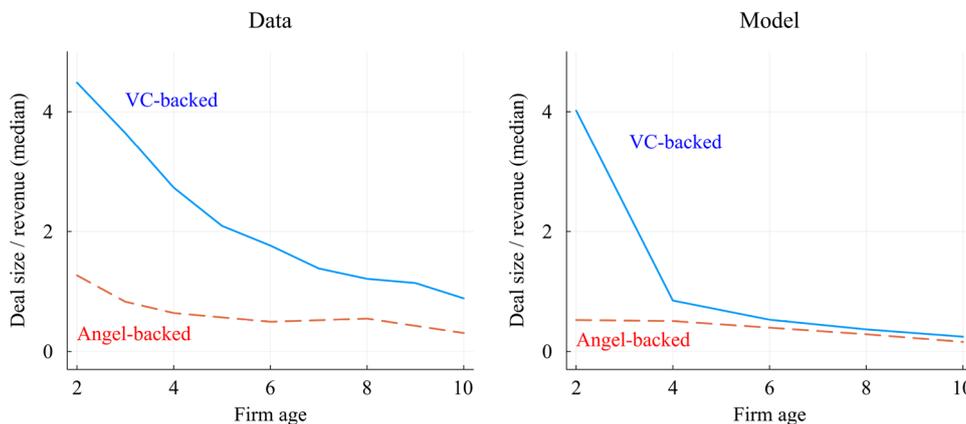
**Two Motivational Facts.** The first motivational fact is the substantial growth of VC-backed firms relative to non-VC-backed firms in the Gazelle sample. The simulated sample of Gazelles is constructed following the same definition as in the data, and the average firm size at each age is computed separately for VC-, angel-, and bank-backed firms. Figure 7 shows the average growth trajectories over the life cycle for the data (left panel) and the model (right panel). The model captures the monotonic relationship between the source of financing and firm growth, although the growth of VC-backed firms is more pronounced in the model.<sup>43</sup>

The second motivational fact is the upfront investment of equity-backed firms. To assess the model's prediction, the ratios of money raised (i.e., deal size) to firm revenue are computed using a simulated sample of VC- and angel-backed firms. Figure 8 displays the median values over the firm's life cycle. Consistent with the data, VC-backed firms make large upfront investments that are several times greater than their revenue in the early stages of their life cycle.



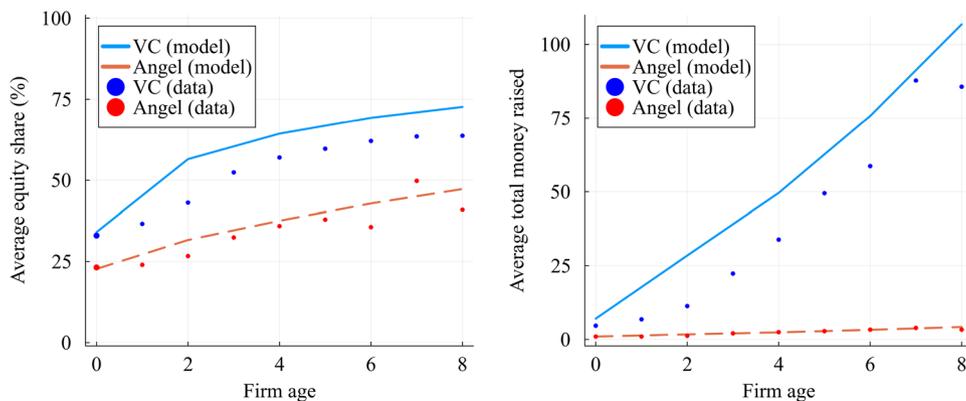
**FIGURE 7** | Growth trajectory of Gazelle firms (data vs. model).

Notes: The left panel presents the motivating facts described in Section 2, while the right panel shows the predictions of the model.



**FIGURE 8** | Upfront investment of high-potential firms (data vs. model).

Notes: The left panel presents the motivating facts described in Section 2, while the right panel shows the predictions of the model. Since firms earn zero revenue at age 0 in the model, deal size over revenue at age 0 is not depicted.



**FIGURE 9** | Average investor equity shares and total money raised (data vs. model).

Notes: The average equity share at age 0 is targeted in the calibration, whereas other moments are untargeted. The equity share represents the total equity share of investors. The total amount of money raised is shown relative to the average amount raised at age 0 in angel financing. The data are drawn from PitchBook (1980–2022).

**Other Untargeted Moments.** Additional untargeted moments include the evolution of investors’ average equity share and the total money raised by VC- and angel-backed firms over their life cycle, as shown in Figure 9. According to the data, VC investors

typically acquire more than half of a firm’s ownership stake after several rounds of investment. Angel investors also increase their ownership stake over the course of financing, but less than VC investors. These features are well captured in the model (left

panel), although only the values at age 0 are targeted in the calibration.<sup>44</sup> The right panel compares the evolution of total money raised over the life cycle between the model and the data, with variables normalized by the funding size of angel-backed firms at age 0. In the data, the amount of money raised by VC-backed firms is significantly larger than that of angel-backed firms and increases substantially over the life cycle.<sup>45</sup> Although the relative size of VC and angel investments is not targeted in the calibration, this aspect is well captured by the model. Finally, the annualized default rate among all firms in the model is around 0.39%, close to the values reported in the literature.<sup>46</sup>

### 4.3 | Counterfactual Experiments

This subsection quantifies the role of VCs at the micro and macrolevels. In the microlevel counterfactual experiment, the hypothetical growth path of VC-backed firms is simulated while the wage is kept unchanged. In a counterfactual economy that differs from the baseline economy in terms of available financing sources, the wage is determined in equilibrium such that the free-entry condition (18) is satisfied. In the steady state, the measure of entrants  $M^e$  is constant over time and is determined by the labor market clearing condition (21), which can be written as follows:

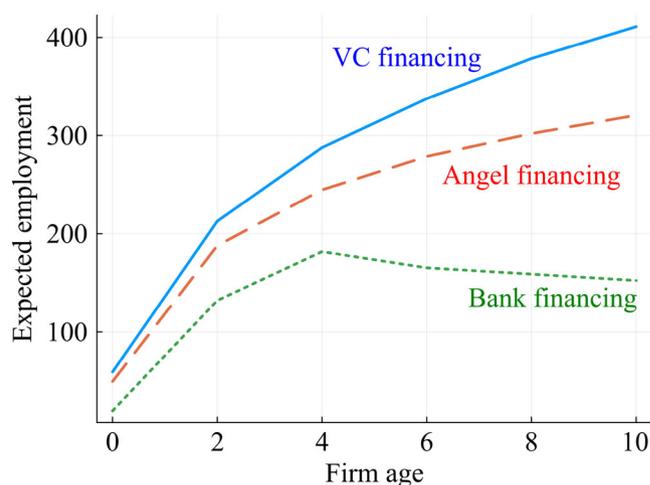
$$M^e \sum_{h=0}^{\infty} \sum_{\epsilon_0, \hat{\theta}} \ell_h(n_h, \epsilon_h, \mathbf{o}_h; \hat{\theta}) \Phi(\epsilon_0, \hat{\theta}) = \underbrace{\bar{L}}_{\text{exogenous labor supply}}.$$

Total labor demand is the sum of labor demand across cohorts  $h = 0, 1, \dots$ . In equilibrium, it equals the representative household's exogenous total labor supply.

**The Role of VCs.** The contribution of VCs' advice at the microlevel is quantified by predicting the growth trajectories of VC-backed firms under alternative financing sources. Figure 10 shows the expected growth trajectories of VC-backed firms under angel and bank financing, computed as the product of the average employment of surviving firms and the survival rate. The counterfactual predicts that firms born with the same growth potential would be 22% smaller at age 10 under angel financing compared to VC financing. Furthermore, the expected firm size would decline by 52% under bank financing relative to angel financing at age 10, underscoring the importance of equity financing for high-growth firms.

A counterfactual exercise at the macrolevel simulates an economy in which VC financing is unavailable to quantify the role of VCs in the macroeconomy. In this scenario, VC-backed firms in the status quo would instead raise angel financing. Table 8 shows that the steady-state aggregate output is predicted to decline by around 0.22%. Aggregate consumption declines by around 0.46%, which is equivalent to approximately 80 billion dollars based on the total consumption expenditures in the US in 2022.<sup>47</sup> Hence, VCs' advice has a sizable impact on the economy. In the counterfactual economy, wages decline such that the value of entry remains unchanged. The employment share of Gazelles also declines since high-potential firms are less likely to succeed in innovation.

The second column shows the simulation results for an economy without any equity (VC or angel) financing. This leads to around



**FIGURE 10** | Predicted growth trajectories of VC-backed firms under alternative financing sources.

*Notes:* Expected employment is defined as the average employment of surviving firms multiplied by the survival rate. The solid line shows the expected employment of VC-backed firms simulated using the calibrated model. The dashed line (angel financing) and dotted line (bank financing) show the expected employment of the same firms under alternative sources of financing.

0.76% lower aggregate consumption in the steady state. Firms that are equity-backed in the status quo now rely on bank financing and are less likely to seize their growth opportunities, leading to a loss in aggregate consumption. The third column reports the simulation results in an economy with more VCs, where the fraction of VC-backed firms is 0.4% instead of 0.2%.<sup>48</sup> If the number of VCs in the economy doubles, more startups benefit from the advice of VCs. In addition, the larger supply of VCs reduces equilibrium management fees, further facilitating the growth of VC-backed firms. As a result, steady-state output and consumption increase by 0.26% and 0.33%, respectively.

Finally, Appendix A.3 quantitatively examines the relationship between the surge in VC and the increase in firm concentration over the past 40 years. The transitional dynamics are approximated by a sequence of steady states. The analysis shows that the rise of VCs accounts for around 27% of the increase in firm concentration (Figure A2).

## 5 | Concluding Remarks

This study quantitatively examines the growth dynamics of VC-backed firms in the US economy. Using an administrative data set, it documents the substantial growth of VC-backed firms at the microlevel and their contribution to growth at the macrolevel. VC-backed firms are characterized by large upfront investments and extra equity stakes acquired by VC investors. Based on this empirical evidence, this study develops a firm dynamics model over the life cycle with innovation-based endogenous firm productivity and the choice of financing from VC, angel, and bank financing. The model explains the growth trajectories of firms under different financing sources and implies that VCs' managerial advice accounts for nearly one-fourth of VC-backed

TABLE 8 | Counterfactual economies.

|                      | Without VCs (%) | Without any equity (%) | More VCs (%) |
|----------------------|-----------------|------------------------|--------------|
| Consumption (EV)     | -0.46           | -0.76                  | 0.33         |
| Output               | -0.22           | -0.51                  | 0.26         |
| Wage                 | -0.18           | -0.45                  | 0.24         |
| Emp share of Gazells | -4.37           | -3.07                  | 1.64         |

Note: This table shows the percentage changes in the aggregate variables in the steady-state analysis from the baseline economy to counterfactual economies without VC, without any equity financing, and with more VCs. Without the VC sector, all firms raise either angel or bank financing. Without equity financing, all firms rely on bank financing. An economy with more VCs has twice as many VCs as the baseline economy. The percentage change in consumption is identical to the equivalent variation (EV) because the household's utility depends only on consumption. The equilibrium wage clears the free-entry condition.

firms' growth. The macroeconomic importance of VC financing is quantified through a general equilibrium analysis.

Based on the results of this study, several directions for future research can be pursued. First, this paper analyzes firm growth in a stationary equilibrium. Extending the model to an endogenous growth framework in which the economy sustains long-run growth would be a valuable next step. Such an extension would enable the analysis of the impact of the VC sector on aggregate growth. Second, the two roles of VCs examined here are equity-based funding and managerial advice. In addition, VCs may also screen startups and monitor firms' use of funds. Extending the framework to incorporate uncertainty in firm potential and information asymmetry between firm owners and investors would be useful for understanding the impact of information frictions on firm growth and aggregate output.

### Acknowledgments

Any views expressed are those of the author and not those of the US Census Bureau. The Census Bureau has reviewed this data product to ensure appropriate access, use, and disclosure avoidance protection of the confidential source data used to produce this product. This research was performed at a Federal Statistical Research Data Center under FSRDC Project Number 2633 (CBDRB-FY23-P2633-R10186, CBDRB-FY23-P2633-R10510, CBDRB-FY23-P2633-R10843, CBDRB-FY25-P2633-R12481), while the author was a Special Sworn Status researcher at the US Census Bureau. The author is grateful to Jeremy Greenwood, Dirk Krueger, and Sergio Salgado for their guidance and helpful suggestions. The author also thanks Jesus Fernandez-Villaverde, the anonymous referee, and the participants of the Midwest Macroeconomics Meeting, BSE Summer Forum Workshop on Entrepreneurship, EEA-ESEM 2024, and ASSA 2025 Annual Meeting for their helpful comments. Access to the Crunchbase database is highly appreciated. All errors are the author's own.

### Data Availability Statement

Code and data moments used in this paper are openly available at <https://doi.org/10.3886/E240241V1>. The confidential microdata maintained by the US Census Bureau are accessible to qualified researchers with approved projects through the Federal Statistical Research Data Center network. The proprietary venture capital data sets used in this study are not publicly available and cannot be shared.

### Endnotes

<sup>1</sup>VC is defined as "independent, professionally managed, dedicated pools of capital that focus on equity or equity-linked investments in privately held, high growth companies" (Gompers and Lerner 2001). VCs raise funds primarily from institutional investors, such as pension

funds, in the form of limited partnerships, and they actively monitor and advise the firms in which they invest. They typically serve as board directors and occasionally recruit executives (cf. Metrick and Yasuda 2021; Greenwood et al. 2022b). Notable examples of VC-backed firms include Amazon, Apple, Facebook, Google, Microsoft, Moderna, Netflix, Starbucks, Tesla, and Uber (Source: SDC New Issues).

<sup>2</sup>Angel investors are wealthy individuals who invest their personal funds in startups. Angel investors do not include friends or relatives (Wetzell 1983).

<sup>3</sup>Alternatively, Gazelles can be defined by firm payroll. The definition of Gazelles in this paper closely follows that of Sterk et al. (2021).

<sup>4</sup>The model assumes that the only difference between VCs and angel investors is that VCs provide managerial advice and assumes no difference between VCs and angel investors in their ability to screen startups and secure funding. Despite the simplifying assumptions, the quantitative model reasonably explains the dynamics of VC-backed firms in several dimensions without explicitly targeting them in the calibration.

<sup>5</sup>Only around 3% of US firms are active in R&D, according to Bessen and Wang (2024). Less than 1% of all firms generate patents each year, according to the PatentsView database. The innovation expenditures in the model are intended to capture broader innovation activities.

<sup>6</sup>For instance, Akcigit et al. (2022) estimate that an economy without VC would have a 0.5 percentage point lower economic growth rate and suffer a welfare loss of 7.58%, measured by a compensating variation. The large welfare loss is partly due to technological spillovers from VC-backed firms to the rest of the economy. This study instead analyzes a stationary environment and closely examines the life-cycle dynamics of VC-backed firms, whereas Akcigit et al. (2022) analyze two phases of firms' life cycle.

<sup>7</sup>In Jovanovic and Szentes (2013), entrepreneurs choose between going solo or VC financing. In Akcigit et al. (2022) and Greenwood et al. (2022a), the choice of VC or non-VC is exogenous.

<sup>8</sup>Recent work on firm dynamics with financial frictions includes studies by Fernández-Villaverde (2010), Buera and Shin (2013), Khan et al. (2014), Midrigan and Xu (2014), Salgado (2020), Sui (2020), Corbae and D'Erasmo (2021), and Kochen (2022).

<sup>9</sup>Hsu (2004) finds that entrepreneurs are more likely to accept financing offers from more reputable VCs even with a discount on the company's valuation, suggesting the extra value of reputable VCs over less reputable VCs.

<sup>10</sup>In this study, non-VC-equity-backed firms are defined as firms that raised equity financing but did not raise VC financing. Bank-backed firms are those that received bank loans but did not raise equity financing.

<sup>11</sup>Since angel investments are undertaken by individual investors, academic researchers generally face challenges in analyzing comprehensive data on angel financing. Crunchbase and PitchBook also cover

only a subset of angel deals. The difference between VC deals and angel deals in this study is underestimated to the extent that financing deals by reputable angel investors are more likely to be included in the data than other angel deals.

<sup>12</sup>The importance of VC-backed firms in the aggregate economy has been documented in the literature (cf. Greenwood et al. 2022a). However, the literature typically examines publicly traded firms, which account for a relatively small share of total employment. According to Dinersoz et al. (2018), the domestic employment of actively traded firms accounts for around 26% of the total private employment in the United States.

<sup>13</sup>Payroll Gazelles are firms with an average annual payroll growth rate above 20% in the first 5 years and whose payroll exceeds 100 times the economy's average real wage per worker by the age of 20. Sterk et al. (2021) define Gazelles as “startups with an ex ante projected growth rate of at least 20 percent annually, over the first five years, and an expected employment level of at least 10 workers at some point during their lifetimes.” In their definition, 5.4% of all startups are Gazelles. Here, the criterion is set to 100 employees instead of 10 employees to narrow the focus on high-growth firms.

<sup>14</sup>Compared to the literature, Puri and Zarutskie (2012) show that the employment share of VC-backed firms is around 4%–7% from 1991 to 2005. From 2017 to 2021, the employment share of VC-backed firms is around 13%, according to Ando et al. (2025).

<sup>15</sup>Here, the fraction of VC-backed firms is smaller than that reported in Table 1, because the sample in Table 1 includes firms established after 2010. In this subsection, firms born from 1980 to 2010 are analyzed so that the growth rate from age 0 to 5 and firm size for at least 10 years are observed for all firms. Compared with the literature, Puri and Zarutskie (2012) report 17,763 VC-backed firms and 16,286,524 non-VC-backed firms born from 1981 to 2005. This implies that about 0.1% of newborn firms are VC-financed. Here, the fraction is slightly different due to three reasons: (a) more firms received VC financing after 2005, (b) this study examines four VC data sets rather than the two used in their study, and (c) the issue of spurious new firms is partially addressed, as described in Appendix B.1.

<sup>16</sup>Furthermore, the regression results in Table A4 in Appendix B.3 show that the DHS firm growth rate, which is robust to survival bias, is higher for VC-backed Gazelles than for non-VC-backed Gazelles. Table A5 compares exit rates, showing that VC-backed firms have lower exit rates than non-VC-backed firms in the full sample but slightly higher rates among Gazelles. Hence, differences in growth trajectories are unlikely to be primarily driven by differences in exit rates.

<sup>17</sup>An alternative interpretation is that the difference in equity stakes reflects differences in the risks involved. However, while VC funds invest in a portfolio of companies and thereby diversify idiosyncratic risk, angel investors typically hold less diversified portfolios. One could also argue that VCs acquire higher equity stakes because of their higher bargaining power, although this advantage may stem from the value they bring to the companies. Finally, one may be concerned about firm characteristics that are unobservable to researchers. If VC-backed firms have higher unobserved quality than angel-backed firms, the estimated 3.3% extra equity stakes are likely understated, as higher-quality firms would give up smaller equity stakes. Consequently, the counterfactual exercise would also underestimate the value-adding effect of VCs.

<sup>18</sup>In the model, firms make the choice at birth and cannot raise money from other sources. In practice, firms may raise money from several sources simultaneously or over time. Nonetheless, Robb and Robinson (2014) show that VC-backed startups raise the majority of their funding from VC. Anecdotally, Google raised around 1 million dollars from angel investors and 25 million dollars from VC in its initial years. The model captures the difference between VC-backed firms that primarily rely on VC financing and angel-backed firms that do not raise VC financing at all. According to Sohl (2012), the angel market invests in more than 10 times as many ventures as the VC market, implying that most angel-backed firms do not raise VC financing. Furthermore,

Hellmann et al. (2021) find that VC and angel financing are dynamic substitutes and that transitions between financing streams are not as common as traditionally assumed.

<sup>19</sup>This approach has limitations since VCs may be better at screening startups, but quantifying such channels would be challenging. In the literature, Sørensen (2007) estimates a two-sided matching model of VC and distinguishes between VCs' influence and sorting under the assumption of complete information. Notably, Georges Doriot, the founder of the American Research and Development Corporation, which is regarded as the first successful VC firm, realized that project selection was the easiest part. He wrote that “the hardest task is to help a company through its growth pains” (Ante 2008, 121).

<sup>20</sup>If the factor of success ( $x_t$ ) depends only on the second term (i.e.,  $\gamma_0 = \gamma_2 = \gamma_3 = \gamma_4 = \gamma_5 = 0$ ), innovation expenditures ( $I_t$ ) can be expressed as a function of the innovation success rate:

$$I_t = \left( \frac{\zeta_{t+1}}{1 - \zeta_{t+1}} \right)^{1/\gamma_1} \quad (6)$$

This functional form is similar to that of Greenwood et al. (2022a), where innovation expenditures can be expressed as  $I_t = \text{constant} \times \zeta_{t+1}^2 / (1 - \zeta_{t+1})$ . Both functional forms have the advantage of having an interior solution for innovation expenditures.

<sup>21</sup>For instance, Michael Seibel, the managing director of Y Combinator, says about startups: “The second that you launch, every week that you're not growing, you're dying.” Source: “7 Rules Every Tech Startup Must Follow,” *Fortune*, November 3, 2016. Cole et al. (2016) introduce the productivity ladder and assume that if a firm stalls at the current step of the ladder, it remains at the current level forever after, implying  $\gamma_3 = -\infty$  in this setting. Here, this assumption is relaxed, and  $\gamma_3$  is calibrated.

<sup>22</sup>In practice, equity-backed firms typically register as incorporated businesses, establish a board of directors, hire lawyers and accountants, and disclose financial information to their investors. The fixed cost for equity-backed firms includes these costs. While the model assumes that non-VC-equity (angel-)financed firms pay a fixed cost  $c_{e,0}$  each period but no management fees to angel investors, the model remains essentially unchanged if, instead, such firms pay no fixed cost but incur management fees of  $c_{e,0}$  to angel investors, potentially due to a limited supply of angel investors.

<sup>23</sup>In reality, firms and VCs form a sophisticated contract in which payments to VCs are contingent on the firm's performance. The setup here simply captures that VCs are compensated for their advice.

<sup>24</sup>The fixed supply of VCs in the economy reflects a shortage of human capital rather than financial resources. VCs possess management expertise and networks that are helpful for startups' growth, but the number of such experts in the economy is limited. Jovanovic and Szentes (2013) also note that “Since venture funds are usually oversubscribed, the binding constraint may indeed be VCs' human capital, and not liquidity” (525).

<sup>25</sup>If startups pay less than  $\bar{\pi}_{vc}$ , VCs will find other startups willing to accept slightly higher compensation. If VCs demand more than  $\bar{\pi}_{vc}$ , startups will find other VCs willing to accept slightly lower compensation. The stable match could be microfounded as an equilibrium under a proper market mechanism, such as a deferred acceptance algorithm.

<sup>26</sup>The model exhibits complementarity between a firm's potential and VCs' advice, as the productivity gain due to successful innovation is larger for high-potential firms than for low-potential firms. Consistently, Fox et al. (2012) estimate a two-sided matching game between entrepreneurs and VCs and show complementarities.

<sup>27</sup>The cubic term is introduced to allow the ladder to have a steep, nonlinear shape. The quadratic term is dropped to reduce the number of parameters in the calibration and to avoid the colinearity issue.

<sup>28</sup>To numerically solve the model, nine values of  $\hat{\theta}_N$ 's are drawn from the log-normal distribution at the percentiles: [0.2, 0.5, 0.7, 0.85, 0.935, 0.9725, 0.9775, 0.989, 0.999]. The probability measures assigned to each percentile are  $1/100 \times [40, 20, 20, 10, 7, 0.5, 0.5, 1.8, 0.2]$ , respectively.

<sup>29</sup>The AR(1) process of  $\epsilon$  in Equation (3) is approximated using the Tauchen method. Appendix C.3.2 describes how grid points are defined. The number of grid points for  $\epsilon$  is set to five.

<sup>30</sup>In practice, initial assets may be correlated with the growth potential  $\hat{\theta}_N$  and initial productivity  $\epsilon$ . However, initial assets at the firm level are typically not observed in the data.

<sup>31</sup>Households also pay for the initial assets of newborn firms and receive cash flows from firms hit by an exogenous exit shock. Banks and angel investors generate zero profits.

<sup>32</sup>Appendix C.3.3 describes how the stationary distribution is numerically computed.

<sup>33</sup>Sterk et al. (2021) estimate an annual exogenous exit rate of around 4.1% in their calibration.

<sup>34</sup>Foster et al. (2008) report that the persistence of various TFP measures and demand shocks ranges from 0.76 to 0.97 at an annual rate. Instead of setting this parameter exogenously, one could internally calibrate  $\rho$  to be consistent with the autocorrelation of firm size in the data, but this would impose an additional computational burden. The calibrated model predicts an autocorrelation of  $\log(\text{employment})$  of around 0.78, within the range of biannual autocorrelations at various ages reported by Sterk et al. (2021).

<sup>35</sup>Robb and Robinson (2014) report that the average owner equity of startups is around \$33,000 in 2004. The average wage in 2004 was around \$36,000, according to the Social Security Administration.

<sup>36</sup>A typical approach would be to measure innovation inputs with R&D expenditure and innovation outputs with patent filing. However, most firms in the economy do not invest in R&D and do not generate patents. Hence, this approach would significantly narrow the scope of innovation. R&D is defined as "creative and systematic work undertaken in order to increase the stock of knowledge and to devise new applications of available knowledge," according to the BRDIS survey form. It does not include activities related to the firm's business expansion, such as market research, management studies, and the creation of new software based on known methods and applications. This study examines firm growth that is not necessarily based on R&D activity or patent generation.

<sup>37</sup>The following derivations show the relationship between the equity shares of investors and the parameter  $\gamma_1$ . The first-order condition (FOC) with respect to innovation expenditure  $I$  is

$$\frac{I}{\mathbb{E}[V_{t+1}(\text{success}) - V_{t+1}(\text{fail})]} = \frac{\gamma_1 \zeta^*(1 - \zeta^*)}{1 + r},$$

where the firm value is given by  $V_t = 1/(1 + r) \{ \zeta V_{t+1}(\text{success}) + (1 - \zeta) V_{t+1}(\text{fail}) \}$ . Under simplifying assumptions, there exists a one-to-one mapping between the parameter  $\gamma_1$  and the equity share of investors. If  $V_{t+1}(\text{fail}) \approx 0$ , the two equations above imply:

$$\frac{I}{V_t} \approx \gamma_1 (1 - \zeta^*). \quad (22)$$

In addition, if all raised money is used for innovation expenditure and if VCs earn zero profits (i.e.,  $I/V_t \approx$  equity share),  $\gamma_1$  can be derived in closed form, using VC investors' equity share.

<sup>38</sup>From the approximated relation (22), it follows that a lower equity share is associated with a higher innovation success rate,  $\zeta$ .

<sup>39</sup>It turns out that the high exit rate observed in the data is difficult to explain with the model. A high exit rate implies high operating costs.

However, this would generate higher growth of surviving firms and would not be in line with the average firm size in the data. Similarly, it appears that Sterk et al. (2021) also have difficulty jointly matching the average firm size and the exit rate.

<sup>40</sup>Sohl (2012) reports that the angel market invested in over 10 times more deals than the VC market in the 2000s. For example, angel investors invested in more than 57,000 startups in 2009. According to the Kauffman Survey (2004), the fraction of firms that raise VC or angel financing at age 0 is around 3.2%. In the Survey of Business Owners (2007), the fraction of equity-backed firms is around 1%. Since the precise fraction of angel-backed firms in the economy is unknown, 2% of all newborn firms are assumed to raise equity financing in this study.

<sup>41</sup>Two moments are taken from the left panel of Figure 6, eight moments from the right panel (targeting firm size at ages 0, 2, 4, 6, 8, 10, 12, and 14), and nine moments from Table 7. The steady-state prices are  $w = 0.41$  and  $\bar{\pi}_{vc} = 7.3$ . In the baseline economy, the measure of entrants  $M^e$  is normalized to one, and the calibrated model implies a value of entry equal to 2.5.

<sup>42</sup>The Nelder–Mead method is used for calibration. The eight moments regarding the average firm size are weighted by 5/8, as the eight moments are primarily used to identify four parameters and one price ( $w$ ). The moment about the exit rate and the Pareto tail are weighted by 1/5 and 2, respectively, given the importance of the moments in the quantitative model. Fitting the exit rate turns out to be challenging, as discussed in footnote <sup>39</sup>, and is not the main focus of this paper, while the Pareto tail is a critical moment for the size of the largest firms in the economy. The other moments have a weight of one.

<sup>43</sup>All high-potential firms in the model seek VC financing, whereas in reality some may choose non-VC financing due to factors not captured by the model, such as founder preferences or geographic distance from investors. Nonetheless, the model replicates the data reasonably well. While the average firm size of all firms and the Pareto tail of the stationary firm-size distribution are targeted in the calibration, neither directly determines the growth trajectory of Gazelles across the three groups. In Figure 7, firm size in the data is measured by payroll (in million USD). In the model, the average firm size in terms of employment is first computed and then multiplied by \$40,000 to allow direct comparison with the data.

<sup>44</sup>In the calibration,  $\gamma_4$  is set such that a threshold firm, indifferent between angel and VC financing, gives up 3.3% more equity to raise VC financing instead of angel financing. However, average VC-backed firms are above this threshold, have higher potential, and raise more funding than angel-backed firms. Consequently, the average equity stake of VC investors is more than 3.3% higher than that of angel investors. The data are drawn from PitchBook and include firms that raised external funding in a given year. In the model counterpart, the sample consists of firms that received positive external funding in a given year. Furthermore, since all firms in the model raise their first financing deal at age 0, firms that obtain their first financing deal after age 2 are excluded from the data. Only a small fraction of firms above age 8 are observed in the data, and these firms are also excluded from the sample.

<sup>45</sup>In the data, angel-backed firms raise an average of \$1.2 million at age 0 and \$4 million by age 8. VC-backed firms initially raise \$5.6 million at age 0 and \$103 million by age 8 on average.

<sup>46</sup>Gomes and Sarkisyan (2023) report a corporate default rate of 0.4% from Moody's.

<sup>47</sup>Personal consumption expenditures in the US GDP in 2022 are approximately 17.5 trillion dollars (Source: US Bureau of Economic Analysis).

<sup>48</sup>A baseline economy is recomputed with 10 values of growth potential ( $\hat{\theta}_N$ ) drawn from the log-normal distribution at the percentiles [0.2, 0.5, 0.7, 0.85, 0.935, 0.9725, 0.9775, 0.988, 0.997, 0.999] and the probability measures assigned to each percentile  $1/100 \times [40, 20, 20, 10, 7, 0.5, 0.5, 1.6, 0.2, 0.2]$ , respectively. Firms in the last two percentiles raise VC

financing in the counterfactual economy. The management fees of VCs ( $\bar{\pi}_{VC}$ ) are computed such that firms at the 99.6 percentile in growth potential are indifferent between VC and angel financing.

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### **Supporting Information**

Additional supporting information can be found online in the Supporting Information section.

**Supporting Information:** [iere70048-supp-0001-Appendices.pdf](#)