The Aggregate Return to Venture Investors*

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January 23, 2024

Abstract

We measure the aggregate lifetime return to equity investments in venture companies. We consider the aggregate portfolio of all equity investments made in various funding rounds of 17,242 ventures that had their first funding round between 1980-2006. We track these ventures till their exits or till 2018 to get a complete picture of their lifetime return. The Kaplan and Schoar (2005) Public Market Equivalent (PME) measure of performance is 1.42, i.e., each dollar invested returned 1.42 dollars after adjusting for risk and time value. We use an imputation model following Hall and Woodward (2010) to address missing data issues.

JEL classification: G11,G24.

Keywords: Venture Investment Returns, Public Market Equivalent.

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1. Introduction

Venture capital (VC) is an important asset class: 88% of institutional investors have some exposure to venture capital and private equity, with nearly a third having an allocation to these assets that is greater than 10%.[1] In this paper we measure the aggregate return to all equity investments in venture companies made in the various funding rounds of ventures. There is a large literature on measuring the return to venture capital investments. Whereas the focus in the literature is on measuring return from one funding round to the next and one funding round to the exit of ventures, our focus is on measuring the lifetime return to all equity investments in venture companies before fees, in the aggregate, thereby contributing to the empirical literature on asset-class returns.

In short, the aggregate return to all equity investors (ARAEI) is the ratio of discounted venture cash inflows to discounted venture cash outflows, encompassing flows to venture capitalists, entrepreneurs, and other equity investors. We match the cash flows of ventures at each time period to an investment in the publicly traded market portfolio, and use the realized market portfolio's return to discount the venture cash flows. ARAEI combines the public market equivalent (PME) method of Kaplan and Schoar (2005) and its generalized version (GPME) of Korteweg and Nagel (2016) for measuring the risk-adjusted returns, with an imputation model for missing first round and exit valuations based on Hall and Woodward (2007), to measure the lifetime risk adjusted returns to venture-companies.

Measuring the risk adjusted return to all equity investors over the entire life cycle of a firm's venture phase necessarily requires aggregating across equity investors who invest at different stages of a venture company and face different levels of risk. We are therefore silent on the risk and return trade-offs across funding rounds. ARAEI is not a new measure for evaluating the performance of a given venture company or venture capital investment, but studying it has some advantages and adds to our knowledge about the historical performance of venture investments as an asset class.

First, measuring the risk-adjusted return to investments on venture companies poses several well-known challenges. Investors of a venture must wait for a long period of time to realize their re-

[1] The percentages are from Whyte (2017).

turns. There is little information on a venture's value between funding rounds. Data on post-money valuation after funding rounds are often missing, and exit values for ventures that exited successfully through events other than IPOs are also sometimes missing in publicly available databases. The available valuation data are subject to sample selection issues since funding rounds tend to occur when ventures are doing well and market conditions are favorable. Such sample selection issues are widely known and addressed in different ways in the empirical literature. While these challenges make round-to-round return measurements unreliable, the aggregate return to all equity investors (ARAEI) in various funding rounds of a venture and the founders taken together as a single group is less sensitive to the above issues.

Second, Gornall and Strebulaev (2020) by going through the legal filings of ventures that are unicorns, find that shares issued in later-stage funding rounds are entitled to protections such as IPO issue price guarantees, vetoes over down-IPOs and seniority to other investors. However, the reported pre-money valuation ignored the fact that shares issued in earlier funding rounds lacked these protections, and treated all shares the same. In their sample, they find that this resulted in the pre-money valuation being overstated by 48% on average. ARAEI is less affected by this valuation bias issue. By measuring the return to all equity investors in the various funding rounds taken as a group, ARAEI sidesteps the need to analyze the allocation of cash flow rights in each funding round between founders and outside investors described by the complex VC contracts.[2]

Measuring ARAEI requires the first-round post-money valuation, the amount raised in the subsequent rounds, and the exit values. We interpret the first-round post-money valuation as the value of initial equity investment made by the founders – the cash-equivalent of founders' monetary and non-monetary investments combined – plus the value of money raised through issuing new equity in the first round. In our sample, the collection of US-based ventures in the SDC VentureXpert database, post-money valuations for the first round are available for 25.5% of these rounds, and the funds raised in these rounds represent approximately 29% of the total amount raised across all

[2] For example, contractual terms of convertible preferred stocks typically vary across funding rounds. See Metrick and Yasuda (2021) for a discussion of the contractual terms. Ewens, Gorbenko, and Korteweg (2022) find that the way the interest is split between founders and VCs are usually complex, heterogeneous, and not observable.

first rounds. We use an imputation model that builds on Hall and Woodward (2010) to impute the missing first-round post-money valuations, and find that the ARAEI measure, aggregated across all ventures, is less sensitive to errors in the imputed values for missing first-round post-money valuations. This alleviates the concern of selection bias in back-filling first-round valuations – that is, information on the first round is more likely to be reported when a venture eventually becomes successful. However, there may still be residual selection bias, since the imputation model we use, like the resampling approach used in the literature (e.g. Korteweg and Nagel (2016)), extrapolates using observed valuation data of ventures.

The next thing we need is the amount raised data for the subsequent rounds, which is missing for only 4.2% of the subsequent rounds. Since the ARAEI measure does not rely on post-money valuation in subsequent funding rounds, it is less subject to selection bias which arises from the fact that ventures performing better are more likely to report their valuations. [3] As for the exit values, we follow ventures for at least 12 years, so to a great extent we observe their exit outcomes – IPO, Mergers and Acquisitions (MA), bankruptcies (i.e., valueless shutdowns), or remaining private during the entire sample. Exit values are available for all IPO exits with only a few exceptions and for more than half of the exits through MA. For exits through bankruptcies and for ventures that remain private during the entire sample, we assume the exit values are zero. We also use an imputation model that builds on Hall and Woodward (2010) to fill the missing exit values in IPO and MA exits. [4] We do not consider option grants to executives and employees since we do not know the value of those options at the time they were granted and the time of a venture's exit. However, this is unlikely to be an issue in measuring the aggregate return to all other equity investors. Such options are treated as liabilities and factored into while valuing the equity at the time of a venture's exit

[3]To address the selection bias, Hwang, Quigley, and Woodward (2005) use the Heckman (1979) model, Cochrane (2005) uses a selection function for venture valuation disclosure, under the assumption that the probability of obtaining new financing smoothly increases with the value of the venture, and Korteweg and Sorensen (2010) build a dynamic selection model.

[4]In IPO exits and MA exits, exit values are the values of equity revealed by these events. In order to improve the data coverage on the exit events, we cross-checked the exit events of ventures using multiple data sources like PitchBook, Bloomberg, NASDAQ, Crunchbase and other Internet sources. We find that many ventures with no recorded exit events in VentureXpert experienced bankruptcies or were acquired according to the other data sources.

via IPO or M&A. Our ARAEI measure concentrates solely on equity investors in various funding rounds with founders' equity valued at the first round valuation, and therefore this exclusion should not significantly impact our analysis.

We present a comprehensive analysis of the ARAEI measure across three dimensions: aggregate, cross-sectional, and time series. First, the ARAEI of the portfolio of all the ventures in our sample had a Public Market Equivalent (PME) of 1.42. This portfolio includes 17,242 ventures that had their first funding round in 1980-2006. It suggests that the ratio of all the discounted cash inflows of this portfolio to all the discounted cash outflows of this portfolio is 1.42. Investments in this portfolio would at the margin add value to an investor's position, value that would not be attainable from the public market factors in the SDF, thus this portfolio is viewed to have outperformed the public benchmark. In their review, Jagannathan, Ouyang, and Wang (2023) summarize the results of several studies that have assessed venture capital performance using PME-related metrics at the fund level. These studies report fund-level PME varying from 0.96 to 1.22 over different time periods in 1980-2010. Closest to us is Harris, Jenkinson, Kaplan, and Stucke (2014b), who find the PME of VC funds in 1984-2008 was 1.22, while the PME of ARAEI was 1.57 during that time period. The ARAEI, derived from company-level data, exceeded the PME of VC fund investment, which was based on fund-level data. Possible explanations for the higher ARAEI include fees charged by the VC funds, compensation (returns) to founders, or differences in the sample of ventures under different studies.

Second, in the cross-section, 30% of ventures have PMEs higher than one, which is viewed to have outperformed the public benchmark, while the majority of ventures have zero PMEs due to unsuccessful exits. The high ARAEI of the portfolio of all ventures is attributable to relatively few ventures. The best-performing 3% of ventures in terms of the PME explain the out-performance for the entire 17,242 ventures in our sample that had their first funding round in 1980-2006, as other ventures collectively matched the public benchmark. It is well known that returns to early-stage equity investments in ventures are highly risky and positively skewed. Our findings suggest that the distribution of returns to all equity investors over the life cycle of individual ventures is also positively skewed, as highly as returns to investing in publicly traded individual stocks.[5]

Third, in the time series, the ARAEI as measured by the PME and GPME and the ARAEI without risk adjustment as measured by IRR significantly come down after 1999Q1. This is consistent with Harris, Jenkinson, and Kaplan (2014a) who observed that venture returns have come down after 2000. We form a portfolio of ventures that had their first funding round in a given calendar quarter between 1992Q1 and 2006Q4, and construct the quarterly time series of the ARAEI. [6] Compared with Harris et al. (2014a), who find that the PME of venture capital funds is lower than or close to one after 2000, we find that investments in ventures although declined, continued to outperform their public market equivalent after 2000. The PME of ventures was above 1.0 for all but one of the twenty-four quarters (2001Q1-2006Q4) with an average value of 1.40. The IRR after 2000 was 16%, which is much higher than the IRR of 6% on the venture-mimicking public market industry portfolios during the same period.[7]

What may have caused this structural break? The structural break in the time series of ARAEI exists even after removing ventures with funding rounds or exits within the dot-com bubble period.[8] Ewens and Farre-Mensa (2020) find that the National Securities Markets Improvement Act (NSMIA) effective in 1997 increased the supply of capital to ventures. This increase in the supply of capital may have played a role in venture returns coming down after 1999Q1.

Related Literature

[5]See Bessembinder (2018), who finds that the majority of common stocks that have appeared in the Center for Research in Security Prices (CRSP) database since 1926 have lifetime buy-and-hold returns less than one-month Treasuries. When stated in terms of lifetime dollar wealth creation, the best-performing 4% of listed companies explain the net gain for the entire US stock market since 1926, as other stocks collectively matched Treasury bills.

[6]Prior to 1992, post-money valuation data for the first round was missing for most ventures. Further, the amount raised was small. For those reasons, we examine the time series properties of ARAEI for ventures that had their first funding round in 1992Q1 or later.

[7]We construct the venture-mimicking public market industry portfolio by investing each venture's amount raised into its corresponding industry's portfolio (taking returns from Fama-French 10 industry portfolios). We liquidate the industry portfolio when the venture exits through IPO, MA, and bankruptcy, or, 12 years after the last observed round and December 31, 2018, if no exit is observed. Note that the portfolio of ventures has higher systematic risk due to higher leverage when compared to the venture-mimicking public market industry portfolio, and the IRR measure of return does not correct for the differential systematic risk exposure.

[8]Ventures exited during the bubble period would have high valuation and higher return; ventures that raised money during the bubble would have high valuation and lower return.

Several methods have been proposed in the literature for computing the risk-adjusted present value of cash flows from ventures and venture capital and private equity funds. Driessen, Lin, and Phalippou (2012) propose a modified internal rate of return method. Gupta and Van Nieuwerburgh (2021) propose a "strip-by-strip" method for risk adjustment. Ang, Chen, Goetzmann, and Phalippou (2018) develop a Bayesian Markov Chain Monte Carlo method for private equity (PE) returns using cash flows accruing to limited partners and factor returns from public capital markets. Kaplan and Schoar (2005) and Korteweg and Nagel (2016) develop methods for risk-adjusting venture capital cash flows and returns based on the stochastic discount factor framework, which we make use of in this article. As Sorensen and Jagannathan (2015) show, the use of the PME corresponds to the use of the Rubinstein (1976) dynamic capital asset pricing model for risk adjustment. In their review, Jagannathan et al. (2023) summarize the results of several studies that have assessed venture capital performance using various metrics and approaches at both the fund and company levels.

Cochrane (2005) and Korteweg and Sorensen (2010) address the selection bias and information incompleteness in venture's disclosure. Gornall and Strebulaev (2020) find that post-money valuations in later funding rounds of ventures have a potentially large upward bias. Since our focus is on measuring the return over the life cycle of a venture company to equity investors in the various funding rounds and the founders taken together as a group, this is not an issue.

Phalippou and Gottschalg (2009) examine return to investing in PE funds by selecting funds that are at least ten years old and have no sign of activities to ensure that the funds have been liquidated to avoid using potentially inflated self-reported net asset values. By limiting our analysis to ventures that had their first round of funding in 2006 and following them through till 2018 we provide a more complete picture of the return to investors in venture companies.

Ljungqvist and Richardson (2003) find a return premium to investing in private equity (PE) relative to the public equity market, which potentially compensates for the illiquidity of PE investments. Harris, Jenkinson, and Kaplan (2015) find that the performance of VC funds varies over time, and VC funds that started when the venture sector received high capital inflows had a lower performance. Harris, Jenkinson, and Kaplan (2014a) show that VC funds outperformed public equities in the 1990s, but under-performed in the 2000s. Nanda and Rhodes-Kropf (2013) find that VC-backed startups receiving initial investment in hot markets are more likely to go bankrupt. Our findings using venture-company-level cash flows complement the above studies that use the return to VC fund limited partners. Venture company investment returns that we measure is before VC fund fees and other factors that affect VC fund returns, and therefore higher, and the difference is a measure of the value of the intermediation services provided by VCs.[9]

2. Methodology

2.1. Public Market Equivalent Measure of Venture Performance

Our primary risk-adjusted return measure is the ratio of discounted venture cash inflows to cash outflows, i.e., the Public Market Equivalent (PME) proposed by Kaplan and Schoar (2005). We also examine its generalized version (GPME) proposed by Korteweg and Nagel (2016). The PME method matches the investments in ventures at each time period to an investment in the publicly traded market index portfolio, and uses the realized market return to risk adjust the venture investment return. The GPME method nests PME, and ensures the modeled SDF can accurately reflect risk-free rates and returns on the market index portfolio. In addition, we also examine the internal rate of return (IRR), a measure of return without any risk adjustment. Since a venture's cash flows are random and occur infrequently at random unknown times with possibly time-varying exposure to systematic risks, we cannot directly apply the linear beta version of the standard capital asset pricing model (CAPM) or their multifactor analogs for risk adjustments. The PME and GPME methods overcome this issue. As Sorensen and Jagannathan (2015) point out, the PME method is equivalent to discounting cash flows using the stochastic discount factor (SDF) corresponding to the dynamic Rubinstein CAPM for a particular choice of the wealth portfolio of the evaluator.

The PME and GPME we use are based on the present value of cash flows that the venture

[9] Fees and pre-fee performance may be related, with more skilled VCs charging higher fees.

company receives from all the equity investors taken together as a group in the various funding rounds, and the cash flows equity investors receive upon exit. They differ in the way they compute the present values of future cash flows. Both are measures of the return to a hypothetical investor who participates in all the funding rounds of a venture and provides all the financing cash flows.

VC databases record the amount raised by a venture in VC funding rounds – we treat those as cash outflows from outside equity investors. Before VC investments, the founders of the venture have already invested various resources, including effort and financial resources. We treat the pre-money valuation of the venture in the first VC funding round as cash outflow from founders – that is, the value of founders' total investment.

The cash flow inflow received by equity holders upon the venture's exit is measured by its equity value. If a venture exits through a Merger or Acquisition (MA), then the equity value at exit is computed using the fraction of equity transacted and the transaction value. If the venture exits through an IPO, then the equity value at exit is the pre-IPO equity value. If the venture goes bankrupt, we regard the exit equity value as zero.

To calculate the present value of the cash flows, we need to appropriately adjust for the risk. The PME method computes the *realized* present value at time 0 of a cash flow, C_t, that occurs at a random time t in the future as $M_t C_t$, where the M_t equals the inverse of the time t value of a dollar invested at time 0 in the market portfolio of all stocks, i.e., $\frac{1}{(1+R_{m1})...(1+R_{mt})}$, where R_{ms} is the publicly traded equity market portfolio's rate of return during time period s. The realized present value $M_t C_t$ is the amount one would have had to invest in the market portfolio at time 0 to get C_t at time t. We use the return on the CRSP value-weighted stock index portfolio as the proxy for the market portfolio of all stocks, retrieved from Ken French's data library (Fama and French, 1993).

More generally, as Hansen and Richard (1987) show, the present value at time 0 of a random cash flow, C_t, that occurs at a random time t in the future can be written as $\mathbf{E}(M_t C_t)$, where M_t is the stochastic discount factor (SDF) and $\mathbf{E}(.)$ is the expectation operator. Each asset pricing model – either the standard Capital Asset Pricing Model (CAPM), or the multifactor asset pricing model, or other models like the Black-Scholes option pricing model – takes a particular stand on what the valid SDF is. The PME method's choice of $\frac{1}{(1+R_{m1})...(1+R_{mt})}$ as the SDF is supported by the dynamic capital asset pricing model of Rubinstein (1976). In the case of the GPME, the stochastic discount factor (SDF) is specified as:[10]

$$M_t = exp(at - br_{m,t}) \tag{1}$$

where t is the time of funding round or exit since the first round – that is, the first round of the venture takes place at time $t = 0$. a and b parameters that are positive constants, and $r_{m,t}$ is the log cumulative return on the publicly traded equity market portfolio since the first round. [11] We use the parameter values, a = 0.033, and b = 1.444, which are the values estimated by Korteweg and Nagel (2016) using round to round returns on ventures.[12] The SDF of the GPME nests the SDF of the PME as the special case where a = 0 and b=1 in the expression for the SDF given in equation(1). For clarity, we will use PME as an example to demonstrate the calculation of this performance measure. The same principles apply to GPME. Hereafter, we often use the generic term PMEs to refer to both the PME and the GPME except where it becomes necessary to differentiate the two.

The realized PME performance measures equal the discounted cash inflow divided by the sum of discounted cash outflows, using the corresponding SDFs, i.e.,

$$\text{Realized Venture PME} = \frac{PV_{in}}{PV_{out}} = \frac{M_T \times c_T}{\sum_{t=0}^{T-1} M_t \times C_t} \tag{2}$$

where c_T is the outflow from the venture paid out to investors upon exit. C_0 is first-round post-money valuation, which is the sum of the first-round pre-money valuation and first-round amount raised, and C_1,... C_{T-1} are the cash contributions by equity holders in subsequent funding rounds. We use capital letters to denote money invested in the venture, i.e., outflows from investors, and lowercase letters to denote money paid out to investors, i.e., inflows to investors. Equation (2)

[10]This comes from Equation (1) in Korteweg and Nagel (2016).

[11]To simplify the calculation, we treat the cash flows after 15 years from the first round as occurring in the 15th year. Few ventures still receive funding or successfully exit after 15 years from the first round.

[12]See Table 6 of Korteweg and Nagel (2016). We also re-estimated the SDF parameters based on round-to-round returns using our sample of data. The re-estimated parameters are close to these values.

defines the realized PME when we set the $a = 0$ and $b = 1$ in the equation. A venture with a realized PME greater than one means the investments in the venture would at the margin add value to an investor's portfolio, value that would not be attainable from the public market factors in the SDF, thus investing in this venture is viewed to have outperformed the public benchmark.

Similar to the PME of a venture, we define the PME of a portfolio of ventures as the ratio of the present value of total cash inflows to investors to the present value of total cash outflows to ventures. The realized PME for a portfolio is calculated by aggregating the present values of cash inflows and outflows from each venture, discounted to their first funding rounds. This calculation helps assess performance over different time frames and understand the variability and likelihood of the PME being less than 1. Moreover, we examine the performance of portfolios based on their first funding round, either by quarter or year, to analyze the time series properties of these PMEs, in order to understand the aggregate performance of venture investments compared to market benchmarks and identify trends and patterns over time.

2.2. *Venture PME and the Gornall and Strebulaev (2020) Bias*

While the bias in the valuation data documented in Gornall and Strebulaev (2020) materially affects all the measured round-to-exit returns, it does not affect the realized venture PME measure. To see why, consider the hypothetical venture given in Table 1. The venture raises one round per year and exits through an IPO at the end of the 4th year. The market return is 10% every year. With the amount raised and post-money valuation data in each round, we can calculate the realized venture PME. We also calculate ownership given up, and the round-to-round return and round-to-exit return.

$$\text{Ownership Given Up by Founder} = \frac{\text{Amount Raised}}{\text{Post-Money Valuation}}$$

$$\text{Round-to-Round Return for Round } t \text{ Investor} = \frac{\text{Pre-Money Valuation}_{t+1}}{\text{Post-Money Valuation}_t} - 1$$

$$\text{Round-to-Exit Return for Round } t \text{ Investor} = \frac{\text{Exit Value to Equity Holders in Round t}}{\text{Post-Money Valuation}_t}$$

Panel A reports the return measures calculated based on correct data. Panel B in contrast reports the return measures when the post-money valuation of round 4 is biased upwards – to reflect the fact that the observed value of existing common shares in late rounds is biased upward as documented by Gornall and Strebulaev (2020). We see that this bias in round 4 would bias the round-to-round returns from both round 3 and round 4, and round-to-exit returns for all rounds. But it does not affect the calculated realized PME of the venture, and it follows that the realized venture GPME will also not be affected since the two differ only in their SDFs.

3. Data

3.1. Data Sources

We augment the SDC VentureXpert database, the standard database for many venture capital studies, with data on funding rounds and exit events from multiple other sources. There are 17,242 US-based ventures in the SDC VentureXpert database that had the first funding round in 1980–2006. This is our sample of ventures and we trace their funding rounds and exit events until 2018, observing every venture for at least 12 years since the first round. Figure 1 is a diagram that summarizes the key facts of our data. It shows the number of ventures in the sample, and their aggregate amount raised, exit value, and measures of the investment returns. In our data, 11.1% of ventures went to IPO, after on average receiving 4.1 rounds, raising 46.8 million dollars, and exiting with a value of 296.3 million dollars. 37.2% of ventures went to MA, after on average receiving 3.9 rounds, raising 32.9 million dollars, and exiting with a value of 108.6 million dollars. 22.6% of ventures went to bankruptcy, after on average receiving 2.9 rounds, raising 17.4 million dollars. We excluded the debt-financed funding rounds from the sample based on the funding stage flag in Crunchbase and SDC Platinum.

We collect data on venture funding rounds from VentureXpert that includes the time, amount raised, and post-money valuation of each funding round. We also collect data on ventures' exit events. We classify a venture's exit event as IPO, MA, or bankruptcy. Ventures whose VentureXpert status is "Went Public" are classified as exiting through an IPO. Those whose VentureXpert status is "LBO", "Merger", "Acquisition" or "Pending Acquisition" are classified as exiting through an MA. Those whose VentureXpert status is "Defunct", "Bankruptcy – Chapter 7" or "Bankruptcy – Chapter 11" are classified as exiting through bankruptcy. Finally, we classify the final outcome of a venture having none of these exit events as of 2018 as remaining private. For the ventures that exited through an IPO or MA, we further collect the data on their exits from SDC Merger and Acquisition and SDC Global New Issues databases.

Some ventures in VentureXpert either have no recorded exit events or have recorded exit events but not the associated exit values. We cross-checked the outcomes and exit events of 10,175 ventures that received the first funding round during 1992 –2006 and were not bankrupt according to VentureXpert, with Crunchbase, PitchBook, Bloomberg, NASDAQ, IPO prospectuses, and other internet sources. We report in Table A.1 in the Online Appendix that of the 2,090 ventures with no recorded exit events in VentureXpert that we have cross-checked, 628 exited through bankruptcy, 14 exited through IPO, and 460 exited through MA according to the other data sources.[13] Only 988 ventures have no recorded exit events after checking with other data sources.

This cross-check improved the availability of exit values. For example, among the 17,242 US-based ventures, 6,407 eventually exited through MA. 5,779 of these MAs are recorded by the SDC data, while 628 of the MAs are revealed by the other data sources. Meanwhile, SDC provides the pre-MA valuations data of 2,809 ventures, and the other data sources supplement the pre-MA valuations for 546 ventures. There are 150 ventures whose pre-MA valuations in the SDC databases differ by more than 5% from the other data sources. For these cases, we verify the data case by case and adopt the data that appear more reliable.

For the ventures that exited through IPOs, we note that some pre-IPO valuation data in SDC databases can be incorrect. For example, the pre-IPO market value of Targanta Therapeutics Corp is reported as 0.3 million dollars, however, the prospectus suggests that the pre-IPO market value is about 152 million dollars as there were 15.2 million pre-IPO shares outstanding and the offering

[13]For the 14 venture exits through IPOs, we list the ventures' names, IPO exchanges, IPO dates, and CRSP permco in Table A.2 in the Online Appendix.

price was $10 per share. The product of pre-IPO shares outstanding and the IPO offering price, the difference between post-IPO market value and the IPO proceeds, and the pre-IPO market value in the SDC databases should all equal to the pre-IPO valuation if they are correct. When we observe a large discrepancy among these three values, we manually check the prospectus to find the correct pre-IPO market value. More details on how exit values of ventures in different exit events are supplemented by the other data sources can be found in Table A.3 of the Online Appendix.

3.2. The Missing Data Issue

The first data issue is that post-money valuations of the funding rounds are usually unavailable. Overall, post-money valuation is missing for 76.3% of the rounds and the availability of data varies significantly over time. As Figure 2 shows, post-money valuation is available for fewer than 5% of the funding rounds that happened before 1990. The availability of post-money valuation data increases from 1990 to 2000, but declined rapidly after 2000. In contrast, the amount raised data is available for more than 90% of the funding rounds every year.

Over its life cycle, a venture can either have only one round or multiple rounds. If it has multiple rounds, a funding round is either the first round, an interim round, or the last round. We report in Table 4 that the amount raised data is available for 93.5% - 96.8% of the first rounds, interim rounds, and last rounds, and for 86.8% of the ventures that received only one round over the entire life cycle. Post-money valuation is available for 21.1% - 25.5% of the first rounds, interim rounds, and last rounds, and for 16.6% of the rounds of ventures with only one round. Round-to-round and round-to-exit returns used in literature are available for only around 15% of the rounds, due to the lack of post-money valuation data.

ARAEI requires the first-round post-money valuation, the amount raised in all the funding rounds, and the exit value. The availability of ARAEI is mainly constrained by the lack of first-round post-money valuation. While 86.9% of ventures have the amounts raised data for all the rounds, only 22.9% of ventures have first-round post-money valuation. Table 4 shows that 21.7% of all ventures have data on the first-round post-money valuation and amount raised in all the funding rounds. We observe the exit values for 29.6% of all ventures (97.8% of ventures that exited through IPOs and 50.5% of ventures that exited through MAs). We assume that bankrupt ventures and ventures with no observed exit until 2018 have zero exit value. Under this assumption, we can compute the ARAEI for 17.1% of all ventures. In Section 3.3, we discuss the imputation method we use that addresses the missing data on first-round post-money valuation, the amount raised in all the funding rounds, and the exit values.

The second data issue is right-censoring. The time to exit of ventures is usually very long, and Table 5 shows that it takes a venture on average 5-7 years before the exit event of IPO, MA, or bankruptcy. Right-censoring refers to the fact that some ventures' exit events may happen after the ending time of our current data, 2018. To deal with this issue, we limit attention to ventures that had their first funding rounds before 2006, allowing for observation of a minimum life cycle length of 12 years. The data indicates that observing a venture for a minimum of 12 years significantly mitigates the issue of right-censoring. We report in Table A.4 in the Online Appendix that after 12 years from the first round, the fraction of ventures that exited through IPO, MA, or bankruptcy would remain roughly unchanged with the observation time. In other words, not many more exit events will be observed even if we extend the sample further after 2018. The table also reports that in the aggregate, 86.7% of the ventures' exit values are realized and 98.2% of the venture equity investments are made within 12 years from the first round.

As of 2018, 5,031 ventures (29.2% of the sample) remained private, of which 291 ventures (5.8%) received some funding rounds during 2013-2018, the five-year period before 2018, while the remaining 4,740 (94.2%) had no funding rounds. We call the former group the active ventures and the latter group the inactive ventures. Our assumption is that the exit values of these ventures are zero. This assumption is likely innocuous, as the active ventures account for only 5.6% of the aggregate amount raised by ventures, and the inactive ventures are unlikely to have successful exits based on historical data. The latter point can be seen from a "bootstrap" approach: 3,448 ventures remained private as of 2006 and had no funding rounds during 2001-2006, the five-year period before 2006. These are the inactive ventures as of 2006, and we trace their final outcomes as of

2018. These ventures are much less likely to have successful exits than the average venture in the full sample, and even if they indeed had successful exits their aggregate amount raised and exit value are very small compared to the full sample. Table A.5 in the Online Appendix reports that only 0.7% of them went to IPO, and 12.3% of them went to MA, and those that successfully exited in total raised 12 billion dollars, and were valued in total 64.2 billion dollars in the exits. Compared to the full sample, these successful exited ventures account for only 2.7% of the total amount raised, and 5.1% of the total exit values.

3.3. Methodology for Addressing the Missing Data Issue

We consider two methods to address the missing data issue: an imputation method that uses a variation of the statistical models in Hall and Woodward (2010); and a resampling method that is a variation of the resampling method in Korteweg and Nagel (2016) and Korteweg and Sorensen (2010).

The imputation method uses observed characteristics of a venture and statistical models to predict its first-round post-money valuation, amount raised in a funding round, and the exit value, and the fitted values from the model are the imputed values for the missing data. The three regression equations below are the imputation models.

$$\log AmountRaised_{i,r} = \alpha_r + \beta_r \log AmountRaised_{i,r-1} + \gamma_r Z_{i,r} + \epsilon_{i,r} \tag{3}$$

$$\log \frac{OwnershipGivenUp_{i,r}}{1 - OwnershipGivenUp_{i,r}} = \alpha + \beta_1 \log AmountRaised_{i,r} + \beta_2 (\log AmountRaised)^2_{i,r} + \beta_3 \log CumulativeAmountRaised_{i,r} + \gamma Z_{i,r} + \epsilon_{i,r} \tag{4}$$

$$\begin{aligned} Valuation_i = {} & \alpha + \beta_1 \overline{Valuation}_i + \beta_2 lastPMVtoExit_i + \beta_3 \overline{Valuation}_i \times lastPMVtoExit_i \\ & + \beta_4 \log FinalAmountRaised_i + \beta_5 FinalRoundtoExit_i \\ & + \beta_6 NASDAQReturn_i + \gamma Z_i \epsilon_i \end{aligned} \tag{5}$$

In these equations, subscript i refers to a venture, and subscript r refers to round r of the venture. Equation (3) is the model to impute the amount raised data. We estimate the relationship between the amount raised in a certain round (round r) and the number of investors who participated, the amount raised in the previous round (round $r-1$), as well as industry fixed effects, funding stage fixed effects and time fixed effects ($Z_{i,r}$). We group together the funding rounds after the ninth round, as few ventures have more than nine rounds.

To impute the first-round post-money valuation, we estimate Equation (4), a model of first-round ownership given up by the existing equity holders (founders). Ownership given up in a funding round is the ratio of amount raised over post-money valuation. The benefit of modeling ownership given up is that it is bounded between 0 and 1. We estimate a logit model relating the ownership given up in each round to log amount raised in the round and its square, log cumulative amount raised starting from the first round, and controlling for fixed effects at the levels of industry, funding stage, the number of rounds that have occurred, time and the number of investors ($Z_{i,r}$).

To impute the exit values, namely the pre-IPO valuations and pre-MA valuations of ventures, we estimate Equation (5). In that equation, $Valuation_i$ is either pre-IPO valuation or pre-MA valuation of venture i. $\overline{Valuation_i}$ is the extrapolated valuation for venture i, which equals the last available post-money valuation multiplied by the cumulative NASDAQ stock return from the last post-money valuation date to the venture's exit date. $lastPMVtoExit_i$ is the number of years from the last post-money valuation date to the venture's exit date. $FinalAmountRaised_i$ is the amount raised by the venture in its last funding round. $FinalRoundtoExit_i$ is the number of years from the venture's last funding round to its exit. $NASDAQReturn_i$ is the cumulative NASDAQ stock return from the venture's last funding round to its exit. Z_i includes fixed effects at the levels of industry, funding stage, and number of rounds received.

We report the estimation results and the performance of these imputation models in Table A.6, A.7, A.8, and A.9 in the Online Appendix. We add the explanatory variables in Equation (3), (4) and (5) sequantially, and select the specification with the highest out-of-sample R^2 computed from a ten-fold cross-validation method. Details about the definition of out-of-sample R^2 can be found in the Online Appendix. Compared with Hall and Woodward (2010), who also provide an imputation model for the first-round ownership given up, [14] our model has some improvement in terms of the out-of-sample R^2. The out-of-sample R^2 of our model is 0.244. When we apply the model in Hall and Woodward (2010) to predict first-round ownership given up in our data, the out-of-sample R^2 is 0.116. [15] The improvement of our model comes from including more covariates such as the square of log amount raised, log cumulative amount raised, and fixed effects on round number, industry, funding stage, calendar year, and the number of investors. These covariates are significantly related to the ownership given up, for example, the square of log amount raised is negatively related to ownership given up. The improvement also comes from the model selection that explicitly optimizes the out-of-sample R^2 and avoids overfitting.

The reweighting method is a variation of the resampling method in Korteweg and Nagel (2016) and Korteweg and Sorensen (2010). The subsample of ventures with the first-round post-money valuation data, amount raised data, and exit value data, are more likely to be available for successful ventures. 2,954 ventures (17% of the full sample) have all these data, and 23.3% of them exited through IPO, 29.6% exited through MA, 27.8% exited through bankruptcy, and 19.4% remain private as of 2018. In contrast, in the full sample of 17,242 ventures, 11.1% exited through IPO, 37.2% through MA, 22.6% through bankruptcy, and 29.2% remain private as of 2018. It suggests that the likelihood of reaching an exit event is different between the sample with data and the full sample, hence a selection bias. The reweighting method corrects for this selection bias by reweighting ventures with all data available, to match the distribution of exit types in the full sample. For example, for each venture that went to IPO and has all the data, we weight its cash flows by 0.48 (0.48=11.1%/23.3%). The reweighting method is equivalent to resampling ventures infinite times with replacement.

[14]The Hall and Woodward (2010) model imputes the venture share of ownership in each funding round. See Table A2 in their paper. Their model controls for the amount raised and the cumulative increase in the Wilshire index over the past two years in the first round. Instead of controlling for the increase in Wilshire index, we control for the increase in Nasdaq index. Another difference of our model is that we estimate ownership given up in *all funding rounds* with round fixed effects. Using data from all funding rounds enlarges the sample for estimating the imputation model.

[15]We calculate this out-of-sample R^2 by estimating their model on the first rounds, constructing the fitted values for first-round ownership given up, and calculating the pseudo-R^2's.

Our preferred method is the imputation method. It has the advantage of not oversampling time periods that had many more ventures exiting through IPOs such as the dot-com bubble period. Panel (e) and (f) of Figure 2 show that the reweighting method overstates the ventures that were initiated during the dot-com bubble and understates the ventures initiated after 2003. This is because a large fraction of ventures receiving financing during the dot-com bubble eventually exited through MAs with observed valuations.[16] The imputation method also makes use of the information in observed covariates, and we have seen that these covariates are strongly correlated with the variables of interest, and improved the out-of-sample performance of the imputation model. While the reweighting method uses data of only 17% of all ventures, the imputation method leverages the observed data of more ventures.

We report in Table 5 how the aggregate cash flows change when we step-wise increase the number of variables imputed. 2,945 out of 17,242 ventures have first-round valuation, amount raised and exit values data all available. After we impute all three variables, the effective sample size grows from 2,945 to 17,242, a 485% increase, and the aggregate first round valuation, aggregate amount raised, and aggregate exit valuation increase only by 292%, 316%, and 244%, respectively. The imputation models tend to yield values that are, on average, lower than their observed data. In Section 4.4, we discuss the sensitivity and robustness of our results to the imputation model.

4. Empirical Results

4.1. The Average ARAEI of Ventures

We compute the realized PME of a portfolio of ventures using four sets of parameters for the SDF specification in Equation (1) for individual ventures, to study the average ARAEI in our data.

[16]In our subsample with complete cash flow data (2,954 ventures), 23.3% exited via IPOs, while 29.6% exited via MAs. However, in the full sample (17,242 ventures), 11.1% exited via IPOs and 37.2% exited via MAs. The reweighting method weights the ventures that exited through IPOs and have cash flow data by a factor of 0.48 (11.1%/23.3%), and weights the ventures that exited via MAs and have cash flow data by a factor of 1.26 (37.2%/29.6%). This over-weights ventures receiving financing during the dot-com bubble period, because a disproportionally large fraction of those ventures eventually exited through MAs with observed valuations. Our preferred imputation method does not have this problem.

The four sets of parameters are: (a) $a = b = 0$ (no discounting) [17]; (b) $a = 0, b = 1$ (the PME); (c) $a = 0.033, b = 1.444$ (the GPME) and (d) $a = -r_f, b = 0$ (discounting using risk-free rate). We discount cash outflows and inflows of an individual venture to its first funding round and calculate the realized PME of the portfolio of ventures as the ratio of aggregate first-round time's value of cash inflows to aggregate first-round time's value of cash outflows. We also provide the IRR of the portfolio of ventures, by ranking all the cash flows to the portfolio of ventures by calendar time and finding the IRR that sets the total discounted value of these cash flows to zero.

We consider three samples: the full sample including 17,242 ventures receiving the first funding round before 2006, the no-bubble sample, and the pre-2006 sample. The no-bubble sample is derived by excluding from the full sample the ventures that had any funding rounds or exits in 1999 and 2000. [18] We evaluate ARAEI in the no-bubble sample to exclude the effect of the dot-com bubble on the return to investing in ventures. The pre-2006 sample is derived from the full sample but assuming the observation of these ventures stop in 2006/12, and excludes from the full sample 5,097 ventures that remain private as of 2006 but had financing activities between 2001 and 2006. [19] We use the pre-2006 sample to show the effect of the right-censoring data issue.

Table 2 provides the results. First, the PME using any set of SDF parameters of the portfolio of ventures in any of the three samples is greater than one, which means, the portfolio of all ventures outperformed the public benchmark. The IRR of investing in ventures is about 22% - 30%, also large. For comparison, the IRR of the venture-mimicking portfolio of public market industry portfolios was 7%. We construct the venture-mimicking portfolio by investing each venture's amount raised into its corresponding industry's portfolio at the funding round's time. We liquidate the industry portfolio (taking returns from Fama-French 10 industry portfolios) when the venture exits

[17] This is the same return measure used in Cole, Melecky, Mölders, and Reed (2020) to evaluate the performance of investment portfolios without accounting for market risk or the time value of money, thereby providing a straightforward ratio of the total gains from the investment relative to the invested capital, known as the Total Value to Paid-In Capital (TVPI).

[18] We define the bubble period as from 1999 to 2000, when Nasdaq return significantly deviates from SP500.

[19] The boom of ventures that initiated around 2000 leads to disproportionately more young actively financed ventures that remain private as of 2006. It is no longer appropriate to assume these actively financed 5,097 ventures that remain private as of 2006 have zero exit values, since Table A.5 in the Online Appendix indicates that 6.8% and 52.6% of them eventually went to IPO and MA. So the pre-2006 sample excludes from the full sample these 5,097 ventures.

through IPO, MA and bankruptcy, or if no exit is observed, at the earlier of (a) 12 years after the last observed round and (b) December 31, 2018. The IRR that sets the present value of the net cash inflows of the venture-mimicking portfolio to 0 is 7%.

Second, the imputation method and the reweighting method to fill in missing data result in comparable PMEs in the full sample, which are around 1.42–1.47. Our preferred set of SDF parameters are $a = 0.033, b = 1.444$ (GPME) following Korteweg and Nagel (2016). Under this set of parameters, the the reweighting method produces a PME of 1.47 in the full sample, 1.19 in the no-bubble sample, and 1.61 in the pre-2006 sample, while the imputation method produces very consistent PMEs ranging between 1.41–1.48 in the three samples.

Third, the ARAEI of the portfolio of all the ventures in our sample had a Public Market Equivalent (PME) of 1.42. This portfolio includes 17,242 ventures that had their first funding round in 1980-2006. In their review, Jagannathan et al. (2023) summarize the results of several studies that have assessed venture capital performance using PME-related metrics at the fund level. These studies report fund-level PME varying from 0.96 to 1.22 over different time periods in 1980-2010. Panel C of Table 2 provides the comparison of the ARAEI with the fund-level PMEs in these studies. The ARAEI was higher than the fund-level PMEs. Closest to us is Harris et al. (2014b), who find the PME of VC funds in 1984-2008 was 1.22, while the PME of ARAEI was 1.57 during that time period. The fee charged by the funds and the compensation (return) to founders may be reasons why ARAEI was higher.

How long would it take starting from the first funding round for the ARAEI to become positive? Building upon the PME methodology, we examine the cash flows over the life cycle of the ventures. We construct the cumulative discounted cash inflows and outflows for each individual venture following its first funding round. These are then aggregated across all ventures and plotted in Figure 3 against the time elapsed from the first funding rounds. In the aggregate, investors have to wait five years from the first funding round for the discounted net cash flows from the ventures to become positive (see Panels C and D of the figure). That is, a hypothetical investor who participates in all funding rounds of all ventures had to wait five years in expectation of breaking even relative to the alternative of investing in the public market benchmark, equivalently for the PME to become greater than one in the aggregate.

4.2. Cross Section of Venture ARAEI

The high ARAEI of the portfolio of all ventures is attributable to relatively few ventures. Panel B of Table 2 reports the percentiles of the PMEs (and GPMEs) of individual ventures. In the cross-section, 70% of ventures had a PME below one and 61% had a PME below 0.5, indicating that the majority of the ventures did not outperform the public market benchmark. The distribution was highly skewed right with the 95th percentile PME at 6.39 and the 99th percentile at 21.37. After we exclude from the portfolio of all ventures the best-performing 3% of ventures, which are those with individual venture PME greater than 9.33, the PME and GPME of the remaining portfolio are 0.98 and 1.01. This means that the best-performing 3% of ventures explain the out-performance for the entire 17,242 ventures in our sample, as other ventures collectively matched the public benchmark.

This highlights a slightly more positively skewed distribution of individual venture returns, when compared to the public equity markets. Bessembinder (2018) finds that the majority of common stocks that have appeared in the Center for Research in Security Prices (CRSP) database since 1926 have lifetime buy-and-hold returns less than one-month Treasuries. When stated in terms of lifetime dollar wealth creation, the best-performing 4% of listed companies explain the net gain for the entire US stock market since 1926, as other stocks collectively matched Treasury bills.

4.3. Time Series Properties of ARAEI

Based on the PME methodology, we examine how the ARAEI to investing in ventures changes over time. A venture's vintage is the calendar year of the first funding round. For each year from 1980 to 2006, we form a portfolio of ventures based on their vintage. We compute the PME of a vintage portfolio as the ratio of the sum of discounted cash inflows of the portfolio divided by the sum of discounted cash outflows. Table 3 reports the historical time series of PME and IRR. We see quite large variations in the PMEs over time, ranging from 0.34 to 2.89. The median and average of the PMEs are 1.48 and 1.39. Data for the ventures whose vintage was after 1991 are more reliable, and from 1991 to 2006, venture PME ranges from 1.00 to 2.89. Venture PME was high from 1991 to 1998 and declined after 1998.

Ang, Chen, Goetzmann, and Phalippou (2018) (ACGP) provide a historical time series of returns to investment in private equity funds from 1994 to 2008. They use Bayesian Markov Chain Monte Carlo (MCMC) to estimate a time series of PE returns using cash flows accruing to limited partners, and decompose returns into a component due to exposure to traded factors and a time-varying PE premium not spanned by traded factors. Our results are consistent with ACGP despite the differences between the two approaches. The average fund PMEs in ACGP comparing private equity returns to synchronous investments in the S&P 500 index, is 1.67. The private equity return in ACGP was also high during 1994-1998 and declined after 1998.

We study the time series properties of ARAEI. Here, for each quarter from 1992Q1 to 2006Q4, we form a portfolio of ventures based on their vintage and compute the PME of the vintage portfolio. Although it is possible to extend this exercise to the 1980s, the PMEs before 1992 are less reliable and excluded from the analysis since we would have to fill in a lot of data for the earlier time – as Table 3 shows, before 1991 fewer than 4.4% of the ventures have first-round valuation data. Figure 4 plots the historical time series of the quarterly PMEs. The plot shows that venture PME is generally greater than one over time, and are less than one only in four quarters during the period 1992Q1 to 2006Q4. [20] Using the quarterly time series of PMEs, we conduct some formal statistical tests of whether the expected PME is greater than one while taking into account the serial correlation in the realized PMEs. We first approximate the time series of PMEs by an ARMA(p,q) process, and choose the best ARMA based on the BIC information criterion. Table 6 reports the estimation results. AR(2) is the best model for the PMEs in both 1992Q1-2006Q4 and 1999Q2-2006Q4. AR(1) is the best model for the PMEs in 1992Q1-1999Q1. Then we conduct a t-test of the mean

[20] Figure A.1 in the Online Appendix presents the histogram of the realized NPVs of ventures that had their first round in each calendar quarter. Between 1992Q1 and 2006Q4, NPVs were positive in 55 of 60 quarters using PME discounting, and in 56 quarters with GPME. For 1980-1989, both methods showed negative NPVs in 7 out of 10 years, but this data is less reliable due to limited post-money valuation information for less than 5% of ventures.

of the time series against one, based on the standard errors implied by the best ARMA model. The tests show that the mean of PMEs is significantly greater than one, regardless of the time periods. We also conduct the t-test based on Newey-West standard errors, and the results are similar. To not let the dot-com bubble to confound the PMEs, we repeat the exercise on the no-bubble sample, which excludes ventures that ever had financing activities or exit events during 1999-2000 from the full sample, and the results are the same. [21]

We also observe from Figure 4 that there is a structural break in the time series – venture PME declines substantially after around 1999. The same structural break is also visible in the times series of IRR, and is visible when we plot the time series using the no-bubble sample that excludes ventures with any financing activities or or exits between 1999 and 2001. To confirm the observation of the structural break, and to identify the time of the break, we apply a Supremum Wald test (Quandt, 1960; Andrews, 1993). The test assumes the PME fluctuates around a constant, and looks for a structural break in the constant parameter of the model, at an unknown break time. Table 6 shows the test result, indicating that there is a structural break in the time series of PME at 1999Q1, and after that PME significantly declines. The test results are similar for the time series of IRR, suggesting a structural break at 1999Q2. The interpretation of the test results requires some cautiousness, as the Supermum Wald test assumes uncorrelated residuals in the PME time series while the fitness of AR(1) and AR(2) processes suggests strong autocorrelation. We provide additional test results in Table 6 that allow for heteroskedastic and serially correlated residuals. That is, we report regression results from $\text{GPME}_t = a + a_1\mathcal{I}_{t\geq 1999Q1} + \epsilon_t$, with the t-statistics of a_1 using White standard errors and Newey-West standard errors. The t-statistics suggest a_1 is significantly negative, again confirming the presence of a structural break in 1999Q1.

What might have caused the structural break? There may be two causes. The first one is the dot-com bubble. Figure 2 Panel A plots the time series of the aggregate amount raised and the aggregate exit value of ventures in each calendar quarter. As can be seen, both the amount raised

[21] Table 6 also reports the best ARMA models for the no-bubble sample. The best ARMA model for the PMEs is AR(1) during 1992Q1-1999Q1, and is AR(2) during 2001Q1-2006Q4. The t-tests show that the mean of PMEs is significantly greater than one.

and value realized through exits rose sharply during the early 1990s, and reached a peak in the dot-com bubble period (1999-2000 when the Nasdaq index was higher than the S&P500 index when the latter was normalized to match the Nasdaq index value of 771 in January 1994), and crashed in 2001. One can argue investors overvalued the ventures and paid too much when investing in ventures during this bubble period, and eventually earned poor returns on those investments.

The second cause might be the NSMIA Act passed in 1996 that increased the supply of capital to the ventures (Ewens and Farre-Mensa, 2020), hence lowering the return of investing in ventures. Two distinct provisions of NSMIA have helped increase the supply of private capital, including venture capital. First, NSMIA exempts qualified private security issuers from having to comply with the blue sky laws of each state. Traditionally, a venture seeking external financing needed to comply with the laws governing the issuance of securities in each state where its securities were sold, commonly known as blue sky laws. Compliance with blue sky laws required significant time and effort. NSMIA exempts private issuers from compliance with blue sky laws in each and every state, as long as all investors are "accredited investors", hence facilitating venture's security issuance. Second, NSMIA makes it possible for VC and PE funds to raise capital from a large number of investors but without registering under the Investment Company Act (ICA) of 1940, enabling VC and PE funds to raise funds at a lower cost.[22]

It is difficult to disentangle the two causes since they may be influencing each other. We attenuated the effect of the dot-com bubble period by excluding ventures that had any funding rounds or exits during these two years. The Andrews (1993) structural break test when applied to the PME times series with this exclusion restriction still identifies 1999Q1 as the structural break quarter. This suggests that the structural break may not be solely due to investor exuberance during the dot-com bubble period.

[22]The ICA required VC and PE funds to register with the SEC and imposed extensive regulations on registered entities, including investment and leverage restrictions, restrictions on related party transactions, and ongoing reporting requirements. NSMIA to a large extent allows exemptions of these regulatory requirements, for certain classes of investors.

4.4. Sensitivity and Robustness

We conduct a set of analyses to evaluate the robustness of the ARAEI estimates. ARAEI requires data on the first-round post-money valuation, the amount raised in each funding round, and the exit value of a venture. We used the imputation method to address the missing data in these three variables. The effective sample size grows from 2,945 to 17,242 after we impute all three variables, but one concern is that the ARAEI is sensitive to the imputation models.

To alleviate this concern, the first exercise we conduct is to provide the bootstrapped standard errors and confidence intervals of the ARAEI estimates. We construct 500 bootstrap samples each of the same size as the full sample. Each bootstrap sample is constructed by randomly drawing ventures from the full sample with an equal probability and with replacement. In each bootstrap sample, we re-estimate the imputation models and use the re-estimated models to impute the missing data and construct the ARAEI. The distribution of the bootstrapped ARAEI estimates is used to construct confidence intervals of ARAEI in the population. In Table A.10 of the Online Appendix, we provide the bootstrapped confidence intervals of the historical time series of ARAEI we presented in Table 3. The lower boundaries of the 90% confidence intervals of PMEs and GPMEs are still mostly greater than one for the portfolio of ventures that received the first funding rounds from 1992 to 2006. We conclude that the portfolio of all ventures outperformed the public benchmark after considering the estimation errors of the imputation method. The lower and upper boundaries of the 90% confidence intervals of PMEs and GPMEs also declined substantially after 1999. This exercise assumes that the imputation model is correctly specified, but the parameters of the model are not known and are estimated, and provides some measure of the effect of those estimation errors on estimated PMEs.

Since lots of data first-round post-money valuation and exit values are imputed for the ARAEI, if the imputation models are misspecified, that would lead to large biases in ARAEI. To alleviate this concern, we perform scenarios-based sensitivity analysis and find that ARAEI is not sensitive to errors in first-round post-money valuation. First-round ownership given up is mapped one-to-one to the first-round post-money valuation. We consider two scenarios where we increase and decrease first-round ownership given up by 18%, a one standard deviation change in the variable. The increase or decrease applies across the board, not only to imputed values but also to the observed values. Table A.11 in the Online Appendix tabulates the historical time series of PMEs, GPMEs and IRRs in the two scenarios. An across-the-board 18% increase in first-round ownership will increase the mean of historical PMEs from 1.49 to 1.61, representing an 8.1% increase, and increase the mean of historical GPMEs from 1.39 to 1.51, representing an 8.6% increase. Conversely, an 18% decrease in first-round ownership will reduce the mean of historical PMEs from 1.49 to 1.34, indicating a 10.1% decrease, and reduce the mean of historical GPMEs from 1.39 to 1.26, marking a 9.4% decrease. ARAEI also declines substantially after 1999 in the two scenarios.

In order to assess the sensitivity of ARAEI to errors in imputed exit values, we consider two scenarios where we increase and decrease the imputed exit values by 25% while keeping the observed exit values unchanged. Table A.12 in the Online Appendix reports the resulting ARAEI. An across-the-board 25% reduction in imputed exit values will reduce the mean of historical PMEs from 1.49 to 1.46, a decrease of approximately 2.0%, reduce the mean of historical GPMEs from 1.39 to 1.36, a decrease of around 2.2%, and reduce the mean of historical IRRs from 32% to 31%, which is a 3.1% decrease. These results suggest investments in ventures still outperform the public market equivalent. ARAEI also declines substantially after 1999 in the two scenarios.

Finally, the imputation method we use to impute first-round post-money valuation involves back-filling – we use data in the first round as well as the subsequent rounds for the imputation. The purpose of using data in the subsequent rounds is to utilize existing data on valuation as much as possible. Given that valuation data is rare, this enlarges the sample size and reduces the estimation error. The drawback of the back-filling is that it may exacerbate the selection bias – imputed first-round valuation relies more on ventures that turn out to be successful, have more subsequent rounds, and are more likely to have valuation data. To alleviate this concern, we estimate the imputation model in Equation (4) only using data on the first funding round, and use the estimated parameter values to impute the first-round post-money valuation. We report the resulting ARAEI of ventures in Table A.13, A.14 and Figure A.2 in the Online Appendix. Our findings regarding the average

ARAEI across ventures and the time series properties of ARAEI are not materially affected.

5. Conclusion

We measure the aggregate lifetime return to equity investments (ARAEI) in venture companies during their venture phase, by applying the public market equivalent (PME) method of Kaplan and Schoar (2005) and its generalized version (GPME) of Korteweg and Nagel (2016) for measuring the risk-adjusted return to venture capital funds to the individual venture-companies. We use an imputation model for missing first round and exit valuations based on Hall and Woodward (2007). ARAEI is the ratio of discounted venture cash inflows to discounted venture cash outflows, where we match the cash flows of ventures at each time period to an investment in the publicly traded market portfolio, and use the realized market portfolio's return to discount the venture cash flows. ARAEI is less subject to errors in valuation data and sidesteps the need to analyze complex VC contracts.

We document three facts based on ARAEI of 17,272 ventures. First, the ARAEI of the portfolio of all the ventures had a PME of 1.42, which is higher than the venture fund-level PME. The fee charged by the funds, the compensation (return) to founders, and differences in the sample of ventures under different studies may be reasons why ARAEI was higher. Second, in the cross-section, the distribution of individual venture returns is positively skewed. The best-performing 3% of ventures in terms of the PME explain the out-performance for the entire 17,242 ventures in our sample that had their first funding round in 1980-2006, as other ventures collectively matched the public benchmark. Third, in the time series, the ARAEI as measured by the PME and GPME and the ARAEI without risk adjustment as measured by IRR significantly come down after 1999Q1, consistent with Harris et al. (2014b). Compared with Harris et al. (2014b), who find that the PME of venture capital funds is lower than or close to one after 2000, we find that ARAEI of ventures although declined, continued to outperform their public market equivalent after 2000.

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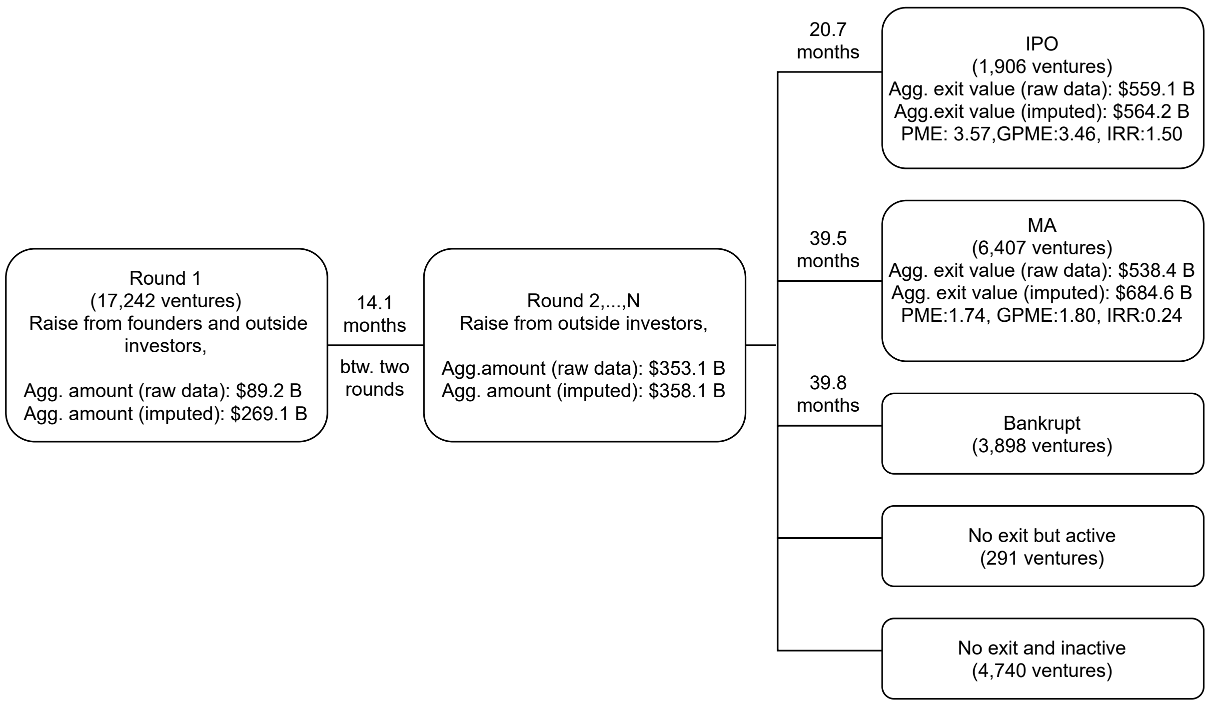
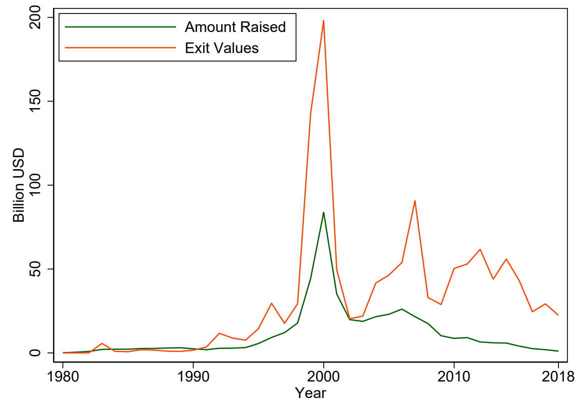
Fig. 1: The Venture Data: Amount Raised, Exit Events, Valuations, and Returns to Investments



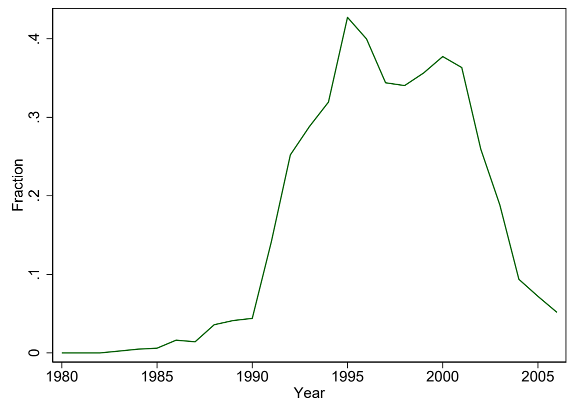
Notes: In round 1, 17,242 ventures raise $89.2 billion from founders and outside investors in the aggregate, based on the raw data; while based on the imputed data, that is after filling in the missing observations of first-round post-money valuations, the ventures raise $269.1 billion. In the subsequent rounds, the ventures raise $353.1 billion in the aggregate based on the raw data and $358.1 billion based on the imputed data. The average time between two rounds is 14.1 months. After the last round, ventures spend 20.7 months on average before IPO, with an aggregate exit value of $559.1 billion based on raw data, and $564.2 billion based on the imputed data. After the last round, ventures spend 30.5 months on average before MA, with an aggregate exit value of $538.4 billion based on the raw data, and $684.6 billion based on the imputed data. We also provide the average PME, GPME and IRR for ventures that went to IPO and MA, respectively.

Fig. 2: Availability of Data on Amount Raised, First-Round Valuations and Exit Values

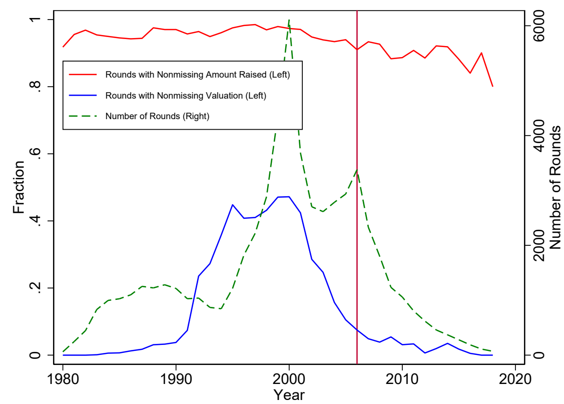
(a) Aggregate amount raised and exit values



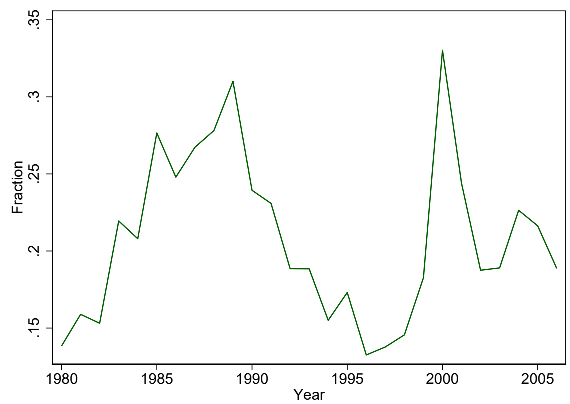
(b) Fraction of first rounds with valuation data



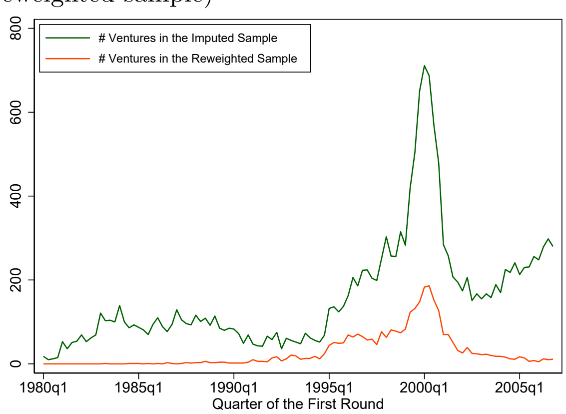
(c) Fraction of rounds with amount raised and valuation data



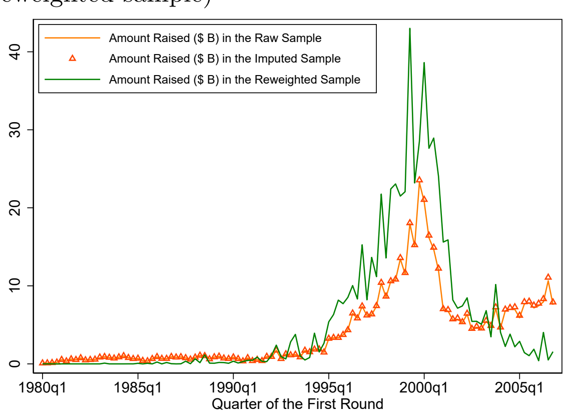
(d) Amount raised in the first rounds as a fraction of life-time amount raised



(e) Total number of ventures (imputed sample vs. reweighted sample)

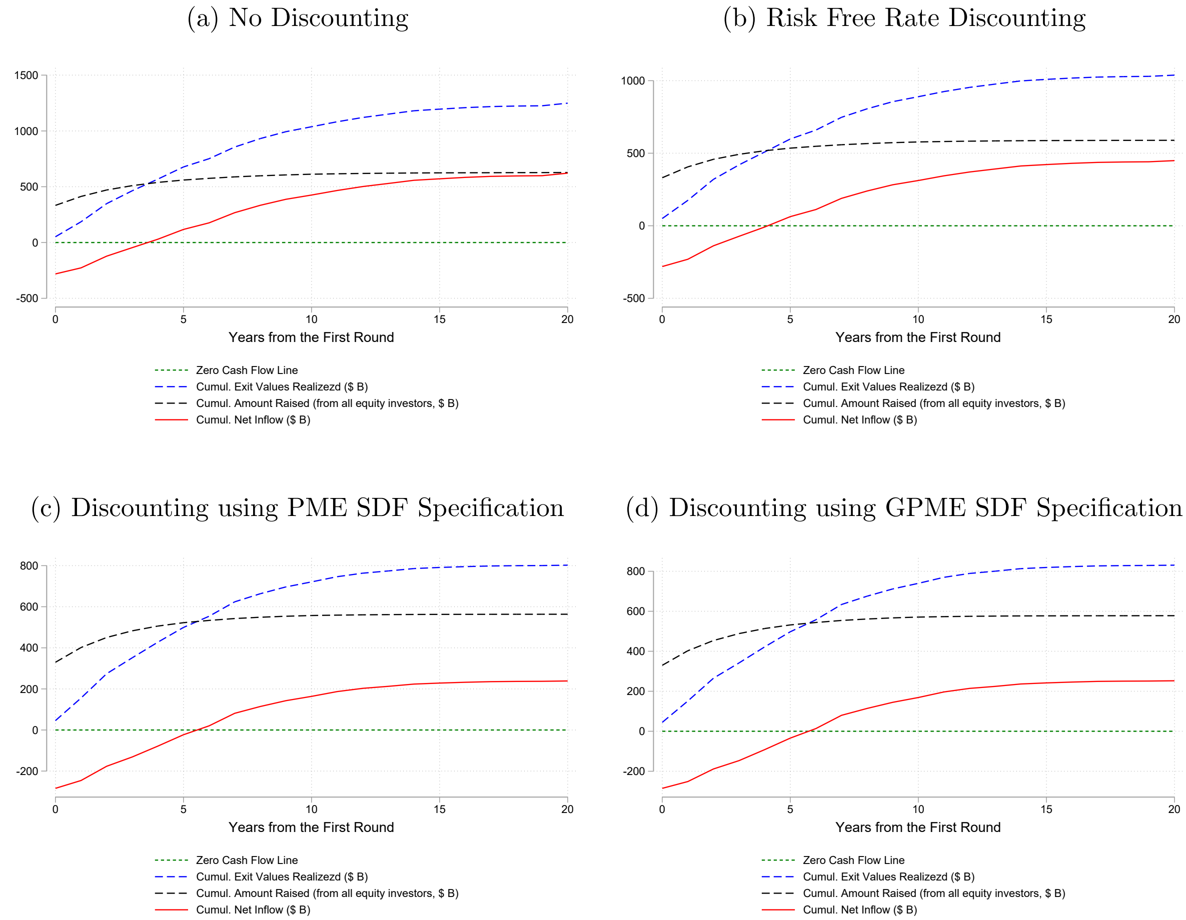


(f) Aggregate amount raised (imputed sample vs. reweighted sample)



Notes: Panel (a) plots the total amount raised and exit values of ventures in each calendar year. Panel (b) plots the fraction of first rounds with non-missing post-money valuation data. Panel (c) plots the number of funding rounds received by the ventures and the fraction of the funding rounds that have non-missing amount raised data and non-missing post-money valuation data in each year. Panel (d) plots the amount raised in first rounds as a fraction of life time amount raised. Panel (e) plots the number of ventures in the imputed sample, and the reweighted sample by the quarter of the first funding round. We start from the 17,242 US-based ventures in the SDC VentureXpert database that had the first funding round in 1980–2006 ("raw sample"). The imputed sample is derived by imputing missing data in first-round post-money valuation, amount raised, and exit value in the raw sample. The reweighted sample includes ventures with data in these three variables. Panel (f) plots the amount raised of ventures in the raw sample, the imputed sample, and the amount raised in the reweighted sample weighted by a factor of 5.84 (17,242/2,954).

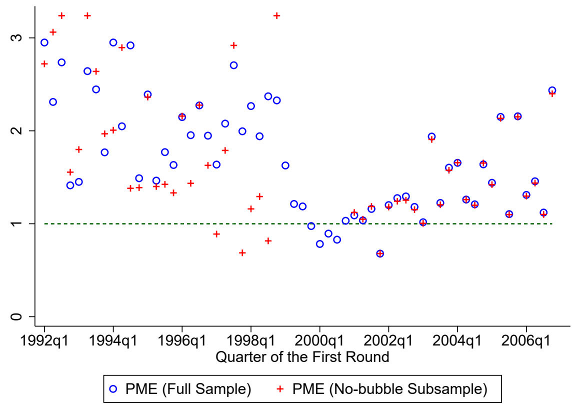
Fig. 3: Cumulative Venture Cash Flows by Time Elapsed from the First Round



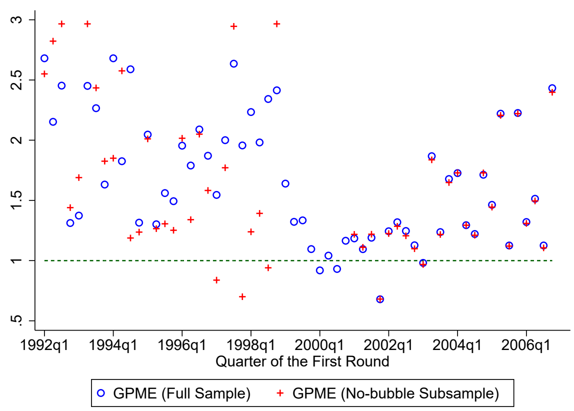
Notes: Over the life cycle of the venture, the figure plots the aggregate cumulative exit values realized, aggregate cumulative amount raised (from all equity investors) and aggregate cumulative net cash flow for investors investing in the portfolio of 17,242 US-based ventures in SDC VentureXpert database who had the first funding round in 1980–2006, and we trace their funding rounds in 1980–2018. Cumulative net cash flow is defined as cumulative amount raised minus cumulative exit values realized. Amount raised and exit values are not discounted in Panel (a), discounted with risk free rate in Panel (b), discounted with SDF specification in PME (a=0, b=1) in Panel (c), discounted with SDF specification in GPME (a=0.033,b=1.444) in Panel (d) to the venture's first funding round's date.

Fig. 4: ARAEI Return to Investing in Ventures by Time of the First Round

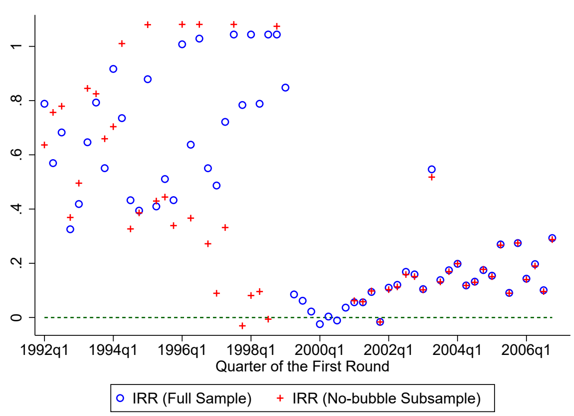
(a) PME



(b) GPME



(c) IRR



Notes: The figure plots the PME, GPME and IRR of the ARAEI of portfolio of ventures that received the first funding round in each quarter. The sample includes 13,516 US-based ventures in SDC VentureXpert database that had the first funding round in 1992–2006, and we trace their funding rounds in 1992–2018. The no-bubble subsample excludes ventures that ever had financing activities or exit events in 1999 and 2000.

Table 1: Effects of Error in Post-Money Valuation Data in One Funding Round: An Example

Panel A. Hypothesized Correct Valuation

Year	0	1	2	3	4
Stage	Round 1	Round 2	Round 3	Round 4	IPO
Amount Raised ($ M)	5.14	***9.37***	***14.43***	***16.76***	n.a.
Post-Money Valuation ($ M)	***14.63***	37.66	70.59	86.07	***368.34***
Market Return from Last Round	n.a.	16.8%	14.1%	15.6%	19.6%
Gross Market Return from Year 0	n.a.	116.8%	133.3%	154.1%	184.3%
Present Value of Cash Flows	-14.63	-8.02	-10.82	-10.88	199.91
Pre-Money Valuation	9.49	28.29	56.16	69.31	n.a.
Ownership Given Up	35.1%	24.9%	20.4%	19.5%	n.a.
Round-to-Round Return	93.3%	49.1%	-1.8%	328.0%	n.a.
Round-to-Exit Return	1111.3%	526.5%	320.2%	328.0%	n.a.
PME	4.51				
NPV (PME Approach)	155.55				

Panel B. Observed Valuation

Year	0	1	2	3	4
Stage	Round 1	Round 2	Round 3	Round 4	IPO
Amount Raised ($ M)	5.14	***9.37***	***14.43***	***16.76***	n.a.
Post-Money Valuation ($ M)	***14.63***	37.66	70.59	127.38	***368.34***
Market Return from Last Round	n.a.	16.8%	14.1%	15.6%	19.6%
Gross Market Return from Year 0	n.a.	116.8%	133.3%	154.1%	184.3%
Present Value of Cash Flows	-14.63	-8.02	-10.82	-10.88	199.91
Pre-Money Valuation	9.49	28.29	56.16	110.62	n.a.
Ownership Given Up	35.1%	24.9%	20.4%	13.2%	n.a.
Round-to-Round Return	93.3%	49.1%	56.7%	189.2%	n.a.
Round-to-Exit Return	1206.3%	575.7%	353.1%	189.2%	n.a.
PME	4.51				
NPV (PME Approach)	155.55				

Notes: The table shows the life cycle of a hypothetical venture with complete information on funding rounds and the exit. The venture raises one round per year and exits through an IPO at the end of the 4th year. The amount raised and exit value of this venture reflects that of the average venture in our sample. The market return is 10% every year. Panel A records the correct amount raised and valuation data, and the corresponding return measures calculated based on the data. In Panel B, the post-money valuation of round 4 is biased upwards due to measurement error – to reflect the fact that observed value of existing common shares in late rounds is biased upwards as documented by Gornall and Strebulaev (2020). Numbers colored in red show that this bias leads to biases in some return measures.

Table 2: The ARAEI: Full Sample and Sub-Sample Results

Panel A. ARAEI of the aggregate portfolio of ventures in different samples

Sample	PME_{nodisc}	PME	GPME	PME_{rf}	IRR	#Ventures	Amount Raised ($B)	Exit Value ($B)
Full Sample (Imputation)	1.99	1.42	1.44	1.76	0.22	17,242	452.8	1248.8
Full Sample (Reweighted)	1.86	1.46	1.47	1.70	0.30	2,954	595.2	1610.2
No-bubble Sample (Imputation)	2.05	1.42	1.41	1.82	0.19	10,542	210.2	603.2
No-bubble Sample (Reweighted)	1.72	1.20	1.19	1.52	0.15	1,066	261.4	678.6
Pre-2006 Sample (Imputation)	2.05	1.51	1.48	1.82	0.35	11,552	225.2	710.2
Pre-2006 Sample (Reweighted)	2.07	1.63	1.61	1.88	0.45	2,307	311.0	1038.3

Panel B. Distribution of ARAEI across ventures in the full sample

Percentiles	p50	p60	p70	p80	p90	p95	p99
PME	0	0.46	1.00	1.80	3.63	6.39	21.37
GPME	0	0.47	1.05	1.83	3.60	6.35	21.38

Panel C. Comparison with venture capital performance measures across studies

Article	Period	Fund-level PME	ARAEI PME
Kaplan and Schoar (2005)	1980-1994	0.96	1.44
Harris, Jenkinson, and Kaplan (2014)	1984-2008	1.2	1.57
Korteweg and Nagel (2016)	1987-2005	1.05	1.74
Robinson and Sensoy (2016)	1984-2009	1.06	1.57
Gupta and van Nieuwerburgh (2021)	1990-2010	1.22	1.83

Notes: The table provides a comparison of the returns by the different samples, missing data-filling methods and return measures. The full sample includes 17,242 US-based ventures in SDC VentureXpert database that had the first funding round in 1980–2006, and we trace their funding rounds in 1980–2018. The no-bubble sample is derived by excluding ventures with any financing activities or exits in 1999 and 2000 from the full sample. For the two samples, we assume the ventures that remain private as of 2018 have an exit value of 0. The pre-2006 sample is derived from the full sample but assuming our observation of these ventures stop in 2006/12, and excludes from the full sample 5,097 ventures that remain private as of 2006 but had financing activities since 2001. In this sample, we assume the ventures that remain private as of 2006 but had no financing activities since 2001 have an exit value of 0. "Imputation" and "reweighted" refer to two ways of filling in the missing data (see text for the details). For example, for the full sample, we reweight 2,954 ventures that have all the required data for the venture GPME calculation. PME_{nodisc} is the venture PME without discounting the cash flows (i.e., $M_t = 1$). PME uses in the SDF specification the PME's parameters (i.e., $a = 0, b = 1$). GPME uses the GPME's parameters (i.e., $a = 0.033, b = 1.444$). PME_{rf} uses the risk free rate to discount the cash flows (i.e., $M_t = e^{-r_f t}$). IRR is the internal rate of return.

Table 3: ARAEI of Ventures by the Calendar Year of Their First Rounds

1st-Round Year	PME_{nodisc}	PME	GPME	PME_{rf}	IRR	# Ventures	Amount Raised ($B)	Exit Value ($B)	# With 1st Val.	% With 1st Val.
1980	1.85	1.16	1.02	1.46	0.31	55	0.5	1.2	0	0.0%
1981	2.29	1.62	1.51	1.86	0.61	194	2.0	5.7	0	0.0%
1982	1.75	0.80	0.69	1.22	0.11	253	2.3	5.0	0	0.0%
1983	3.48	0.52	0.42	1.47	0.07	428	3.3	15.3	1	0.2%
1984	0.87	0.39	0.34	0.61	-0.02	418	3.3	3.5	2	0.5%
1985	1.67	0.45	0.37	0.97	0.05	332	2.1	4.4	2	0.6%
1986	1.86	0.60	0.52	1.10	0.06	370	3.2	7.9	6	1.6%
1987	1.86	0.89	0.82	1.31	0.10	423	3.1	7.3	6	1.4%
1988	2.63	1.63	1.48	2.15	0.30	418	3.6	12.7	15	3.6%
1989	2.29	0.98	0.86	1.65	0.14	364	3.2	10.4	15	4.1%
1990	2.74	1.35	1.21	2.11	0.22	273	2.6	9.7	12	4.4%
1991	5.07	2.52	2.22	4.03	0.51	198	2.3	17.2	28	14.1%
1992	6.96	3.38	2.89	5.74	0.63	230	4.6	38.5	58	25.2%
1993	2.81	2.01	1.87	2.56	0.60	229	4.9	17.0	66	28.8%
1994	6.12	3.25	2.78	5.15	0.70	238	6.7	51.2	76	31.9%
1995	2.91	1.78	1.57	2.56	0.55	529	13.7	50.6	226	42.7%
1996	2.87	2.07	1.92	2.63	0.77	778	24.1	82.9	311	40.0%
1997	2.67	2.11	2.05	2.46	0.78	878	30.5	96.7	302	34.4%
1998	2.53	2.23	2.25	2.38	1.09	1,131	43.7	131.9	385	34.0%
1999	1.38	1.18	1.29	1.22	0.08	1,857	68.5	110.2	662	35.6%
2000	0.98	0.87	1.00	0.85	0.00	2,446	64.7	86.9	923	37.7%
2001	1.31	1.00	1.06	1.19	0.05	944	25.6	38.1	343	36.3%
2002	1.75	1.24	1.24	1.62	0.14	698	21.1	39.1	181	25.9%
2003	1.99	1.49	1.50	1.86	0.21	669	22.3	45.4	126	18.8%
2004	1.91	1.43	1.48	1.77	0.15	854	26.2	53.0	80	9.4%
2005	2.27	1.72	1.77	2.14	0.20	930	29.6	74.4	67	7.2%
2006	2.05	1.54	1.56	1.98	0.19	1,105	35.1	81.2	57	5.2%

Notes: The table provides a historical time series of the return to investing in ventures. The full sample includes US-based ventures in SDC VentureXpert database that had the first funding round in 1980–2006, and we trace their funding rounds in 1980–2018. PME_{nodisc} is the venture PME without discounting the cash flows (i.e., $M_t = 1$). PME uses in the SDF specification the PME's parameters (i.e., $a = 0, b = 1$). GPME uses the GPME's parameters (i.e., $a = 0.033, b = 1.444$). PME_{rf} uses the risk free rate to discount the cash flows (i.e., $M_t = e^{-r_f t}$). IRR is the internal rate of return.

Table 4: ARAEI Suffers Less from Data Availability Issues

Panel A: Fraction of rounds with available data for the existing valuation measures

Sample	Variable	All	Round Type			
			First	Interim	Last	Single
Full Sample	# Rounds	54,525	12,260	30,005	12,260	4,982
With Amount Raised	# Rounds	52,262	11,760	29,042	11,460	4,324
	% Rounds	95.8%	95.9%	96.8%	93.5%	86.8%
With Post-money Valuation	# Rounds	12,913	3,123	7,201	2,589	827
	% Rounds	23.7%	25.5%	24.0%	21.1%	16.6%
With Round-to-Next-Event Return	# Rounds	8,393	1,971	4,297	2,125	687
	% Rounds	15.4%	16.1%	14.3%	17.3%	13.8%

Panel B: Fraction of ventures with data needed to compute the GPME of ARAEI

		All	IPO	MA	Bankrupt	Private (Active)	Private (Inactive)
Full Sample	# Ventures	17,242	1,906	6,407	3,898	291	4,740
With All Cash Outflows	# Ventures	3,740	697	1,650	821	26	546
	% Ventures	21.7%	36.6%	25.8%	21.1%	8.9%	11.5%
With Exit Values	# Ventures	5,100	1,864	3,236	-	-	-
	% Ventures	29.6%	97.8%	50.5%	-	-	-
With All Cash Flows	# Ventures	2,954	688	873	821	26	546
	% Ventures	17.1%	36.1%	13.6%	21.1%	8.9%	11.5%

Notes: In Panel A, we report the fraction of rounds in different stages with available data for the purpose of valuing the venture. The data availability of a funding round may depend on whether it is the first round, a interim round or the last round of a venture (if the venture has multiple rounds), as well as if it is the only round of a venture (if the venture has a single round). In Panel B, we report the fraction of ventures with the data necessary for the calculation of venture GPME (ARAEI) by exit type. "Private (Active)" ventures refer to those with no observed exit events as of 2018 and had financing activities in the past 5 years, that is, from 2013 to 2018. "Private (Inactive)" ventures refer to those with no observed exit events as of 2018 and had no financing activities in the past 5 years, that is, from 2013 to 2018. A venture "with all cash outflows" data refers to that it has data on first round post-money valuation and amount raised in all funding rounds. A venture "with all cash flows" data refers to that it has data on first round post-money valuation, amount raised in all funding rounds and exit values. The sample includes 17,242 US-based ventures in SDC VentureXpert database that had the first funding round in 1980–2006, and we trace their funding rounds in 1980–2018. We assume ventures that are bankrupt and that remain private as of 2018 have an exit value of 0.

Table 5: Summary Statistics of Venture Data by Exit Type

Panel A: Summary statistics by exit type of ventures						
	Statistics	Exit Type				
		IPO	MA	Bankrupt	Private (Active)	Private (Inactive)
# Ventures	Sum	1,906	6,407	3,898	291	4,740
% Ventures	Sum	11.1%	37.2%	22.6%	1.7%	27.5%
# Rounds	Mean	4.1	3.9	2.9	8.1	2.7
First Round to Exit (Years)	Mean	5.0	6.6	6.2	-	-
Total Amount Raised ($ M)	Mean	46.8	32.9	17.4	87.3	12.6
Exit Valuation ($ M)	Mean	296.3	108.6	-	-	-
First Round to Exit (Months)	Mean	60.7	80.8	75.6	-	-
Last Round to Exit (Month)	Mean	20.7	39.5	39.8	-	-
Between Rounds (Month)	Mean	12.8	14.0	12.0	21.9	14.9

Panel B: How does imputation affect the data?						
		Exit Type				
	Total	IPO	MA	Bankrupt	Private (Active)	Private (Inactive)
Case 1. (no imputation)						
# Ventures	2,945	688	871	820	26	540
Agg. First Round Valuation	68.6	19.8	21.1	17.2	0.3	10.3
Agg. Amount Raised ($ B)	108.9	34.1	39.1	20.9	4.1	10.8
Agg. Exit Valuation ($ B)	363.4	231.5	131.9	-	-	-
Case 2. (only first round valuation is imputed)						
# Ventures	12,201	1,671	2,827	3,564	179	3,960
Agg. First Round Valuation	198.0	35.6	57.8	46.5	1.7	56.4
Agg. Amount Raised ($ B)	310.1	74.8	107.2	62.3	15.0	50.7
Agg. Exit Valuation ($ B)	897.2	467.7	429.5	-	-	-
Case 3. (only first round valuation and exit values are imputed)						
# Ventures	14,984	1,704	5,577	3,564	179	3,960
Agg. First Round Valuation	243.0	36.2	102.2	46.5	1.7	56.4
Agg. Amount Raised ($ B)	385.4	75.5	181.9	62.3	15.0	50.7
Agg. Exit Valuation ($ B)	1027.7	472.1	555.6	-	-	-
Case 4. (first round valuation, amount raised, and exit values all imputed)						
# Ventures	17,242	1,906	6,407	3,898	291	4,740
Agg. First Round Valuation	269.2	39.6	113.7	49.4	3.1	63.4
Agg. Amount Raised ($ B)	452.8	89.3	210.7	67.7	25.4	59.7
Agg. Exit Valuation ($ B)	1248.8	564.2	684.6	-	-	-

Notes: In Panel A, we report summary statistics of the key variables. In Panel B, we report how our imputation procedure could affect the amounts raised and valuations in the aggregate, when we step-wise increase the number of variables imputed. We classify ventures into five groups based on their exit types. "Private (Active)" ventures refer to those with no observed exit events as of 2018 and had financing activities in the past 5 years, that is, from 2013 to 2018. "Private (Inactive)" ventures refer to those with no observed exit events as of 2018 and had no financing activities in the past 5 years, that is, from 2013 to 2018. The sample includes 17,242 US-based ventures in SDC VentureXpert database that had the first funding round in 1980–2006, and we trace their funding rounds in 1980–2018. We assume ventures that are bankrupt and that remain private as of 2018 have an exit value of 0.

Table 6: Time Series Properties of the ARAEI of Ventures

Panel A: Is the ARAEI venture return greater than 1?										
	(1992Q1-2006Q4)		(1992Q1-1999Q1)		(1999Q2-2006Q4)		(1992Q1-1998Q4)		(2001Q1-2006Q4)	
Model\ BIC	PME	GPME	PME	GPME	PME	GPME	PME	GPME	PME	GPME
AR(1)	102.0	92.1	44.4	42.1	40.1	38.4	75.5	68.2	32.1	33.1
MA(1)	109.6	96.3	44.4	42.2	40.2	38.4	75.3	68.1	32.5	33.5
ARMA(1,1)	93.6	86.6	46.1	43.9	38.0	38.0	77.0	69.5	32.1	32.7
AR(2)	90.4	82.6	47.6	45.0	34.1	33.1	78.5	71.1	31.4	31.8
MA(2)	101.1	89.7	47.8	45.1	36.5	35.1	77.8	70.3	30.9	32.7
ARMA(1,2)	95.0	87.9	49.4	47.1	38.8	38.3	80.3	72.8	35.0	35.3
ARMA(2,1)	94.0	86.6	49.6	47.1	35.4	35.1	81.6	72.8	33.2	34.0
ARMA(2,2)	93.8	86.6	51.0	49.5	37.5	36.4	83.0	76.1	35.8	36.0
Chosen Model	AR(2)	AR(2)	AR(1)	AR(1)	AR(2)	AR(2)	AR(1)	AR(1)	AR(2)	AR(2)
Estimated Mean	1.70	1.66	2.11	1.98	1.32	1.37	1.97	1.83	1.40	1.42
Model Implied t	9.85	10.47	13.70	12.60	3.98	4.72	6.40	6.30	4.39	4.55
Newey West t (lag=8)	4.46	5.29	17.70	13.12	2.57	3.28	4.85	4.96	3.68	3.77
Newey West t (lag=4)	5.51	6.37	15.64	12.42	3.15	4.00	5.56	5.63	4.25	4.40

Panel B: Is there a structural break in the ARAEI venture return?						
	PME		GPME		IRR	
	(1)	(2)	(3)	(4)	(5)	(6)
PostBreak		-0.840***		-0.658***		-0.599***
		(-7.600)		(-6.190)		(-12.786)
Constant	1.706***	2.140***	1.665***	2.005***	0.416***	0.725***
	(22.055)	(26.939)	(24.536)	(26.244)	(9.166)	(21.537)
Observations	60	60	60	60	60	60
Break Date	1999q1	-	1999q1	-	1999q2	-
Chi2	59.76	-	38.97	-	163.5	-
P Value	0	-	0	-	0	-
White t on PostBreak	-	(-7.564)	-	(-6.190)	-	(-12.786)
NW (lag=8) t on PostBreak	-	(-6.160)	-	(-4.773)	-	(-7.855)
NW (lag=4) t on PostBreak	-	(-6.835)	-	(-5.368)	-	(-9.156)

Notes: In Panel A, we test whether the PME and GPME specification of the ARAEI venture return measure are significantly greater than 1. We compute the time series of PME and GPME for ventures that received the first funding round in each year, and winsorize the PME and GPME at 5% tails. We report the best ARMA models that fit the time series of PME and GPME of ventures in different time periods according to the BIC criteria. Model implied t is based on the standard errors of the estimated mean implied by the best ARMA model. Newey-West t is based on Newey-West standard errors. In Panel B, we test if there is a structural break in the ARAEI venture return.In columns (1), (3) and (5), we show the test statistics from the Supremum Wald tests of whether the constant parameter of time series of GPME, PME and IRR is different before and after an unknown break date, assuming the time series fluctuate around a constant. We also report in columns (2), (4) and (6) regression results from $\text{GPME}_t = \alpha + \beta \mathcal{I}_{t \geq 1999Q1} + \epsilon_t$, with t-statistics of a_1 using White standard errors and Newey-West standard errors. t-statistics are in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

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Online Appendix of "The Aggregate Return to Venture Investors", Jagannathan, Ouyang and Yu (2024)

(Not Intended for Publication)

This document contains three sections. In Section A, we describe in detail the data sources and the data cleaning process for the data on cash flows of venture investments used in our paper. In Section B, we provide details of the imputation method we used to impute the missing data on first-round post-money valuation, amount raised, and exit values. In Section C, we discuss the sensitivity and robustness of the ARAEI measure.

A. Data Sources and Data Cleaning

Our primary dataset is 17,242 US-based ventures in the SDC VentureXpert that had the first funding round in 1980–2006. Among those ventures, 10,175 US-based ventures had the first funding round in 1992-2006 and were not bankrupt according to VentureXpert data. We cross-checked the outcomes of those 10,175 ventures with various other data sources including PitchBook, Bloomberg, Nasdaq, Crunchbase and other Internet sources. Among the cross-checked ventures, 2,090 ventures have no recorded exit events (namely, remain private) according to VentureXpert data. We report in Table A.1 that among the 2,090 ventures, 628 exited through bankruptcy, 14 exited through IPO, and 460 exited through MA according to the other data sources. For the 14 venture exits through IPOs, we list the ventures' names, IPO exchanges, IPO dates, and CRSP permco in Table A.2.

Table A.3 presents how exit values of ventures in different exit events are supplemented by the other data sources. For the ventures that exited through IPOs, we note that some pre-IPO valuation data in SDC databases can be incorrect. To ensure the data is correct, we calculate three measures of the pre-IPO market value and cross-validate them. The first measure is the product of pre-IPO shares outstanding and the IPO offering price. The second measure is the difference between post-

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We thank Honghao Wang in particular for his help with the data on cash flows of venture investments.

IPO market value and the IPO proceeds. The third measure is the pre-IPO market value as reported in the SDC database. If a large discrepancy is observed across these three measures, we manually check the prospectus and use the prospectus value. Overall, we find the first measure to be most reliable. In calculating these three measures, we closely examine other detailed data issues. First, shares outstanding data in SDC might be missing for some NASDAQ IPOs, for which we use the shares outstanding on the first trading day in CRSP for calculation. Second, in some foreign IPOs the offering prices are in foreign currencies instead of US dollars, for which we either avoid using the offering price, or use the ratio of proceeds and offering shares to back out the price in dollars.

Table A.4 shows the fraction of ventures in each status by years from the first round. After 12 years from the first round, the fraction of ventures that exited through IPO, MA, or bankruptcy would remain roughly unchanged with the observation time. For instance, the percentage of ventures that went bankrupt after 12 years from the first round is 21.5%, which is similar to the percentage of ventures that went bankrupt after 20 years from the first round, which is 22.5%.

Table A.5 shows that inactive ventures that remained private at the end of the observation period are unlikely to have successful exits based on historical data. This point can be seen from a "bootstrap" approach: 3,448 ventures remained private as of 2006 and had no funding rounds during 2001-2006, the five-year period before 2006. These are the inactive ventures as of 2006, and we trace their final outcomes as of 2018. These ventures are much less likely to have successful exits than the average venture in the full sample, and even if they indeed had successful exits their aggregate amount raised and exit value are very small compared to the full sample.

Figure A.1 presents the histogram of the realized NPVs of ventures that had their first round in each calendar quarter. Between 1992Q1 and 2006Q4, NPVs were positive in 55 of 60 quarters using PME discounting, and in 56 quarters with GPME. For 1980-1989, both methods showed negative NPVs in 7 out of 10 years, but this data is less reliable due to limited post-money valuation information for less than 5% of ventures.

Table A.1: Outcomes of Ventures that Remain Private According to SDC

Outcomes in Other Data:	Remain Private	BR	IPO	MA	Total	Other Data
	62	463	8	395	928	PitchBook
	202	97	0	37	336	Bloomberg
SDC Outcome:	0	0	4	0	4	Nasdaq
Remain Private	31	16	1	6	54	Crunchbase
	693	52	1	22	768	Others
Total	988	628	14	460	2090	

Notes: We collect information on ventures' outcomes from the universe of SDC VentureXpert, SDC Merger & Acquisition, and SDC Global New Issues data from 1980 until the end of 2018. Based on the SDC data, we classify a venture whose current situation is active or if we do not observe its exit event as "Remain Private". For 10,175 US-based ventures that had the first funding round in 1992-2006 and was not bankrupt according to VentureXpert data, we cross-checked their outcomes with various other data sources including PitchBook, Bloomberg, Nasdaq, Crunchbase and other Internet sources. Among the cross-checked ventures, for 2,090 ventures that remain private, the table tabulates their outcomes based on the other data sources.

Table A.2: IPOs not Recorded by VentureXpert

name	IPO exchange	IPO date	PERMCO
Ikano Communications Inc	NASDAQ	9/22/2005	47441
EXDS Inc	NASDAQ	3/19/1998	16018
Ivow Inc	NASDAQ	7/3/1997	15577
Jmxi Inc	NASDAQ	5/7/1999	16518
Rubio's Restaurants Inc	NASDAQ	5/21/1999	16543
Greenway Health Inc	NYSE	2/2/2012	53986
Ambicom Inc	OTC	3/4/2011	
Modular Space Corp	OTC	2/22/2017	
Infoteria Corp	TKS	6/22/2007	
Morpho Technologies	TOKYO SE	7/21/2011	
Crown Bioscience Inc	TPEX	12/12/2016	
CoadNA Photonics Inc	TWSE	9/9/2011	
Intelligent Epitaxy Technology Inc	TWSE	7/24/2013	
Netex Inc	MADRID SE	10/31/2017	

Notes: The list is based on the SDC data we retrieved in 2018.

Table A.3: Data Sources of Venture Outcomes and Exit Values

Panel A. Source of the Venture Outcomes				
# of Ventures \ Outcome	IPO	MA	BR	Remain Private
Outcome recorded in SDC	1,592	5,779	3,353	4,545
Outcome solely from other sources	314	628	545	486
Total	1,906	6,407	3,898	5,031
Panel B. Exit Values for Outcomes Recorded in SDC				
# of Ventures \ Outcome	IPO	MA		
Exit values non-missing	1,438	2,809		
Exit values complemented by other sources	124	401		
Total	1,592	5,779		
Panel C. Exit Values for Outcomes Solely from Other Sources				
# of Ventures \ Outcome	IPO	MA		
Exit values non-missing	303	145		
Total	314	628		
Panel D. Miscellaneous				
# of Ventures \ Outcome	IPO	MA		
Total # of ventures with exit values	1,865	3,355		
SDC exit values conflicted with other sources	75	150		

Notes: We collect information on ventures' outcomes from the universe of SDC VentureXpert, SDC Merger & Acquisition, and SDC Global New Issues data from 1980 until the end of 2018. Based on SDC data, ventures are observed to exit through IPO, MA, bankruptcy (i.e. "BR"), or have no observed exit (i.e. "Remain Private"). For 10,175 US-based ventures that had the first funding round in 1992-2006 and was not bankrupt according to VentureXpert data, we cross-checked their outcomes with various other data sources including PitchBook, Bloomberg, Nasdaq, Crunchbase and other Internet sources, and we supplement the SDC data with data from these other sources. Our sample for analysis includes 17,242 US-based ventures in SDC VentureXpert database that had the first funding round in 1980-2006. Panel A of this table reports a breakdown of the data sources that identify the outcomes for ventures in our sample for analysis. Panel B shows a breakdown of the data sources that provide the exit values for ventures in our sample for analysis. A "conflict" in exit values refers to the case where the exit values in SDC databases and in other data source differ by more than 5%.

Table A.4: Statuses of Ventures and Cumulative Cashflows by Years from the First Round

Years From First Round	Private (Active)	Private (Inactive)	IPO	MA	Bankrupt	Cumul. Inflows	%Cumul. Inflows	Cumul. Outflows	%Cumul. Outflows	Cumul. Net Inflows
1	97.9%	0.0%	0.9%	1.0%	0.2%	185.8	14.9%	412.9	65.8%	-227.1
2	92.6%	0.0%	2.3%	4.3%	0.9%	348.5	27.9%	470.8	75.1%	-122.3
3	86.5%	0.0%	3.9%	7.8%	1.8%	464.0	37.2%	509.8	81.3%	-45.9
4	80.2%	0.0%	5.5%	11.7%	2.5%	568.5	45.5%	538.9	85.9%	29.6
5	54.7%	12.6%	6.8%	15.7%	10.3%	677.3	54.2%	559.9	89.3%	117.3
6	44.9%	15.0%	7.7%	19.4%	13.1%	751.3	60.2%	575.1	91.7%	176.2
7	35.1%	18.0%	8.4%	22.6%	15.9%	855.6	68.5%	588.3	93.8%	267.3
8	27.4%	20.4%	9.1%	25.4%	17.8%	931.7	74.6%	598.0	95.3%	333.7
9	21.3%	22.1%	9.5%	27.8%	19.2%	993.3	79.5%	605.9	96.6%	387.4
10	16.4%	23.6%	9.9%	29.8%	20.4%	1,037.6	83.1%	612.1	97.6%	425.4
11	12.9%	24.5%	10.2%	31.3%	21.0%	1,082.3	86.7%	615.9	98.2%	466.3
12	9.9%	25.3%	10.4%	32.8%	21.5%	1,120.6	89.7%	618.9	98.7%	501.7
13	7.6%	25.9%	10.6%	34.0%	21.8%	1,150.9	92.2%	621.4	99.1%	529.4
14	5.9%	26.5%	10.8%	34.8%	22.1%	1,180.9	94.6%	623.1	99.3%	557.8
15	4.4%	27.0%	10.8%	35.4%	22.3%	1,195.4	95.7%	624.4	99.5%	571.0
16	3.4%	27.5%	10.9%	35.9%	22.4%	1,208.7	96.8%	625.0	99.6%	583.7
17	2.5%	27.9%	11.0%	36.3%	22.4%	1,218.3	97.6%	625.6	99.7%	592.7
18	1.8%	28.2%	11.0%	36.6%	22.5%	1,223.1	97.9%	626.4	99.9%	596.6
19	1.3%	28.5%	11.0%	36.7%	22.5%	1,225.5	98.1%	626.7	99.9%	598.8
20	1.0%	28.6%	11.0%	36.9%	22.5%	1,248.8	100.0%	627.3	100.0%	621.5

Notes: The table reports the fraction of ventures in each status by years from the first round. For example, %IPO refers to the percent of ventures that have gone to IPO as of a specific number of years after the first round. %Private (Active) refers to percent of ventures that remain private as of a specific number of years after the first round, but remain active, that is, have had financing activities in the past 5 years. The table also reports the cumulative cash inflows and outflows (not discounted, the unit of the numbers is billion dollars) of the universe of ventures by years from the first round.The sample includes 17,242 US-based ventures in SDC VentureXpert database that had the first funding round in 1980–2006, and we trace their funding rounds in 1980–2018.

Table A.5: Summary Statistics for Ventures that Remain Private as of 2006

Panel A. Ventures with No Activity Since 2001

		Exit Type				
Variable	Statistics	IPO	MA	Bankrupt	Private (Active)	Private (Inactive)
# Ventures	Sum	24	430	13	17	3,004
% Ventures	Sum	0.7%	12.3%	0.4%	0.5%	86.1%
# Rounds	Median	3.0	2.0	1.0	4.0	2.0
	Mean	3.4	2.8	2.8	5.1	2.6
	S.D.	2.1	2.0	3.1	3.2	2.3
First Round to Exit (Year)	Median	14.6	12.7	9.9	-	-
	Mean	16.1	13.3	12.8	-	-
	S.D.	7.2	4.8	6.6	-	-
Total Amount Raised ($ M)	Sum	852.9	11,125.6	268.0	807.4	28,976.0
	Median	15.2	13.1	10.0	26.0	3.9
	Mean	35.5	25.9	20.6	47.5	9.6
	S.D.	58.8	39.0	20.7	50.1	16.9
Exit Value ($ M)	Sum	9,560.1	54,676.0	-	-	-
	Median	192.7	44.6	-	-	-
	Mean	415.7	127.4	-	-	-
	S.D.	464.4	417.9	-	-	-
Amout Raised/ Total Amout Raised	Median	0.17	0.24	0.13	0.10	0.25
	Mean	0.30	0.35	0.35	0.20	0.39
	S.D.	0.30	0.32	0.39	0.23	0.36
Exit Value/ Total Amount Raised	Median	6.02	2.90	-	-	-
	Mean	60.06	16.82	-	-	-
	S.D.	140.44	97.44	-	-	-

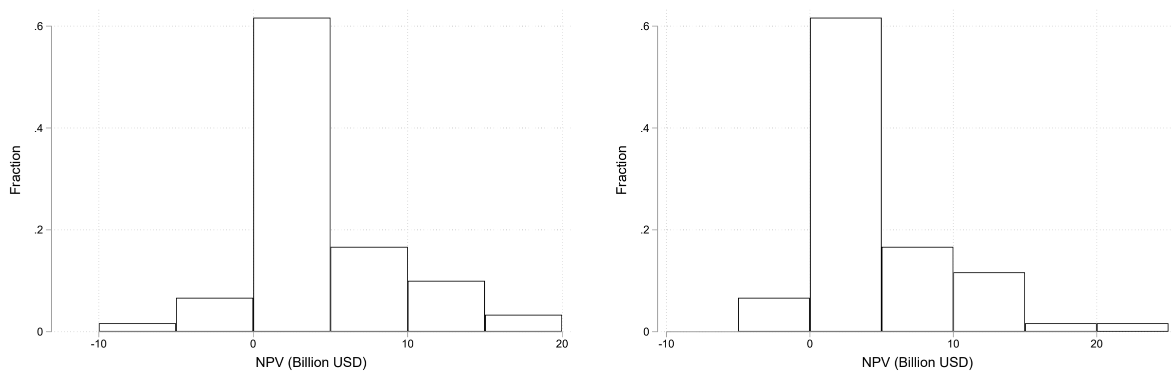
Panel B. Ventures with Some Activities Since 2001

		Exit Type				
Variable	Statistics	IPO	MA	Bankrupt	Private (Active)	Private (Inactive)
# Ventures	Sum	345	2,683	59	274	1,736
% Ventures	Sum	6.8%	52.6%	1.2%	5.4%	34.1%
# Rounds	Median	6.0	4.0	4.0	8.0	2.0
	Mean	6.6	4.8	4.1	8.3	2.9
	S.D.	3.5	3.0	2.5	3.7	2.7
First Round to Exit (Year)	Median	8.6	7.9	5.0	-	-
	Mean	9.0	8.3	5.3	-	-
	S.D.	3.6	3.9	2.4	-	-
Total Amount Raised ($ M)	Sum	37,416.9	109,585.1	2,508.9	24,584.6	30,735.4
	Median	83.6	27.0	22.6	62.9	5.6
	Mean	108.5	40.8	42.5	89.7	17.7
	S.D.	94.0	48.6	54.1	116.6	32.0
Exit Value ($ M)	Sum	164,093.3	308,421.7	-	-	-
	Median	255.8	47.4	-	-	-
	Mean	477.0	117.4	-	-	-
	S.D.	898.6	386.2	-	-	-
Amout Raised/ Total Amout Raised	Median	0.10	0.14	0.16	0.08	0.21
	Mean	0.15	0.21	0.24	0.12	0.34
	S.D.	0.17	0.21	0.25	0.14	0.34
Exit Value/ Total Amount Raised	Median	2.41	1.54	-	-	-
	Mean	6.37	3.96	-	-	-
	S.D.	27.84	27.21	-	-	-

Notes: The table reports the summary statistics of the key variables by venture's exit type, for ventures that remain private as of 2006. Among these ventures, Panel A reports summary statistics for those that are inactive as of 2006, that is, those that have had no financing activities in the past 5 years, from 2001 to 2006. Panel B reports summary statistics for those that are active as of 2006, that is, those that have had financing activities in the past 5 years, from 2001 to 2006. We trace the outcomes and the exits of all the ventures until the end of 2018, based on which we produce the summary statistics. In both panels, the columns labeled by "Private (Active)" and "Private (Inactive)", refer to ventures that remain private as of 2018 and had financing activities in the past 5 years, from 2013 to 2018, and ventures that remain private and had no financing activities in the past 5 years, respectively. We assume ventures that are bankrupt and that remain private as of 2018 have an exit value of 0.

Figure A.1: Histogram of Quarterly Historical Venture NPVs

(a) PME Discounting (b) GPME Discounting



Notes: The figure plots the histogram of the NPV of the portfolio of ventures that received the first rounding round in each quarter. The sample includes 13,516 US-based ventures in SDC VentureXpert database that had the first funding round in 1992-2006, and we trace their funding rounds in 1992-2018. The cash flows are discounted with SDF specification in PME (a=0, b=1) in Panel (a), and discounted with SDF specification in GPME (a=0.033,b=1.444) in Panel (b), to the venture's first funding round's date.

B. Imputation Models

The imputation method uses observed characteristics of a venture and statistical models to predict its first-round post-money valuation, the amount raised in a funding round, and the exit value, and the fitted values from the model are the imputed values for the missing data. Our imputation models described in Equation (3), (4) and (5) follow Hall and Woodward (2010).

We add the explanatory variables in these equations sequentially and select the specification with the highest out-of-sample R^2 computed from a ten-fold cross-validation method. We report the estimation results and the performance of these imputation models in Table A.6, A.7, A.8, and A.9. Table A.6 presents the imputation model for the amount raised in each funding round. Table A.7 presents the imputation model for first-round post-money valuation. Table A.8 and A.9 present the imputation models for exit values in IPOs and MAs, respectively.

The out-of-sample R^2 reported in these tables is computed in the following way. First, we randomly partition the sample that enters the regression model, into ten equal-sized sub-samples. Second, we iterate over each one of the ten subsamples, while in each iteration, we calculate the fitted values for one subsample based on the model estimated by the rest nine subsamples, and record the pseudo-R^2, that is, the square of the correlation coefficient of the fitted and actual values of the dependent variable. After ten iterations, we collect ten pseudo-R^2's for the subsamples. Finally, we repeat the random sample partition ten times, while each time performing the same procedure and collecting the pseudo-R^2's, and we report the average of all the pseudo-R^2's after ten sample partitions as the out-of-sample R^2. The in-sample adjusted R^2 and out-of-sample R^2 of our model in predicting ownership given up in all the funding rounds are 0.488 and 0.486 (See Table A.7).

The out-of-sample R^2 of the Hall and Woodward (2010) model in our data in predicting first-round ownership given up is 0.116. We calculate this out-of-sample R^2 by estimating their model on the data of the first rounds, constructing the fitted values for first-round ownership given up, and calculate the pseudo-R^2's. In comparison, the out-of-sample R^2 of our model in predicting first-round ownership given up is 0.244. We calculate this out-of-sample R^2 by estimating our model in Equation (4) on all the rounds, constructing the fitted values for the first round ownership given up, and calculate the pseudo-R^2's only for the first rounds.

Table A.6: Performance of the Imputation Model for Amount Raised

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
VARIABLES					Log Amount					
ROUND	1	2	3	4	5	6	7	8	9	>9
Log Amount$_{t-1}$		0.305***	0.336***	0.297***	0.291***	0.258***	0.282***	0.292***	0.272***	0.274***
		(0.008)	(0.009)	(0.011)	(0.013)	(0.016)	(0.019)	(0.024)	(0.028)	(0.023)
Constant	16.656***	16.151***	12.179***	14.147***	12.273***	14.717***	13.099***	13.419***	13.299***	13.548***
	(0.691)	(0.883)	(0.787)	(0.779)	(0.795)	(0.718)	(0.691)	(0.922)	(0.905)	(0.622)
Observations	16,084	11,803	8,716	6,366	4,450	3,041	2,041	1,391	924	1,770
Adjusted R^2	0.328	0.507	0.547	0.533	0.508	0.466	0.508	0.486	0.490	0.495
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Stage FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
# Investors FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Psuedo-R^2 Mean	0.318	0.481	0.502	0.505	0.494	0.485	0.481	0.478	0.450	0.466
Psuedo-R^2 Sd	0.009	0.008	0.009	0.011	0.011	0.015	0.016	0.017	0.020	0.025
Repeats of CV	10	10	10	10	10	10	10	10	10	10

Standard errors in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Notes: The table reports the regression results when estimating the imputation models for the amount raised in each venture funding round. The sample includes all US-based ventures in SDC VentureXpert database that had the first funding round in 1980–2006, and we trace their funding rounds in 1980–2018.

Table A.7: Performance of the Imputation Model for First-Round Post-Money Valuation

	(1)	(2)	(3)	(4)
VARIABLES	Logit Ownership Given Up			
Log Amount	0.429***	0.431***	2.349***	2.438***
	(0.007)	(0.008)	(0.097)	(0.089)
Log Amount Squared			-0.063***	-0.049***
			(0.003)	(0.003)
Log Cumulative Amount				-0.713***
				(0.015)
Recent Nasdaq Return	-0.264***	-0.129***	-0.117***	-0.119***
	(0.014)	(0.033)	(0.033)	(0.030)
Constant	-6.956***	-7.262***	-21.453***	-15.255***
	(0.103)	(0.444)	(0.837)	(0.784)
Observations	13,710	13,710	13,710	13,710
Adjusted R^2	0.317	0.383	0.400	0.488
Round Number FE	Yes	Yes	Yes	Yes
Industry FE	No	Yes	Yes	Yes
Stage FE	No	Yes	Yes	Yes
Year FE	No	Yes	Yes	Yes
# Investors FE	No	Yes	Yes	Yes
Psuedo-R^2 Mean	0.316	0.380	0.398	0.486
Psuedo-R^2 Sd	0.026	0.026	0.028	0.030
Repeats of CV	10	10	10	10

Standard errors in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Notes: The table reports the regression results when estimating the imputation models for the ownership given up by the venture founders. The sample includes all the US-based ventures in the SDC VentureXpert database and had the first funding round in 1980–2006, and we trace their funding rounds in 1980–2018. Column (4) is the specification adopted for the imputation.

Table A.8: Performance of the Imputation Model for Pre-IPO Valuation

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
VARIABLES				Log Pre-IPO Valuation				
Extrapolated Valuation		0.509***	0.579***	0.529***	0.504***	0.424***	0.487***	0.574***
		(0.024)	(0.028)	(0.032)	(0.032)	(0.066)	(0.046)	(0.069)
Years between Valuation and Exit			0.557***	0.548***	0.539***	0.534**	0.546***	0.622**
			(0.118)	(0.119)	(0.119)	(0.227)	(0.181)	(0.243)
Extrapolated Valuation × Years between Valuation and Exit			-0.029***	-0.028***	-0.027***	-0.026**	-0.030***	-0.032**
			(0.007)	(0.007)	(0.006)	(0.012)	(0.010)	(0.013)
Log(Final Round Amount)				0.052***	0.056***	0.087***	0.095***	-0.026
				(0.017)	(0.017)	(0.032)	(0.026)	(0.036)
# Years (Final Round to Exit)				-0.036**	-0.077***	-0.120***	-0.079**	-0.021
				(0.018)	(0.020)	(0.039)	(0.035)	(0.042)
NASDAQ Return (Final Round to Exit)					0.204***	0.307***	0.413***	-0.033
					(0.048)	(0.095)	(0.080)	(0.086)
Constant	19.658***	10.150***	8.805***	9.054***	9.454***	9.586***	10.255***	10.770***
	(0.738)	(0.797)	(0.834)	(0.836)	(0.837)	(1.324)	(1.613)	(1.767)
Observations	1,880	1,833	1,833	1,833	1,833	555	873	405
Adjusted R^2	0.361	0.480	0.488	0.505	0.510	0.440	0.545	0.508
Industry FE	Yes	Yes	Yes	Yes	Yes	No	No	No
Stage FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Round Number FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Psuedo-R^2 Mean	0.229	0.399	0.415	0.450	0.450	0.356	0.345	0.362
Psuedo-R^2 Sd	0.026	0.035	0.034	0.034	0.034	0.035	0.034	0.038
Repeats of CV	10	10	10	10	10	10	10	10
Industry	All	All	All	All	All	Health	IT	Others

Standard errors in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Notes: The table reports the regression results when estimating the imputation models for the pre-IPO valuations of ventures. The sample includes all US-based ventures in SDC VentureXpert database that had the first funding round in 1980–2006, and we trace their funding rounds in 1980–2018. Column (5) is the specification adopted for the imputation.

Table A.9: Performance of the Imputation Model for Exit Values in Mergers and Acquisitions

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
VARIABLES	Log Mergers and Acquisitions Valuation							
Extrapolated Valuation		0.599***	0.766***	0.744***	0.740***	0.491***	0.825***	0.733***
		(0.028)	(0.039)	(0.043)	(0.044)	(0.104)	(0.057)	(0.096)
Years between Valuation and Exit			0.690***	0.785***	0.789***	0.258	0.937***	0.990***
			(0.112)	(0.112)	(0.113)	(0.228)	(0.160)	(0.243)
Extrapolated Valuation × Years			-0.038***	-0.039***	-0.039***	-0.011	-0.049***	-0.048***
between Valuation and Exit			(0.006)	(0.006)	(0.006)	(0.013)	(0.009)	(0.013)
Log(Final Round Amount)				0.108***	0.110***	0.203***	0.088***	0.085*
				(0.021)	(0.021)	(0.049)	(0.029)	(0.044)
# Years (Final Round to Exit)				-0.109***	-0.114***	-0.115**	-0.097***	-0.115***
				(0.017)	(0.018)	(0.046)	(0.024)	(0.034)
NASDAQ Return					0.037	0.073	0.086	-0.082
(Final Round to Exit)					(0.051)	(0.187)	(0.070)	(0.087)
Constant	18.078***	7.580***	4.546***	3.144***	3.186***	7.911***	3.111**	1.652
	(0.874)	(0.955)	(1.072)	(1.068)	(1.069)	(2.357)	(1.554)	(2.099)
Observations	3,523	3,438	3,438	3,438	3,438	629	1,974	835
Adjusted R^2	0.045	0.157	0.166	0.194	0.194	0.193	0.214	0.169
Industry FE	Yes	Yes	Yes	Yes	Yes	No	No	No
Stage FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Round Number FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
CV Psuedo-R2 Mean	0.006	0.091	0.100	0.133	0.133	0.087	0.108	0.101
CV Psuedo-R2 Sd	0.004	0.014	0.014	0.017	0.017	0.016	0.014	0.015
Repeats of 10-fold CV	10	10	10	10	10	10	10	10
Industry	All	All	All	All	All	Health	IT	Others

Standard errors in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Notes: The table reports the regression results when estimating the imputation models for exit values for MA exits. The sample includes all US-based ventures in SDC VentureXpert database that had the first funding round in 1980–2006, and we trace their funding rounds in 1980–2018. Column (5) is the specification adopted for the imputation.

C. Sensitivity and Robustness

We conduct three exercises to assess the robustness of the ARAEI estimates.

1. Bootstrapped Confidence Intervals for ARAEI

The first exercise we conduct is to provide the bootstrapped standard errors and confidence intervals of the ARAEI estimates. We construct 500 bootstrap samples each of the same size as the full sample. Each bootstrap sample is constructed by randomly drawing ventures from the full sample with an equal probability and with replacement. In each bootstrap sample, we re-estimate the imputation models and use the re-estimated models to impute the missing data and construct the ARAEI. The distribution of the bootstrapped ARAEI estimates is used to construct confidence intervals of ARAEI in the population. Table A.10 provides the bootstrapped confidence intervals of the historical time series of ARAEI we presented in Table 3.

2. Sensitivity of ARAEI to Valuation Assumptions

The second exercise we conduct is a scenarios-based sensitivity analysis. Since lots of data first-round post-money valuation and exit values are imputed for the ARAEI, if the imputation models are misspecified, that would lead to large biases in ARAEI. To alleviate this concern, we perform scenarios-based sensitivity analysis and find that ARAEI is not sensitive to errors in first-round post-money valuation. First-round ownership given up is mapped one-to-one to the first-round post-money valuation. We consider two scenarios where we increase and decrease first-round ownership given up by 18%, a one standard deviation change in the variable. The increase or decrease applies across the board, not only to imputed values but also to the observed values. Table A.11 reports the historical time series of PMEs, GPMEs and IRRs in the two scenarios. ARAEI also declines substantially after 1999 in the two scenarios.

ARAEI is not sensitive to errors in imputed exit values. We consider two scenarios where we increase and decrease the imputed exit values by 25% while keeping the observed exit values unchanged. Table A.12 reports the resulting ARAEI. These results suggest investments in ventures still outperform the public market equivalent. ARAEI also declines substantially after 1999 in the two scenarios.

3. Imputing First-Round Valuation Without Backfilling

The third exercise we conduct is to check whether back-filling first-round post-money valuation distorts the ARAEI estimates. The imputation method we use to impute first-round post-money valuation involves back-filling – we use data in the first round as well as the subsequent rounds for the imputation. The purpose of using data in the subsequent rounds is to utilize existing data on valuation as much as possible. Given that valuation data is rare, this enlarges the sample size and reduces the estimation error. The drawback of the back-filling is that it may exacerbate the selection bias – imputed first-round valuation relies more on ventures that turn out to be successful, have more subsequent rounds, and are more likely to have valuation data. To alleviate this concern, we estimate the imputation model in Equation (4) only using data on the first funding round, and use the estimated parameter values to impute the first-round post-money valuation. We report the resulting ARAEI of ventures in Table A.13, A.14 and Figure A.2. Our findings regarding the average ARAEI across ventures and the time series properties of ARAEI are not materially affected.

Table A.10: Historical Time Series of ARAEI: Bootstrapped 90% Confidence Intervals

1st-Round Year	PME^l_{nodisc}	PME^u_{nodisc}	PME^l	PME^u	$GPME^l$	$GPME^u$	PME^l_{rf}	PME^u_{rf}
1980	0.70	2.80	0.37	1.83	0.32	1.62	0.50	2.28
1981	-0.04	3.67	-0.40	2.77	-0.40	2.59	-0.26	3.10
1982	1.15	2.29	0.53	1.08	0.45	0.94	0.84	1.59
1983	-0.41	5.98	0.32	0.70	0.28	0.56	0.20	2.35
1984	0.66	1.06	0.27	0.50	0.23	0.43	0.45	0.76
1985	0.06	2.72	0.18	0.64	0.17	0.51	0.11	1.53
1986	0.71	2.71	0.39	0.77	0.35	0.67	0.55	1.50
1987	1.25	2.29	0.68	1.07	0.61	0.99	0.95	1.56
1988	0.84	3.84	0.44	2.47	0.39	2.24	0.67	3.19
1989	1.03	3.27	0.63	1.29	0.60	1.12	0.83	2.31
1990	1.57	3.59	0.92	1.69	0.82	1.53	1.34	2.67
1991	1.76	7.41	1.34	3.39	1.28	2.92	1.67	5.71
1992	0.56	11.05	1.11	4.86	1.25	4.03	0.68	8.96
1993	2.21	3.37	1.60	2.38	1.48	2.22	2.03	3.04
1994	1.22	9.52	0.83	4.92	0.80	4.15	0.93	7.95
1995	2.48	3.31	1.53	2.02	1.35	1.79	2.18	2.93
1996	2.53	3.21	1.81	2.33	1.68	2.15	2.32	2.96
1997	1.97	3.18	1.54	2.54	1.50	2.45	1.82	2.95
1998	2.11	2.93	1.85	2.59	1.87	2.61	1.97	2.76
1999	1.17	1.54	1.03	1.31	1.14	1.43	1.04	1.37
2000	0.89	1.09	0.78	0.95	0.90	1.10	0.77	0.94
2001	1.13	1.46	0.86	1.12	0.91	1.19	1.03	1.32
2002	1.47	1.98	1.04	1.41	1.04	1.42	1.37	1.84
2003	1.58	2.32	1.17	1.76	1.16	1.77	1.48	2.17
2004	1.64	2.17	1.26	1.62	1.29	1.68	1.52	2.01
2005	1.64	2.76	1.24	2.11	1.26	2.17	1.54	2.60
2006	1.35	2.54	1.08	1.87	1.10	1.88	1.30	2.45

Notes: The table provides the bootstrapped 90% confidence intervals of the historical time series of ARAEI. The full sample includes US-based ventures in SDC VentureXpert database that had the first funding round in 1980–2006, and we trace their funding rounds in 1980–2018. We construct 500 bootstrap samples each of the same size as the full sample, and from a equal-probability random draw of ventures with replacement. In each bootstrap sample, we re-estimate the imputation models and use the re-estimated models to impute the missing data, and construct the return estimates. The bootstrap distribution of return estimates is used to construct confidence intervals of venture returns in the population. The table is to be compared with Table 3, where PME_{nodisc} is venture PME without discounting the cash flows (i.e., $M_t = 1$). PME uses in the SDF specification the PME's parameters (i.e., $a = 0, b = 1$), GPME uses the GPME's parameters (i.e., $a = 0.033, b = 1.444$), PME_{rf} uses the risk free rate to discount the cash flows (i.e., $M_t = e^{-r_f t}$), IRR is the internal rate of return. The variables superscripted with l and u, for example, PME^l_{nodisc} and PME^u_{nodisc}, are the lower and upper boundaries of 90% confidence intervals of the corresponding venture return measure.

Table A.11: Historical Time Series of ARAEI: Sensitivity to First-Round Post-Money Valuation

	(A) Increase FOGU by 18%					(B) Decrease FOGU by 18%				
1st-Round Year	PME_{nodisc}	PME	GPME	PME_{rf}	IRR	PME_{nodisc}	PME	GPME	PME_{rf}	IRR
1980	1.95	1.23	1.09	1.55	0.35	1.74	1.07	0.94	1.35	0.25
1981	2.41	1.72	1.61	1.98	0.70	2.14	1.48	1.38	1.71	0.50
1982	1.84	0.86	0.75	1.29	0.14	1.63	0.73	0.62	1.12	0.09
1983	3.72	0.56	0.45	1.59	0.07	3.18	0.46	0.38	1.33	0.06
1984	0.93	0.43	0.37	0.66	-0.01	0.80	0.35	0.30	0.55	-0.03
1985	1.81	0.50	0.41	1.06	0.06	1.50	0.39	0.32	0.87	0.04
1986	2.00	0.66	0.57	1.19	0.07	1.68	0.53	0.46	0.99	0.05
1987	2.01	0.97	0.89	1.42	0.12	1.68	0.79	0.73	1.17	0.08
1988	2.84	1.80	1.64	2.35	0.34	2.37	1.43	1.29	1.92	0.25
1989	2.49	1.08	0.96	1.82	0.16	2.04	0.86	0.76	1.46	0.11
1990	2.95	1.49	1.34	2.30	0.26	2.48	1.19	1.06	1.89	0.18
1991	5.50	2.78	2.45	4.40	0.58	4.56	2.22	1.95	3.60	0.43
1992	7.37	3.66	3.14	6.13	0.69	6.44	3.04	2.59	5.26	0.56
1993	2.99	2.19	2.03	2.74	0.68	2.59	1.81	1.67	2.33	0.50
1994	6.46	3.52	3.02	5.48	0.77	5.69	2.93	2.49	4.75	0.62
1995	3.11	1.95	1.73	2.75	0.63	2.67	1.59	1.39	2.33	0.45
1996	3.03	2.22	2.07	2.79	0.88	2.67	1.88	1.73	2.43	0.64
1997	2.81	2.26	2.20	2.61	0.91	2.48	1.93	1.86	2.27	0.65
1998	2.67	2.37	2.39	2.51	1.29	2.36	2.05	2.07	2.20	0.87
1999	1.47	1.26	1.37	1.31	0.10	1.26	1.08	1.18	1.11	0.05
2000	1.08	0.95	1.09	0.94	0.01	0.87	0.77	0.89	0.75	-0.02
2001	1.41	1.08	1.14	1.28	0.07	1.19	0.91	0.96	1.07	0.03
2002	1.85	1.33	1.33	1.72	0.16	1.62	1.13	1.14	1.50	0.11
2003	2.09	1.59	1.60	1.96	0.24	1.85	1.36	1.37	1.72	0.17
2004	2.03	1.54	1.58	1.89	0.18	1.76	1.30	1.34	1.62	0.13
2005	2.42	1.85	1.89	2.28	0.23	2.09	1.57	1.61	1.95	0.17
2006	2.18	1.65	1.66	2.11	0.21	1.89	1.41	1.43	1.81	0.15

Notes: In the table, FOGU refers to first round ownership given up. The table is to be compared with Table 3, which provides a historical time series of the return to investing in ventures. In Panel (A) we increase first round ownership given up of all ventures by one standard deviation, i.e., 18%. In Panel (B) we decrease first round ownership given up of all ventures by 18%.

Table A.12: Historical Time Series of ARAEI: Sensitivity to Imputed Exit Values

	(A) Increase Imputed Exit Values by 25%					(B) Decrease Imputed Exit Values by 25%				
1st-Round Year	PME_{nodisc}	PME	GPME	PME_{rf}	IRR	PME_{nodisc}	PME	GPME	PME_{rf}	IRR
1980	1.85	1.16	1.02	1.46	0.31	1.85	1.16	1.02	1.46	0.31
1981	2.31	1.62	1.51	1.87	0.61	2.27	1.61	1.50	1.85	0.61
1982	1.76	0.80	0.70	1.22	0.11	1.74	0.80	0.69	1.21	0.11
1983	3.49	0.52	0.42	1.48	0.07	3.46	0.51	0.41	1.46	0.07
1984	0.90	0.40	0.34	0.62	-0.02	0.85	0.39	0.33	0.60	-0.02
1985	1.73	0.46	0.37	1.00	0.05	1.61	0.44	0.36	0.94	0.05
1986	1.88	0.61	0.53	1.12	0.06	1.84	0.59	0.51	1.08	0.06
1987	1.92	0.91	0.84	1.34	0.10	1.80	0.87	0.80	1.27	0.09
1988	2.66	1.64	1.49	2.17	0.30	2.59	1.62	1.47	2.13	0.30
1989	2.32	0.99	0.87	1.68	0.14	2.25	0.97	0.85	1.63	0.14
1990	2.79	1.37	1.23	2.15	0.23	2.69	1.33	1.19	2.08	0.22
1991	5.13	2.55	2.24	4.08	0.51	5.02	2.49	2.19	3.99	0.50
1992	7.05	3.43	2.93	5.82	0.63	6.86	3.33	2.84	5.66	0.62
1993	2.86	2.04	1.89	2.60	0.60	2.76	1.99	1.84	2.52	0.59
1994	6.18	3.28	2.80	5.20	0.70	6.06	3.22	2.75	5.11	0.69
1995	2.98	1.82	1.61	2.62	0.55	2.84	1.74	1.54	2.51	0.54
1996	2.93	2.10	1.96	2.68	0.77	2.81	2.03	1.88	2.58	0.76
1997	2.73	2.16	2.10	2.52	0.80	2.60	2.07	2.00	2.41	0.77
1998	2.58	2.27	2.30	2.42	1.10	2.48	2.19	2.21	2.34	1.08
1999	1.43	1.23	1.35	1.27	0.09	1.32	1.13	1.23	1.17	0.06
2000	1.03	0.91	1.05	0.89	0.00	0.93	0.82	0.95	0.81	-0.01
2001	1.38	1.05	1.10	1.25	0.06	1.25	0.96	1.01	1.13	0.04
2002	1.81	1.29	1.29	1.68	0.15	1.68	1.19	1.19	1.56	0.13
2003	2.06	1.54	1.55	1.92	0.22	1.91	1.44	1.44	1.79	0.20
2004	1.99	1.49	1.54	1.84	0.17	1.83	1.37	1.42	1.70	0.14
2005	2.36	1.78	1.83	2.22	0.21	2.18	1.66	1.70	2.05	0.19
2006	2.12	1.60	1.62	2.05	0.20	1.98	1.48	1.50	1.91	0.18

Notes: The table is to be compared with Table 3, which provides a historical time series of the return to investing in ventures. In Panel (A) we increase the imputed exit values of all ventures by 25%. In Panel (B) we decrease the imputed exit values of all ventures by 25%. See the text for details.

Table A.13: ARAEI of the aggregate portfolio of ventures in different samples

Sample	PME_{nodisc}	PME	GPME	PME_{rf}	IRR	# Ventures	Amount Raised ($B)	Exit Value ($B)
Full Sample (Imputation)	1.99	1.42	1.43	1.76	0.22	17,242	452.8	1245.8
No-bubble Sample (Imputation)	2.06	1.43	1.42	1.83	0.20	10,542	210.2	600.5
Pre-2006 Sample (Imputation)	2.05	1.51	1.48	1.82	0.35	11,552	225.2	710.3

Notes: This table is to be compared with Table 2. The only difference is that first-round post-money valuation is imputed using only data on the first rounds when constructing the ARAEI in this table.

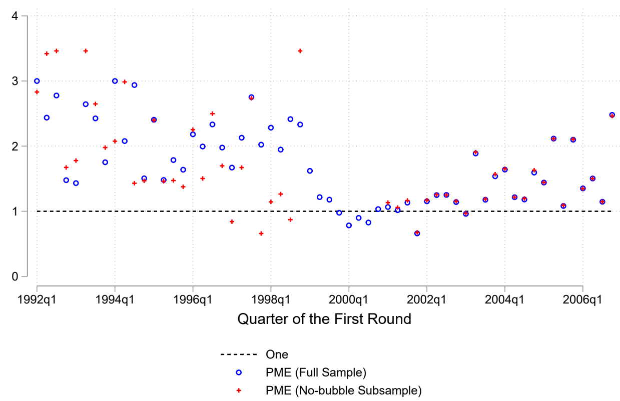
Table A.14: Portfolios of Ventures that Had Their First Rounds in the Same Calendar Year

Year of Round 1	PME_{nodisc}	PME	GPME	PME_{rf}	IRR	# Ventures	Amount Raised ($B)	Exit Value ($B)	# With 1st Val.	% With 1st Val.
1980	1.86	1.47	1.16	1.03	0.31	55	0.5	1.2	0	0.0%
1981	2.34	1.89	1.64	1.53	0.63	194	2.0	5.7	0	0.0%
1982	1.77	1.22	0.80	0.69	0.11	253	2.3	5.0	0	0.0%
1983	3.50	1.48	0.52	0.42	0.07	428	3.3	15.3	1	0.2%
1984	0.94	0.64	0.40	0.34	-0.01	418	3.3	3.5	2	0.5%
1985	1.76	1.00	0.45	0.37	0.05	332	2.1	4.4	2	0.6%
1986	1.88	1.12	0.61	0.53	0.06	370	3.2	7.9	6	1.6%
1987	1.95	1.35	0.90	0.83	0.10	423	3.1	7.3	6	1.4%
1988	2.67	2.18	1.64	1.49	0.30	418	3.6	12.7	15	3.6%
1989	2.29	1.66	0.98	0.87	0.14	364	3.2	10.4	15	4.1%
1990	2.88	2.24	1.44	1.29	0.25	273	2.6	9.7	12	4.4%
1991	4.88	3.87	2.41	2.11	0.48	198	2.3	17.2	28	14.1%
1992	7.16	5.93	3.51	3.01	0.66	230	4.6	38.5	58	25.2%
1993	2.80	2.54	2.00	1.85	0.59	229	4.9	17.0	66	28.8%
1994	6.17	5.20	3.28	2.81	0.70	238	6.7	51.2	76	31.9%
1995	2.92	2.58	1.79	1.58	0.55	529	13.7	50.6	226	42.7%
1996	2.90	2.67	2.11	1.96	0.80	778	24.1	82.9	311	40.0%
1997	2.70	2.50	2.15	2.09	0.81	878	30.5	96.7	302	34.4%
1998	2.55	2.39	2.25	2.27	1.12	1,131	43.7	131.9	385	34.0%
1999	1.37	1.22	1.18	1.29	0.08	1,857	68.5	110.2	662	35.6%
2000	0.98	0.85	0.87	1.00	0.00	2,446	64.7	86.9	923	37.7%
2001	1.28	1.16	0.98	1.03	0.05	944	25.6	38.1	343	36.3%
2002	1.70	1.57	1.20	1.21	0.13	698	21.1	39.1	181	25.9%
2003	1.93	1.80	1.43	1.44	0.19	669	22.3	45.4	126	18.8%
2004	1.87	1.73	1.39	1.44	0.15	854	26.2	53.0	80	9.4%
2005	2.23	2.09	1.69	1.74	0.20	930	29.6	74.4	67	7.2%
2006	2.09	2.02	1.58	1.60	0.20	1,105	35.1	81.2	57	5.2%

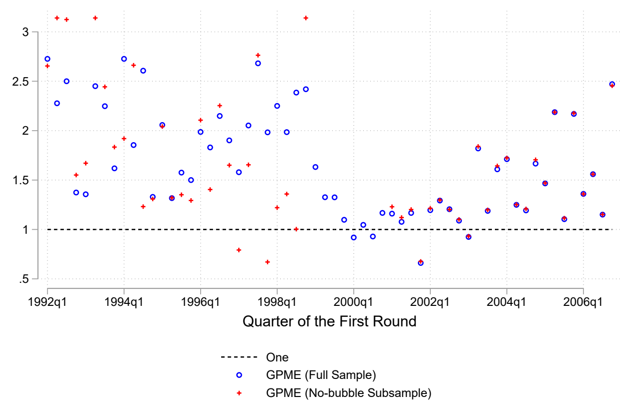
Notes: The table is to be compared with Table 3 that provides the historical time series of ARAEI. The only difference is that first-round post-money valuation is imputed using only data on the first rounds when constructing the ARAEI in this table.

Figure A.2: Portfolios of Ventures that Had Their First Rounds in the Same Calendar Quarter

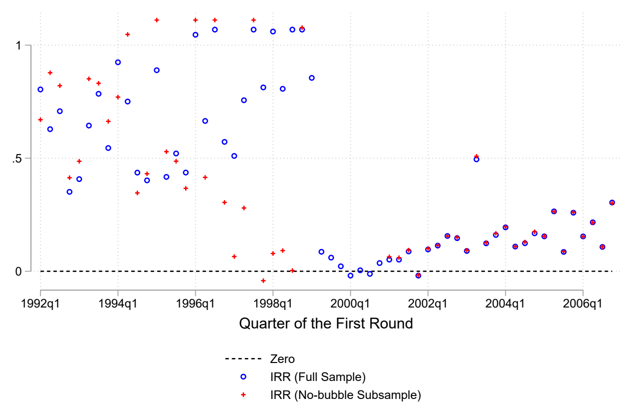
(a) PME



(b) GPME



(c) IRR



Notes: The figure is to be compared with Figure 4, which plots quarterly historical time series of ARAEI. The only difference is that first-round post-money valuation is imputed using only data on the first rounds when constructing the ARAEI in this figure.