

Cost of Experimentation and the Evolution of Venture Capital

MICHAEL EWENS, RAMANA NANDA AND MATTHEW RHODES-KROPF*

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We study adaptation and entry by financial intermediaries as a response to technological change in the context of venture-capital finance. Using a theoretical model and rich data, we both document and provide a framework to understand the changes in the investment strategy of VCs in recent years - an increased prevalence of investors who “spray and pray” - providing a little funding and limited governance to an increased number of startups that they are more likely to abandon, but where early experiments significantly inform beliefs about the future potential of the venture. We also highlight how this adaptation by financial intermediaries has altered the trajectory of aggregate innovation away from complex technologies where initial experiments cost more towards those where information on future prospects is revealed quickly and cheaply.

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* Ewens: California Institute of Technology, Baxter Hall 301C, 1200 East California Blvd., Pasadena, CA 91125, mewens@caltech.edu. Nanda: Harvard University and NBER, Rock Center 317, Boston Massachusetts 02163, RNanda@hbs.edu. Rhodes-Kropf: Harvard University and NBER, Rock Center 313 Boston Massachusetts 02163, mrhodeskropf@hbs.edu. We are extremely grateful to Marco Da Rin, Brent Goldfarb, David Hsu, Tom Nicholas, Scott Stern, Ayako Yasuda and the participants at the NBER conference on The Changing Financing Market for Innovation and Entrepreneurship, the Academy of Management, the 5th HEC Entrepreneurship Workshop, the Economics of Strategy Workshop at NYU and the 5th Entrepreneurial Finance and Innovation Conference, UC Berkeley, Carnegie Mellon, Columbia University, Arizona State University, Drexel, Boston University for helpful comments. The authors thank VentureSource and Correlation Ventures for access to their data. Ewens and Rhodes-Kropf are advisors to and investors in Correlation Ventures. Ewens recognizes the support of the Kauffman Foundation Junior Faculty Fellowship. All errors are our own.

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I. Introduction

While technological change is increasingly seen as the primary driver of productivity growth (Aghion and Howitt, 1992), adaptation by financial intermediaries may be equally important to realizing the benefits of these new technologies (King and Levine, 1993; Laeven, Levine, and Michalopoulos, 2015). For example, Chandler (1965) documents the adaptation by specialized investment banks as a response to the “vast sums of capital” required to finance the construction of railroads and govern industrial corporations needing arms-length capital from distant investors.¹ Similarly, Nicholas (2015) shows how the modern venture capital model arose in the mid-20th century in order to channel capital to the myriad new technologies emerging outside of the corporate R&D model.

The need for adaptation by financial intermediaries is particularly salient in the context of early stage finance, where investors are “not just passive, but play an active role in deciding whether to make an initial investment to learn about the viability of a radical new idea, how to interpret intermediate results, and whether to continue or abandon their investment” (Kerr, Nanda, and Rhodes-Kropf, 2014b). This process of experimentation by investors is a central aspect of entrepreneurial finance (Hellmann and Puri, 2000; Sorensen, 2007) and plays an important role in the commercialization of new technologies in the US and around the world.

In this paper, we posit that technological shocks to the cost of starting new businesses have led the venture capital model to adapt in fundamental ways over the prior decade, resulting in potentially significant consequences for the trajectory of innovation in the economy. A number of technological developments (e.g., rapid prototyping, gene sequencing, open source, cloud computing etc.) have made the early experiments conducted by startups significantly cheaper in recent years, opening up a whole new range of investment opportunities that were not viable before. While anecdotal accounts of this phenomenon

¹See also Alfred D. Chandler (1977); Baskin and Jr. (1997); Neal (1990), and Laeven et al. (2015).

and the changes in the market for early stage finance have been documented in the press and the managerial implications popularized in frameworks such as the “lean startup model,” we are not aware of any systematic work examining how the changing cost of starting businesses impacts the early stage financing market.

From a theoretical perspective, the changing cost of experimentation requires adaptation by investors, shifting the way in which existing investors manage their portfolios, as well as leading to new types of entrants. This adaptation or entry occurs because investors backing startups engaged in the early stages of innovation face an important tradeoff. On the one hand, investors may want to tolerate early failure in the startup venture to encourage the entrepreneurs to engage in risky experimentation *ex ante* (Manso, 2011). On the other hand, failure tolerance requires investors to forgo abandonment options, and hence makes them less likely to fund the risky experimentation in the first place.² Since the falling cost of experimentation makes abandonment options for investors much more valuable, this directly impacts the tradeoff between failure tolerance and the desire to exercise abandonment options and thus can have first order implications for the types of firms that are financed and the nature of innovation in the economy.

Our paper aims to address this gap and provide a deeper understanding of how the changing cost of experimentation impacts the nature of entrepreneurial finance and venture capital-backed entrepreneurship in the US. Our approach combines rich data on the investments and composition of venture capital portfolios with a theoretical model that guides the interpretation of our results.

Our theoretical model provides three main insights. First, it highlights that the falling cost of starting new businesses allows a set of entrepreneurs who would not have been financed in the past to receive early stage financing. In particular, these are entrepreneurs whose projects have low *expected* value, but potentially very large payoffs, where one can learn a lot about the ultimate outcome of the project from an initial investment in

²The importance of abandonment options in venture capital is noted in much work on VC (see Gompers, 1995; Cornelli and Yosha, 2003; Bergemann and Hege, 2005; Fluck, Garrison, and Myers, 2007; Bergemann, Hege, and Peng, 2008)

the startup. We refer to these startups as “long shot bets.” Second, we show that the only profitable way to finance these projects is for investors to back a large number of such startups in order to learn about their potential, but without committing to tolerate ‘failure’ if intermediate information is negative. This has been colloquially referred to as a “spray and pray” investment approach, in a reference to the large number of startups that receive an initial investment, but a much smaller proportion that receive follow-on funding. The “spray and pray” investment approach is a significant shift away from value-added ‘governance’ in the early stages of ventures to more passive ‘learning’ about startup potential, because the incentives to govern in this new investment approach are lower.³ Finally, the model highlights that because a fall in the cost of experimentation makes a “failure tolerant” investment strategy relatively more costly, this tends to skew investments towards startups with more discriminating early experiments, and away from those with a slower, or more costly, revelation of final project value. This change alters the trajectory of aggregate innovation.

We build on our theoretical model to also examine predictions about the characteristics of the venture capital-backed entrepreneurship, using rich data on venture capital investments and the portfolio companies. Although the concept we examine is broad we focus on a specific and sudden cost reduction in order to get sharp empirical results. We use the advent of Amazon’s elastic cloud compute services (EC2) as a technological shock that lowered the cost of starting businesses in certain segments as a way to examine the impact on the realized investments by VCs in the 2006-2010 period compared to that in the 2002-2005 period. A differences-in-differences estimation approach suggests early stage investors made a larger number of small-ticket investments in industry segments that benefited from Amazon’s EC2 services. They were less likely to take a board seat in the early stages for these investments and were much less likely to follow on with a second round of

³This “spray and pray” investment strategy is typified by a quote from Naval Ravikant, a prominent angel investor and founder of the platform AngelList, noted that “making an [early stage] investment is like throwing darts in the dark.” Source: Fatima Yasmine, February 22 2011, “Naval Ravikant: Twitter, Bubbles, New York and Start Fund [Interview Part 2]”

funding, consistent with a greater move towards a spray and pray investment model. Also consistent with the predictions of the model, investors were more likely to back “long shot bets” in the post period when the startup was in an industry segment that benefited from Amazon’s EC2 services. In these sectors, VCs backed younger firms, younger founders and those who were more likely to be first-time entrepreneurs. These startups were also more likely to fail. These could just be marginally worse investment, however when they received follow-on funding, they had relatively higher step-ups in value relative to firms in other industries in the post-period, indicative of greater learning. Furthermore, when they succeeded they generated greater value, suggesting they were “long shot bets” rather than just lower quality firms. Our results suggest that the falling cost of experimentation has helped to democratize entry, particularly among young, unproven founding teams, but the resulting new form of investing has led to a shift in capital away from sectors where early experiments are less discriminating and more capital intensive.

Our results are related to a small literature on financial innovations and the central role they play translating technological change into economic growth (Allen and Gale, 1994; Laeven et al., 2015)). Historical work on entrepreneurship in the United States has documented the central role of the financial innovations to commercialize new technologies as early as cotton and the railroads (Cain, 2010). More recently, Janeway (2012) notes how venture capital evolved to support the funding of biotechnology ventures, although Fernandez, Stein, and Lo (2012) and Fagnan, Fernandez, Lo, and Stein (2013) have pointed to the need for further financial innovations to help increase funding for cancer therapies that suffer from limited venture capital finance despite great societal interest. Our work is also related to the literature on early stage financing (Kerr, Lerner, and Schoar, 2014a; Hellmann and Thiele, 2015; Puri and Zarutskie, 2012) and the emergence in recent years of “accelerators” that select and shape startups at the earliest stages in their life (Cohen and Hochberg, 2014; Bernstein, Korteweg, and Laws, Forthcoming; Gonzalez-Uribe and Leatherbee, 2015). Our paper provides a framework within which to view the emergence of these new financial intermediaries. Viewed through the lens of our model, these inter-

mediaries can be seen as a response to the greater need for scalable forms of mentorship and governance for young, less experienced founders, given the shifting focus of traditional venture capital investors away from governance towards a spray and pray investing approach early in the life of companies.⁴

The rest of the paper is structured as follows. In Section 2, we develop a model of investment to highlight how the falling cost of experimentation impacts the investment strategies of venture capital investors. In Section 3, we describe how the introduction of Amazon Web Services impacted the cost of starting firms in certain industries, and use it to motivate our identification strategy. In Section 4, we describe the data we use to more-systematically test these ideas. Section 5 outlines our results and several robustness checks, and Section 6 concludes.

II. A Model of Investment

Our goal in this section is to provide a model of venture capital investment that can highlight how falling costs to start new businesses can alter the composition of investments and the portfolio management strategy of VC investors. To do so, we model the creation of new projects that need an investor and an entrepreneur in each of two periods. Both the investor and entrepreneur must choose whether or not to start a project and then, at an interim point, whether to continue the project.⁵ We build on this work by altering features of the problem to explore the effect of a reduction in the cost of early experimentation.

A. Investor View

Let $E[p_2]$ denote the unconditional expectation about the second stage success. The investor updates their expectation about the second stage probability depending on the

⁴It is also interesting to consider VC adaptation in light of the work on persistence (Kaplan and Schoar, 2005; Robert S. Harris and Stucke, 2013; Korteweg and Sorensen, 2014; Ewens and Rhodes-Kropf, 2015) as it suggests persistence may arise partially from an ability to adapt.

⁵This basic set up is a two-armed bandit problem. There has been a great deal of work modeling innovation that has used some form of the two armed bandit problem. From the classic works of Weitzman (1979), Roberts and Weitzman (1981), Jensen (1981), Battacharya, Chatterjee, and Samuelson (1986) to more recent works such as Moscarini and Smith (2001), Manso (2011) and Akcigit and Liu (2011). See Bergemann and Valimaki (2006) for a review of the economics literature on bandit problems.

outcome of the first stage.⁶ Let $E[p_2|S]$ denote the expectation of p_2 conditional on positive intermediate information (success in the first stage), while $E[p_2|F]$ denotes the expectation of p_2 conditional on negative intermediate information (failure in the first stage).⁷ Moreover, success in the second stage yields a payoff of V_S or V_F depending on what happened in the first stage. Failure in the second stage yields a payoff of zero. The probability of ‘success’ (positive information) in the first stage is p_1 .

The project requires capital to succeed. The total capital required is normalized to one unit, while a fraction X is needed to complete the first stage of the project and $1 - X$ to complete the second stage. The entrepreneur is assumed to have no capital while the investor has one unit of capital, enough to fund the project for both periods. An investor who chooses not to invest at either stage can instead earn a safe return of r per period (investor outside option) which we normalize to zero for simplicity. We assume project opportunities are time sensitive, so if the project is not funded at either the 1st or 2nd stage then it is worth nothing.

In order to focus on the interesting cases, we assume that if the project ‘fails’ in the first period (i.e, intermediate information is negative), then it is NPV negative in the second period, i.e., $E[p_2|F] * V_F < 1 - X$. If the project ‘succeeds’ in the first period (i.e., intermediate information is positive), then it is NPV positive in the second period, i.e., $E[p_2|S] * V_S > 1 - X$. Without these assumptions the experiment is not relevant.

Let α_S represent the final fraction owned by the investors if the first period was a success, and let α_F represent the final fraction owned by the investors if the first period was a failure.

The extensive form of the game played by the investor (assuming the entrepreneur is willing to start and continue the project) is shown in Figure 1. We assume investors make

⁶This might be the building of a prototype, initial traction with customers, or the FDA regulated Phase I trials on the path of a new drug, etc.

⁷One particular functional form that is sometimes used with this set up is to assume that the first and second stage have the same underlying probability of success, p . In this case p_1 can be thought of as the unconditional expectation of p , and $E[p_2|S]$ and $E[p_2|F]$ just follow Bayes’ rule. We use a more general setup to express the idea that the probability of success of the first stage experiment is potentially independent of the amount of information revealed by the experiment. For example, there could be a project for which a first stage experiment would work with a 20% chance but if it works the second stage is almost certain to work (99% probability of success).

all decisions to maximize net present value (which is equivalent to maximizing end of second period wealth).

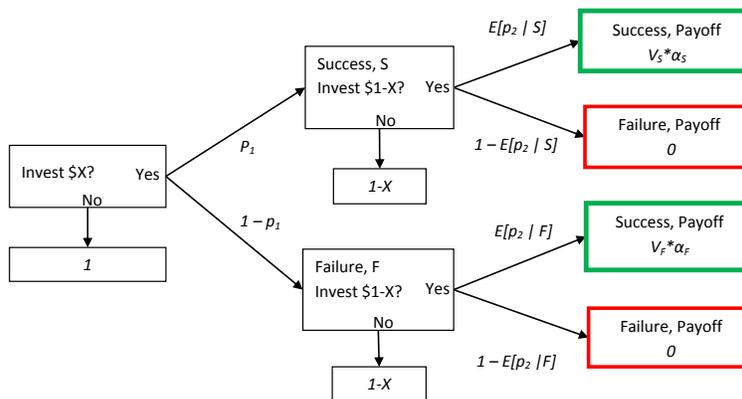


FIGURE 1. EXTENSIVE FORM REPRESENTATION OF THE INVESTOR'S GAME TREE

B. Entrepreneur's View

Potential entrepreneurs are endowed with a project in period one with a given p_1 , p_2 , $E[p_2|S]$, $E[p_2|F]$, V_S , V_F and X . Assuming that an investor is willing to fund the first period of required investment, the potential entrepreneur must choose whether or not to apply their effort as an entrepreneur or take an outside employment option. If the investor is willing to fund the project in the second period then the entrepreneur must choose whether or not to continue as an entrepreneur. If the potential entrepreneur chooses entrepreneurship and stays an entrepreneur in period 2 he generates utility of u_E in both periods. Alternatively, if he chooses not to become an entrepreneur in the first period then we assume that no entrepreneurial opportunity arises in the second period so he generates utility of u_o (outside option) in both periods.

If the investor chooses not to fund the project in the second period, or the entrepreneur chooses not to continue as an entrepreneur, i.e., the entrepreneur cannot reach an agreement with an investor in period 2, then the project fails and the entrepreneur generates utility u_F from his outside option in the second period. We assume $\Delta u_F = u_F - u_E < 0$,

which represents the disutility of a failed entrepreneur. The more negative is Δu_F , the worse is the entrepreneurial experience in a failed project.⁸

Given success or failure in the first period, the entrepreneur updates their expectation about the probability of project success just as the investor does. The extensive form of the game played by the entrepreneur (assuming funding is available) is shown in Figure 2. We assume entrepreneurs make all decisions to maximize the sum of total utility.

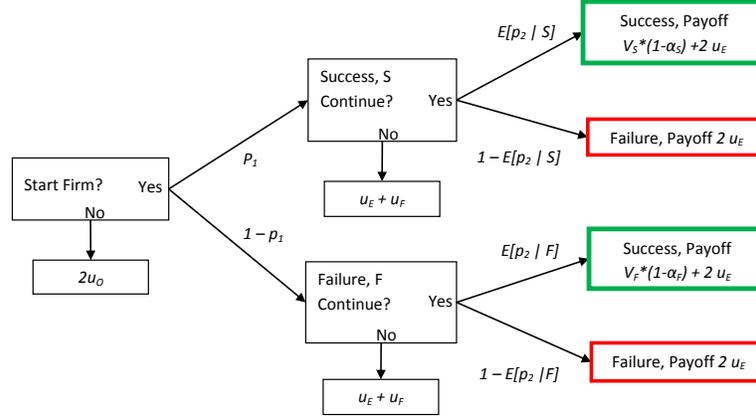


FIGURE 2. EXTENSIVE FORM REPRESENTATION OF THE ENTREPRENEUR'S GAME TREE

C. The Deal Between the Entrepreneur and Investor

In each period the entrepreneur and investor negotiate over the fraction of the company the investor will receive for their investment. The investor may choose to commit in the initial period to fund the project for both periods, or not. Commitment is very important in venture capital financing, as investors form reputations as committed to their entrepreneurs to help attract investments. An investor who commits is assumed to face a cost of c if they fail to fund the project in the second period. We also assume $c > 1 - X - V_F E[p_2 | F]$ to focus on the interesting case when commitment has value. Negotiations will result in a final fraction owned by the entrepreneur if the first period

⁸Entrepreneurs seem to have a strong preference for continuation regardless of present-value considerations, be it because they are (over)confident or because they rationally try to prolong the search. Cornelli and Yosha (2003) suggest that entrepreneurs use their discretion to (mis)represent the progress that has been made in order to secure further funding.

was a success of $1 - \alpha_S$, and $1 - \alpha_F$ if the first period was a failure.⁹

The final fraction owned by investors after success or failure in the first period, α_j where $j \in \{S, F\}$, is determined by the amount the investors purchased in the first period, α_1 , and the second period α_{2j} , which may depend on the outcome in the first stage. Since the first period fraction gets diluted by the second period investment, $\alpha_j = \alpha_{2j} + \alpha_1(1 - \alpha_{2j})$.

The proof is left to the Appendix, but it is easy to see that if investors were to be failure tolerant – that is, if they were to continue to fund the entrepreneur even if the first stage experiment failed (and hence the expected value of the project conditional on initial failure was now negative) – then they would only fund the project at the start of period 1 if they were entitled to a sufficiently large share of the company in the event that the first stage experiment was successful. That is, entrepreneurs do not like the project to be terminated ‘early’ and thus would rather receive an investment from an investor who commits to being failure tolerant. This failure tolerance encourages innovative effort (Manso, 2011), but a committed investor gives up the valuable real option to terminate the project early. Thus, an investor who commits to being failure tolerant must receive a larger fraction of the pie if successful to compensate for the loss in option value. While the entrepreneur would like a committed investor, the commitment comes at a price. An uncommitted investor does not need to take as large a share of the startup if it is successful, but in return will be able to exercise the abandonment option if the initial information does not look promising.

This is the Manso (2011) intuition but at the extensive margin. Rather than encouraging innovative effort, in our set up failure tolerance encourages the entrepreneur to choose the innovative path (i.e., entrepreneurship) rather than the safe path (i.e., employment). However, since failure tolerance is negotiated with the investor it comes at a cost. This gives us the following proposition.

PROPOSITION 1: *For any given project there are three possibilities*

⁹The entrepreneur could also receive side payments from the investor. This changes no results and so is suppressed.

- 1) *the project will be funded by a committed investor,*
- 2) *the project will be funded by an uncommitted investor,*
- 3) *the project cannot be started.*

PROOF:

See Appendix

Thus, there are some projects for which the price the entrepreneur needs to pay is low enough that they would always prefer to match with a committed investors. There are others where the price the entrepreneur needs to pay the committed investor is too high. Thus, they will either not be financed at all (if their dislike of early termination of the project is sufficiently high) or if they choose to be financed, they can only do a deal with uncommitted investors.

The question is then – which projects are more likely to be done by a committed or uncommitted investor? The following proposition demonstrates the three aspects of a project that alter the commitment of the funder.

D. What Types of Projects Receive Funding from a Committed Investor?

We assume that the type of investor who generates the most surplus in a deal funds the deal.

PROPOSITION 2: *For a given expected value and expected capital requirement a project is more likely to be funded by a committed investor if*

- *The project has a higher expected value after failure.*
- *The entrepreneur has a larger disutility from early termination.*
- *The cost of the experiment is higher (X is larger).*

PROOF:

See Appendix A.viii

An entrepreneur with a larger disutility from early termination will more likely get funding from a committed investor because they are willing to pay the cost of a committed contract. The other two points are also intuitive. An investor finds it less costly to commit to a project with a higher expected value after failure. Furthermore, if the cost of the experiment is higher then its value is lower. What is more interesting is the following corollary that demonstrates the importance of the learning that arises from the experiment.

In our model, the first stage is an experiment that provides information about the probability of success in the second stage. A project for which the first stage reveals more information has a more informative experiment. Here, $V_S E[p_2 | S] - V_F E[p_2 | F]$ is larger if the experiment revealed more about what might happen in the future. At the extreme, one might have an experiment that demonstrates nothing, i.e., $V_S E[p_2 | S] = V_F E[p_2 | F]$. That is, whether the first stage experiment succeeded or failed the updated expected value in the second stage was the same. Alternatively, the experiment might provide a great deal of information. In this case $V_S E[p_2 | S]$ would be much larger than $V_F E[p_2 | F]$. The experiment could potentially reveal whether or not the project is worthless ($V_S E[p_2 | S] - V_F E[p_2 | F] = V_S E[p_2 | S]$). Thus, $V_S E[p_2 | S] - V_F E[p_2 | F]$ is the amount or quality of the information revealed by the experiment.¹⁰

For two projects that have the same expected value, $p_1 V_S E[p_2 | S] + (1 - p_1) V_F E[p_2 | F]$ and the same probability of a successful experiment, p_1 we will refer to the one for which $V_S E[p_2 | S] - V_F E[p_2 | F]$ is larger as having the more informative experiment.¹¹ This yields the following corollary.

COROLLARY 1: *A project with a more informative experiment is more likely to be*

¹⁰One special case are martingale beliefs with prior expected probability p for both stage 1 and stage 2 and $E[p_2 | j]$ follows Bayes Rule. In this case projects with weaker priors would have more valuable experiments.

¹¹We use this definition because it changes the level of experimentation *without* simultaneously altering the probability of first stage success or the expected value of the project. Certainly a project may be more experimental if $V_S E[p_2 | S] - V_F E[p_2 | F]$ is larger *and* the expected value is larger. For example, if $E[p_2 | F]$ is always zero, then the only way to increase $V_S E[p_2 | S] - V_F E[p_2 | F]$ is to increase $V_S E[p_2 | S]$. In this case the project will have a higher expected value and be more experimental. We are not ruling this possibilities out, rather we are just isolating the effect of experimentation. If the expected value also changed it would create two effects - one that came from greater experimentation and one that came from increased expected value. Since we know the effects of increased expected value (everyone is more likely to fund a better project) we use a definition that isolates the effect of information.

funded by an uncommitted investor.

This is an important point. Learning, which seems fundamental to innovation, is at odds with failure tolerance, which encourages innovative behavior. With this in mind we will see how a fall in the cost of experimentation affects what receives funding in equilibrium.

E. The Impact of a Fall in the Cost of Experimentation

Suppose now that the cost of experimentation falls. If X is smaller, then the investor can pay a smaller amount in the first period in order to gain knowledge about the value of the project. As the cost of the first stage experiment falls, projects may shift from being funded by one type of investor to another and some projects may get funded that would not have been funded. The following proposition demonstrates the effects.

PROPOSITION 3: *If the cost of the first stage experiment falls (X decreases) then*

- *A set of projects will switch from being funded with commitment to funded without commitment, and a set of projects that previously did not receive funding will now receive funding from an uncommitted investor.*
- *A project is more likely to switch from being funded with commitment to funded without commitment, or switch from unfunded to funded, if it has a smaller probability of success in the first stage, p_1 or has a more valuable experiment.*

PROOF:

See Appendix A.ix

Putting everything together we see that if the cost of the early experiment falls, then the set of firms now funded that were not funded before have more informative experiments and lower probabilities of first stage success, i.e. they have a larger fraction of their value embedded in the option to terminate after early experimentation. The same is true of the projects now funded by an uncommitted investor that were funded by a committed investor. These projects have a lower expected value after failure in the first period, i.e. for a given expected value they have a more informative experiment.

Thus, Proposition 3 predicts that when the cost of experimentation falls a new set of firms will get funded. These firms will have lower probabilities of success so fewer of them will go on to receive future funding. Furthermore, this set will have a more informative experiment, i.e., they will be the type of firms where much can be learned from early experiments. The firms that now get funding that could not before have too low a value after failure to get funding from a committed investor. Those that switch type of investor are those from the set of firms previously funded by a committed investor with the lowest expected values after early failure. So these are higher risk firms that are less likely to get next round funding and have more informative experiments. These firms can now get funded in the first period because the price of the option to see the first stage outcome fell.

This proposition is the main conclusion of the model. Any reduction in the cost of a project would allow a marginally worse project to be funded. Our model demonstrates that a shock to the cost of experimentation shifts how projects are funded and also shifts the set of funded projects to not just worse projects but to those for which learning is more important.

The figures below help to demonstrate the idea. Projects with a given expected payoff after success in the first period (Y-axis) or failure in the first period (X-axis) fall into different regions or groups. We only examine projects above the 45° line because it is not economically reasonable for the expected value after failure to be greater than the expected value after success.

In the left diagram of figure 3 the small dashed lines that run parallel to the 45° line are Iso Experimentation lines, i.e., along these lines $V_S E[p_2 | S] - V_F E[p_2 | F]$ is constant. These projects have an equally informative experiment. Moving northeast along an Iso Experimentation line increases the project's value without changing the degree to which it is experimental.

The large downward sloping dashed lines are Iso Expected Payoff lines. Projects along these lines have the same ex ante expected payoff, $p_1 V_S E[p_2 | S] + (1 - p_1) V_F E[p_2 | F]$.

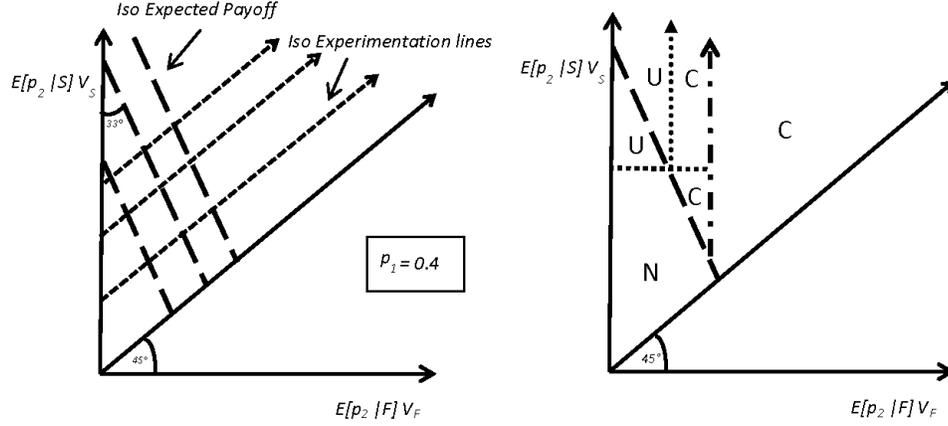


FIGURE 3. INVESTOR REGIONS: N = NO INVESTORS, C = COMMITTED INVESTOR, U = UNCOMMITTED INVESTOR

They have a negative slope that is defined by the probability of success in the first period p_1 .¹² Projects to the northwest along an Iso Expected Payoff line are more experimental, but have the same expected value.

In the diagram to the right in Figure 3 we see the regions discussed in proposition 1. Above the large dashed line (defined by equation (A-1)) the entrepreneur can reach an agreement with a committed investor. Committed investors will not invest in projects below the large dashed line and can invest in all projects above this line. This line has the same slope as an Iso Expected Payoff Line because with commitment the project generates the full ex ante expected value. However, with an uncommitted investor, the project is stopped after failure in the first period. Here the uncommitted investor's expected payoff is independent of $V_F E[p_2 | F]$. Therefore, uncommitted investors could invest in all projects above the horizontal dotted line (defined by equation (A-2)). The vertical line with both a dot and dash is the line where $V_F E[p_2 | F] = 1 - X$. Projects to the right of this line have a high enough expected value after failure in the first period that they are NPV positive even after first period failure so no investor would ever abandon the project, so we focus

¹²In the example shown $p_1 = 0.4$ so the slope of the Iso Expected Payoff Lines is -1.5 resulting in a angle to the Y-axis of approximately 33 degrees.

our attention to the left of this line.¹³

Finally, the point at which the horizontal dotted line crosses the downward sloping large dashed line bifurcates the graph. At points to the left of a vertical dotted line through this point more value is created with funding from an uncommitted investor. At points to the right of this line more value is created by funding from a committed investor.

Where, or whether the dotted and dashed lines cross depends on the other parameters in the problem (c, u_O, u_E, u_F, X) that are held constant in the diagram. If the lines cross, as in the right diagram of figure 3, we see six regions. Entrepreneurs with projects with low enough expected values cannot find investors (region N). Those projects with high enough expected values but with more valuable experiments reach agreements with uncommitted investors (this is the upper U region). The lower U region is the set of projects that a committed investor would never fund but are viable to an uncommitted investor. The lower C small triangle is a set of projects that have enough value after early failure that commitment is valuable in that it allows the project to start. The C region above this contains projects that could be funded by either type of investor but the option to terminate early is less valuable than the loss of utility of the entrepreneur from early termination so commitment creates more value. This displays the intuition of propositions 1 and 2 and Corollary 1. We see that projects may be funded by one of the two types of investor or by neither, and furthermore, projects with a given level of expected payoff are more likely to be funded only by an uncommitted investor (region U) if they are more experimental and more likely to be funded only by a committed investor (region C) if they are less experimental.

To understand the effect of a fall in the cost of experimentation we examine figures 4 and 5.

If the cost of experimentation falls then the horizontal dotted line shifts lower and the vertical dotted line shifts to the right. This demonstrates the effect in proposition 3. The

¹³We have assumed throughout the paper that $V_F E[p_2 | F] < 1 - X$ to focus on the interesting cases where abandonment and commitment matter.

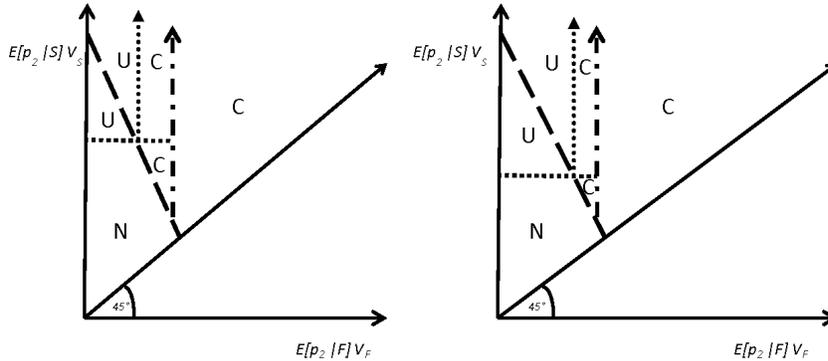


FIGURE 4. INVESTOR REGIONS: N = NO INVESTORS, C = COMMITTED INVESTOR, U = UNCOMMITTED INVESTOR

lower horizontal dotted line means the firms now above this line that used to be in the N region can be funded. The vertical dotted line shifted to the right means the firms now to the left of this line will be funded by an uncommitted rather than by a committed investor.

The magnitude of the impact of a fall in the cost of experimentation depends on the probability of success in the first period. In figures 3 and 4 the probability of first period success was 0.4 and this determined the slope of downward sloping line with large dashes. In figure 5 we decrease the first period probability to 0.2 and examine the same reduction in X. Because the uncommitted investor is much less likely to fund the second period investment when the probability of success is lower, a fall in the cost of the experiment is even more valuable. Thus we see in figure 5 that a large set of “long shot bets” can be funded by an uncommitted investor once the cost of experimentation falls (i.e., projects with low first period probabilities of success and more informative experiments).

When we consider that the set of innovative projects that exists in the world is probably concentrated among projects with low first period probabilities of success and with potentially high payoffs whose expectation depends on the outcome of experiments, then we see that the impact of a large fall in the costs of experimentation is likely to dramatically effect what will be funded.

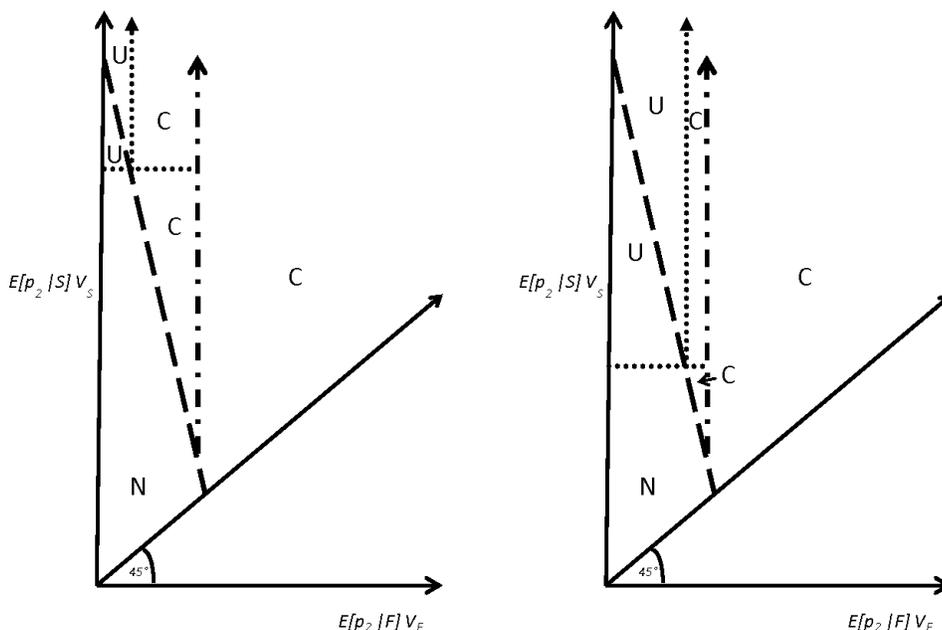


FIGURE 5. INVESTOR REGIONS: N = NO INVESTORS, C = COMMITTED INVESTOR, U = UNCOMMITTED INVESTOR

F. Adaptation of the Investor Model and Impact on Innovation

Consider two VCs, one of whom who has chosen to follow an uncommitted strategy and another that chooses to be a “fully committed investor.” These extremes will help elucidate the effect although nothing in our model precludes an investor from having combinations of such projects. Assume each has $\$Z$ to invest.¹⁴ Both investors will invest X to finance the first stage of the investment. However, they have different expectations about the need to invest $1 - X$: the fully committed investor must invest $1 - X$ if the first stage experiment fails (because the market will not); they can choose to invest $1 - X$ if the first stage succeeds. The uncommitted investor can choose to invest $1 - X$ if the first stage succeeds and will not invest if the first stage fails. Therefore, a committed investor with Z to invest can expect to make at most $Z/(1 - p_1(1 - X))$ investments and at least Z investments. On the other hand, the uncommitted investor will make at most Z/X

¹⁴As in a typical venture capital fund, we assume all returns from investing must be returned to the investors so that the VCs only have Z to support their projects.

investments and expect to make at least $Z/((X + p_1(1 - X)))$ investments.

For all $X < 1$ and $p_1 < 1$, we have $Z/X > Z/(1-p_1(1-X))$ and $Z/((X+p_1(1-X))) > Z$. Therefore, the committed investor will fund fewer startups that have a higher likelihood of success, thereby minimizing the cost of commitment. Moreover, to compensate them for committing to fund the startup when intermediate information is negative (and the NPV is negative), committed investors will take a higher share of the startup upfront. On the other hand, uncommitted investors will own a smaller share of a larger number of startups, but only invest in the second round when it is profitable to do so. This allows them to back startups with a lower likelihood of initial success, as they can abandon the investment if intermediate information is negative. It is worth noting that in the model, both strategies are equally profitable, but as seen above, the investment strategy and the composition of the startups in the portfolio are extremely different.

A fall in the cost of experimentation can therefore lead existing investors to switch towards an uncommitted or “spray and pray” strategy, or alternatively, if there are reputation concerns that make it hard for VCs to switch strategies, it creates room for new investors with a spray and pray investment strategy. Moreover, as VCs become less committed to funding investments across multiple stages and are more willing to start multiple long shot bets, this reduces the time available to govern startups and provide value-added mentoring. This can change the emphasis of early stage investing away from governance towards a more passive ‘learning’ focus. Thus, we would expect to see more investments per fund with a lower probability of taking a board seat.

The effect that such a shift in the investment strategy has on innovation is ambiguous. On the one hand, it is likely to increase the chances of radical new business models - companies such as Airbnb, that was founded by young, inexperienced entrepreneurs and was by all accounts a “long shot bet” when it was founded.¹⁵ On the other hand, the shift in

¹⁵For example, Kerr et al. (2014b) highlight how Fred Wilson of Union Square Ventures wrote about his “regret” at passing on Airbnb, a startup that lets people rent rooms or homes to prospective guests online. Started in 2008, Airbnb currently lists 500,000 properties in more than 34,000 cities across 192 countries, far larger than any hotel chain thereby making it the largest lodging company and brand in the world (Levere (2013)). Fred Wilson writes of Union Square Venture’s decision to pass on the deal in 2009 that “we couldn’t wrap our heads around air mattresses on the living room floors as the next hotel room.... Others saw the amazing team that we saw, funded them, and

investment strategy is likely to make it much harder for more complex technologies where the costs of experimentation are higher or there is a slower revelation of information about the startup's final value. For example, the very long time frames and costs associated with learning about the potential of renewable energy technologies or cancer therapies have led to relatively little financing of such ventures, despite intense societal interest (Fernandez, Stein and Lo, 2012; Nanda, Younge and Fleming, 2015).

III. Descriptive Evidence and Identification Strategy

Before moving to a more systematic analysis of the data, we first motivate the choice to use the introduction of cloud computing as the shock in our identification strategy. As we note in the Introduction, while the concept we examine is broad, our empirical strategy focuses on a specific and sudden cost reduction for a subset of startups in order to get sharp empirical results.

The advent of cloud computing through Amazon Web Services is seen by many practitioners as a defining moment that dramatically lowered the cost of early experiments for internet and web-based startups. The introduction of cloud computing allowed startups to 'rent' space on Amazon's servers in small increments and scale up as demand grew, as opposed to making large upfront investments in hardware when the probability of success for the startup is still extremely low. Thus, entrepreneurs could raise smaller amounts of capital initially and then only raise more capital once their startup showed initial success and needed to scale. The following quote by Mark Andreessen, a prominent venture capital investor, a serial entrepreneur and venture capital investor, describes this fall in costs:

“In the ‘90s, if you wanted to build an Internet company, you needed to buy Sun servers, Cisco networking gear, Oracle databases, and EMC storage systems... and those companies would charge you a ton of money even just to get up and running. The new startups today, they don't buy any of that stuff... They're

the rest is history.” (Source: <http://avc.com/2011/03/airbnb/>)

paying somewhere between 100x and 1000x [less] per unit of compute, per unit of storage, per unit of networking.”

Andreessen also notes that the rise of services such as Amazons Elastic Compute Cloud (EC2) transformed many infrastructure costs from upfront capital expenditures to subscription services that can scale with a company as it grows, thereby reducing the fixed costs associated with starting new firms.¹⁶ This point is also emphasized by Mark Suster, a serial entrepreneur and venture capital investor, who notes that

“Amazon changed our industry... Amazon gave us a 90% reduction in our total operating costs. ... Amazon sped up the pace of innovation because in addition to not having to raise capital to start I also didn’t need to wait for hosting to be set up, servers to arrive, software to be provisioned.... Amazon in turn led to the formation of an earlier stage of venture capital now led by what I call “micro VCs” who typically invest \$250-500k in companies rather than the \$5-7 million that VCs used to invest.”¹⁷

Importantly, technological changes that reduced the costs of starting firms did not impact all industries equally. Paul Graham, the founder of prominent accelerator, Y-Combinator, noted in 2008 that

“[the reason] no one was doing quite what we do is that till recently it was a lot more expensive to start a startup. You’ll notice we haven’t funded any biotech startups. That’s still expensive.”¹⁸

Finally, we note that the products included in Amazon’s cloud computing services were “developed first and foremost for Amazon’s internal infrastructure” before opening these services up to developers outside Amazon in 2006, the timing of which was not anticipated

¹⁶Source: Douglas Macmillan, “Andreessen: Bubble Believers “Don’t Know What Theyre Talking About”,” Wall Street Journal, January 3, 2014

¹⁷<http://www.bothsidesofthetable.com/2011/06/28/understanding-changes-in-the-software-venture-capital-industries/>

¹⁸Source: <http://paulgraham.com/ycombinator.html>.

by entrepreneurs or investors (Clark (2012); Vogels (2011)). Amazon’s CTO Werner Vogels recalled that

“At Amazon we had developed unique software and services based on more than a decade of infrastructure work for the evolution of the Amazon E-Commerce Platform. This was dedicated software and operation procedures that drove excellent performance, reliability, operational quality and security all at very large scale... The thinking then developed that offering Amazon’s expertise in ultra-scalable system software as primitive infrastructure building blocks delivered through a services interface could trigger whole new world of innovation as developers no longer needed to focus on buying, building and maintaining infrastructure. AWS delivered the first storage service (Amazon S3) in the spring of 2006 and compute (Amazon EC2) in the fall of that year” (Vogels (2011)).

A. Hypotheses and Estimation Strategy

We therefore use the introduction of Amazon’s cloud computing services in 2006 as a technological shock that lowered the cost of starting businesses in certain industry segments, and therefore compare VCs’ investments between 2006-2010 with the investments from 2002-2005 for industry segments more impacted by the technology shock relative to those less impacted by it.¹⁹

Our estimation strategy is a standard differences-in-differences regression. The analysis focuses on the initial round of funding among VC-backed startups. Estimations are run

¹⁹The eight industry segments classified as “treated” are “Business Support Services,” “Consumer Information Services,” “Financial Institutions and Services,” “Healthcare Services,” “Media and Content,” “Medical Software and Information Services,” “Software” and “Travel and Leisure.” The eighteen industry segments classified as “non-treated” are “Aerospace and Defense,” “Agriculture and Forestry,” “Biopharmaceuticals,” “Communications and Networking,” “Construction and Civil Engineering,” “Electronics and Computer Hardware,” “Food and Beverage,” “Household and office goods,” “Machinery and Industrial Goods,” “Materials and Chemicals,” “Medical Device Equipment,” “Renewable and Non-Renewable Energy,” “Retailers,” “Semiconductors,” “Utilities,” “Vehicles and Parts,” and “Wholesale Trade and Shipping.”

at the VC firm-startup-year level and take the form:

$$Y_{jit} = \beta_1 Treated_i * Post_t + \beta_2 X_i + \gamma_t + \rho_j + \nu_{jit} \quad (1)$$

where X_i are entrepreneurial firm characteristics at the time of the investment, including industry group and geographic fixed effects and an indicator for whether the firm was in a treated industry segment, γ_t are year fixed effects corresponding to the year of the investment. In many specifications, we also include VC-firm fixed effects, ρ_j , so that the β_1 estimate represents the within-VC dynamics of the dependent variable Y_{jit} . The main coefficient of interest is the interaction between *Treated* and *Post*.

Note that since the definition of “treated” and “non-treated” firms is based on industry segments, which is more granular than broad industry group classifications, the inclusion of industry group fixed effects (such Healthcare, Information Technology, etc.) in all our estimations effectively provides within-industry impacts of the treatment. This is particularly useful as venture capital firms often have a broad industry or sector focus for their investments. Note also that since (1) includes year fixed effects, the main effect of *Post* is not identified.

As with any differences-in-differences estimation strategy, our key identifying assumption is one of parallel trends – that is, that the “untreated” industry segments provide an appropriate counterfactual for what would have happened to the treated firms had they not benefited from the introduction of cloud computing. We validate this hypothesis using dynamic specifications that we discuss in greater detail below. In addition, our identification is predicated on the assumption that the set of firms we classify as “treated” did not change in some other systematic way in the year of treatment. One potential concern along this dimension is that the set of investment opportunities among firms in our “treated” industry segments systematically changed in the post period. While we cannot explicitly rule out this concern, we try to address it in two related ways. First, we examine some of the key candidates (e.g. the introduction of iphone apps) in Section VE

and highlight that these cannot alone explain our results. Second, as we outline below, we use our theoretical model to guide the interpretation of our empirical results. This also implies that an alternate driver of investment opportunities would need to also drive the set of patterns we find in treated industries, which raises the bar in terms of alternate explanations for our results.

Our model generates two sets of testable hypotheses. The first set relates to the fact that if there is a fall in the cost of experimentation that makes abandonment options relatively more valuable, we would expect investors to respond by shifting their portfolio strategy to a “spray and pray” investment approach - smaller first financings, larger number of initial investments that have less governance and a lower likelihood of follow-on investments. The second set of testable hypotheses have to do with the composition of VC firm portfolios. Since it is less costly to run an initial experiment on the prospects of a firm, this allows VCs to back startups that are more likely to be long shot bets. We look at whether younger founders and first-time entrepreneurs are more likely to receive an initial round of financing. In addition, an important distinction between a “long-shot bet” and a lower quality startup is that that if successful, long-shot bets will have higher step-ups in value at their next round of financing. This is because such outcomes have a low initial probability of success, but having demonstrated success, they generate a large amount of information that warrants a higher step-up in value at the next round of funding and ultimately larger payoffs. This is a key implication because if a fall in costs simply allowed the funding of marginally worse projects, then we would not expect larger step-ups or larger ultimate payoffs.

IV. Data

The main analysis uses the VentureSource database of venture capital financings, investors and entrepreneurial firms provided by Dow Jones. The data are supplemented in several ways. Additional valuation information for both financings and exits comes

from both Correlation Ventures and a merge of Thomson’s VentureEconomics.²⁰ The main unit of observation is the first VC financing event of a set of entrepreneurial firms financed between 2002 and 2010. We consider each investor associated with the financing. Additional information about the entrepreneurial firm’s founding team comes from CapitalIQ, LinkedIn, Crunchbase, firm websites and Lexis Nexus.²¹ Founders were identified with data from VentureSource and additional data collection detailed in Ewens and Fons-Rosen (2015).

We begin by including every first round of funding among VC-backed startups that occurred between 2002 and 2010. Sample inclusion further requires that the total capital invested in the financing be less than \$100m and the financing round labeled as either a bridge, Series A, angel or seed event. Investor types in the sample include standard venture capital firms, angel investors, corporations and friends and family. The focus is therefore on first, early stage financings of startups between 2002 and 2010. The final sample includes 8,973 entrepreneurial firms financed by 2,657 unique investors. The main sample has 16,983 observations of financing and investor. Each entrepreneurial firm is categorized as either “treated” or “non-treated” based on the industry segment reported in Venture Source. Table I reports the fraction of treated firms within the larger industry groups and Table II also outlines descriptive statistics for the key variables used in the analysis.

V. Results

A. Capital raised in first financing

We first document that the cost of starting businesses did fall following the introduction of Amazon Web Services (AWS) in 2006, as suggested by practitioners. Table III reports the estimation results from (1) where the dependent variable is log size of the investment

²⁰Correlation Ventures is an active venture capital fund that invests using a data-driven quantitative model.

²¹For each entrepreneurial firm founder, we matched using name and company to these separate data sources. The data sources provided past employment, person age, education background and gender. Lexis Nexus provides a service to collect individual birth years using name and state (of the company).

in the first round round of funding for VC-backed firms in the period 2002-2010. Columns (1) - (3) include VC firms that were active at any point in the sample period. Columns (4) - (6) are run on the subset of VCs that had at least three investment in the pre-2006 time period (i.e. were active in the pre-period). For each set of firms, the first column includes only industry fixed effects, the second column adds year fixed effects and the third column further adds VC-firm fixed effects.

As can be seen from Table III, there is a significant decrease in the capital invested by VCs in first financings for startups in treated industry segments. Relative to the non-treated industry firms, capital invested in treated startups is between 14 to 27% lower. This difference represents \$670K to \$1.3m differences at the mean capital invested. We can also see that the smaller investment amount was a function of both entry by new investors who wrote smaller checks as well as a change in behavior from incumbents. We will continue to see this in all of the regressions below. Thus the effects we find seem to stem both from entry as well as adaptation.

Table IV reports the results from quantile regressions estimated at the 25th, 50th and 75th percentiles, again for any VCs in the sample and for the subset that were most active. It documents that the initial funding size fell in these industry segments across all points in the funding size distribution, not just on average as seen in Table III.

Figure 6 reports the results from a dynamic specification of Equation (1) where each point is an estimate of the interaction of year and treated with 95% confidence bands. Each estimate is relative to year 2006. The patterns in the figure demonstrate both that the timing of the fall in cost is consistent with the introduction of AWS as well as helps strengthen the parallel trends assumption as there is no discernible pre-trend in the cost of starting businesses for the years leading up to the introduction of AWS.

Remember that since our specification uses differences-in-differences, changes in the overall macro environment are differenced away. Thus, alternative stories must include a reason why treated industries were impacted differentially in a manner that accounts for all of our results.

B. Evidence for “spray and pray” investing

Having shown the falling cost of starting businesses in “treated” industry segments, we turn next to understanding its consequences for the investment strategies of VCs and the composition of their portfolios. A key insight from the model is that the falling cost of experimentation makes abandonment options more valuable and hence suggests a shift towards a “spray and pray” investment strategy. First, we provide descriptive evidence of this by calculating the number of new financed firms in treated and non-treated from 2002 to 2010. The ratio of these treated to non-treated numbers is reported in Figure 7, where a ratio of one implies that there were an equal amount of firms financed in the two categories. There is a marked increase in investments that persists in the post period suggesting a shift in the financing rates of treated industry startups.

We next test for this change in a regression context using the dependent variable that is the total number of first-time investments in entrepreneurial firms made by VCs in each year and industry. The count is scaled by the total investors in the round so large syndicated investments do not receive additional weight. A unit of observation is thus a VC firm, year and one of two industry groups - “treated” and “non-treated.” For years with no investment activity by a given investor, the count is zero so that we have a balanced panel across investor-year-industry cells. The dependent variable of interest is the log of one plus this count. Table V reports the results for the sample of all VCs and those with pre-2006 investment activity.

Column (1) of Table V shows an increase in the rate of investing in treated industries after 2006 across all VCs. Column (2) show a similar magnitude when comparing changes in investment rates within a VC’s portfolio over the sample period. When we condition on the sample of VCs who have pre-2006 investments (columns (3) and (4)) the magnitudes are slightly larger and still positive. The economic interpretation of the estimate in the final column suggests 1.5 additional investments every two years in a VC fund. As the typical VC fund invests in 10 - 15 investments, this increase represents a meaningful change

in the composition of the portfolio.

The discussion of the model also suggests that VCs shifting to a spray and pray investment approach might be less likely to actively govern their investments, and instead emphasize a more passive learning role in the earliest stages of their investments. To measure governance, we identify whether any investor in the first financing took a board seat. Unfortunately, we cannot always date the timing of the board's creation and an individual investor's start date on the board. The sample of financings is thus smaller than that of the main analysis. If none of the investors in the first financing are ever listed as a board member, then we label the financing as having no board seat. If at least one investor can be identified as a first financing board member, then the financing is labeled as such. Table VI presents the results from linear probability models where the dependent variable takes the value of 1 if the VC is listed as a board member.

Columns (1) and (2) include all investors active in 2002-2010 and show a lower probability that a first financing has an investor with a board seat. The economic magnitude of these estimates suggest a 15% lower probability of an investor joining the board. The remaining columns of the table include only those financings with active investors with and without VC firm fixed effects. Column (3) shows that on average, the use of boards fell. Here the economic magnitude is a 20% lower probability an investor takes a board seat in the first financing. The last column indicates that this change is also present within-VC, including for the more active investors. Overall, our results indicate that the changes in governance styles are not just driven by a changing composition of investors with different governance styles, but also due to adaptation by existing investors.

C. Evidence of an increased funding of long shot bets

We next ask how the characteristics of VC-backed entrepreneurial firms changed after startup costs fell. The model predicts the falling cost of starting firms reduces the cost of experimentation and hence allows an *initial* funding of more "long-shot bets," defined as having a low probability of success but firms where investors can learn a lot from an

initial experiment.

Table VII presents the ex-ante characteristics of investments made by VCs to see if they shift in a manner that is consistent with “long shot bets.” In particular, we consider three attributes of the portfolio companies - firm age, average age of the founders (to proxy more broadly for founder experience), and the specific entrepreneurial experience of the founding team. Columns (1) and (2) of Table VII show that there was a 11% - 14% fall in the average age of startups in “treated” industries after 2006 relative to those founded in “non-treated” industries. The VC firm fixed effect specification in particular documents that active investors in treated industries shifted to financing younger entrepreneurial firms relative to their typical investment over the sample period. The next two columns of Table VII investigate whether the average age of the founding team in newly financed entrepreneurial firms changes after the introduction of AWS. A decrease in the average age of entrepreneurial firm founders would suggest that investors are investing in less experienced, riskier ventures. The coefficient on the interaction term in both samples “Treated X Post” indicates a statistically significant drop in the relative age of founding teams in VC firm portfolios. Finally, columns (5) and (6) of Table VII study the relationship between the post-period treated investments and the entrepreneurial experience of founding teams. Here, the dependent variable is an indicator that takes the value of 1 if at least one of the founding team members has prior founding experience (i.e. serial entrepreneur). The coefficient estimates on the interaction terms are negative, but are imprecisely estimated. Thus, there is suggestive evidence that VC investors shift to founders with less founding experience. Overall, the results of Table VII provide evidence consistent with the lower cost of initial funding facilitating the investment in more long shot bets.

Note that one might have thought that investing in younger firms and younger founders with less entrepreneurial experience would require *increased* governance. Our framework allows us to expect these features combined with less governance as investors shift to a model learning and away from governance at the earliest investing stages.

Having shown that the ex-ante characteristics of entrepreneurial firms backed by VC changed after 2005, we next investigate whether these differences translate into outcomes and success rates. Table VIII shows first that initial investments in startups in “treated” industries in the post-period were less likely to receive a follow-on investment, and were more likely to fail. The results in columns (1) and (2) of Table VIII show the fall in follow-on rates in the treated group and also suggest that this effect was stronger for those that receive capital from active, incumbent investors. This result is particularly interesting in light of evidence that suggests that experienced VCs are potentially more likely to be failure tolerant (Tian and Wang (2014)). Consistent with anecdotal accounts, this suggests that even experienced VCs may be adapting their investment style towards more “spray and pray” in the early stages, particularly in industries where the cost of starting firms has fallen substantially and hence made abandonment options more valuable. The last two columns of Table VIII also show an increased likelihood of ultimate failure, again particularly driven by active incumbents changing their investment strategies in treated sectors.²²

While an increased failure rates for the treated industry startups is consistent with an increase in long shot bets by investors, the analysis must also study outcomes of those who did not fail to distinguish long shot bets from worse investments. Long shot bets would result in relatively better outcomes, conditional on not failing after the initial round of funding. We consider two measures of success to ascertain if those firms that did not fail differ in their outcomes. The first measure is the step-up in value across rounds, which captures the change in valuation from the post-money valuation in the initial round of financing to the pre-money valuation of the subsequent round of equity financing. A relatively larger increase would suggest that investors learned more from the initial experiment. The second outcome is the ratio the ratio of exit value to total capital invested

²²The large rise in initial number of financing events, combined with a smaller follow-on rate has been colloquially referred to as the “Series A crunch.” However, investors seem to share the perspective that companies deserving of the next round of funding were receiving capital (<http://www.geekwire.com/2014/deserving-companies-will-weather-series-crunch-vcs-say/>)

(or “total economic return”) for startups that ultimately had a successful exit. Columns (1) and (2) show that the increase in equity valuation – “step-up” – is 14 - 19% larger for the treated industry firms after 2005. Again, the results are stronger both statistically and economically for the sample of firms backed by active VCs. The last two columns of Table IX show that this increased valuation change manifests itself in higher exit valuations to capital raised. Thus, both interim valuations increase and the economic returns are larger. Combined with the higher failure rates found in Table VIII, the evidence is in favor of a shift to experimental rather than just lower quality investments after the treatment event of AWS.

D. Entry of New Financial Intermediaries

Several practitioners point to the fact that the introduction of Amazon’s EC2 had a sharp and marked impact on the cost of startup ventures and the subsequent growth of new financial intermediaries such as “micro VCs,” “super-angels” and crowd-funding platforms. Many venture capital firms also lowered their minimum commitment levels to enable them to invest in earlier stage companies. For example, in 2010, Kleiner Perkins Caufield and Byers raised \$250 million for its sFund to invest in seed-stage social media startups.

The mid-2000s were also associated with the birth of new intermediaries known as accelerators, defined as “fixed, cohort-based programs, including mentorship and educational components that culminate in a public pitch or demo day” (Cohen and Hochberg (2014)). Cohen and Hochberg (2014) note that Y-combinator was the first accelerator and it was founded in 2005. Today, estimates of the number of accelerators range from 300 to over 2,000. As with micro-VCs, the emergence of accelerators is consistent with the predictions of the model in Section 2: the falling cost of an initial investment in a startup has allowed for more long shot bets to receive first financing - for example, startups that are founded by young, first time entrepreneurs who would not have received funding in the past. Simultaneously, the incentive for VCs to engage in mentorship and governance has

fallen at the early stages of their involvement with firms, given the rise of smaller sized initial investments with a lower probability of success. Both of these have led to the need for scalable forms of mentorship and governance, to help young, first time entrepreneurs with their firms at precisely the stage when VCs are stepping back from this role. Accelerators also help to screen deal flow for VCs through forums such as ‘demo day’, making the search process for long shot bets more efficient. In fact, Paul Graham, referring to Y-Combinator, notes that “We’re not a replacement for venture capital funds. We occupy a new, adjacent niche... our m.o. is to create new deal flow, by encouraging hackers who would have gotten jobs to start their own startups instead. We compete more with employers than VCs.”²³ This is precisely the insight from the model in Section 2, where the falling cost of experimentation induces entrepreneurs who would not have received initial funding to leave employment and try their hand at a startup. Similarly, in studying a prominent accelerator, Gonzales and Letherbee (2015) find the primary role it plays is that of mentorship, as opposed to the direct effect of finance.

E. Robustness Checks

We find evidence of a falling cost of starting businesses, a change in the investment strategy of VCs and also demonstrate how this is manifested in the characteristics of the startups they backed. The theoretical model provides a framework within which to see all of these results stemming from adaptation of VCs to a falling cost of experimentation, and has also shown how the corresponding entry of new financial intermediaries such as accelerators is consistent with this framework. From an empirical perspective, however, there is a concern that something else that coincided with the introduction of AWS could account for both a shift in the characteristics of investments and a falling cost of starting new businesses in the specific subset of industries we study.

Two potential candidates are the growth of open-source software and the iPhone and its resulting mobile ecosystem. While we can never conclusively tell that our results are not

²³Source: <http://paulgraham.com/ycombinator.html>

impacted by these, we perform several tests to show these are unlikely to be the drivers of the changes we see in our context. We use the Google feature that has tracked search term frequency on their search engine since 2004 to compare search traffic for Amazon EC2 to these alternative events. Figure 8 in the Appendix shows the rapid increase in the search for “EC2” after 2005, which is in line with our identification assumptions. The next two figures in the Appendix show search traffic for the App Store (Figure 9) and open source software (Figure 10). For the App Store, the interest level only rose in 2008, well after the shock we study and towards the end of our sample period. As a second test, we exclude firms from our sample that had a mention of mobile applications, iPhones, Android and other similar technologies. This is to ensure that what we capture is not simply the impact of smart phones and mobile applications changing the opportunity set for VCs, impacting both the characteristics of portfolio companies and the investment strategy of VCs. We use the one paragraph description of the company’s product and customers provided by VentureSource to identify such firms. The exclusion of this sub-sample has no material impact on the major estimates, so we conclude that our results are not primarily driven by the introduction of the iPhone.

Turning next to open source, there is a perception that improvement and dissemination of certain programming languages such as such as Ruby on Rails, PHP and Python may have increased during our sample period, making it cheaper to start and staff software startups. Our search for the frequency of the terms “open source” as well as for Python, popular programming language used for many VC-backed firm’s websites, suggests these were prevalent well before the introduction of AWS and were largely constant across our time period. Figure 10 shows this pattern for the “open source software” search. Ruby on Rails, which is another popular web programming framework introduced in July 2004, shows rapid increases in search frequency two years prior to the introduction of AWS and so is also unlikely to have driven these changes. More generally, however, we should note that the role that these programming languages may have played is in fact consistent with the thrust of our model. The cost of starting businesses has fallen in software and other

industries as well, making abandonment options more valuable for VCs and leading to a shift towards a new investment strategy. Empirically, we need to look for a large shock that differentially impacted some industries but not others, and we believe that AWS is such a shock and is one that practitioners have argued drove a large change in the cost of starting new firms. This does not discount the potential role of other factors such as open source that may have also impacted the cost of starting businesses.

VI. Conclusion

We develop a theoretical model and collect novel data on the characteristics of VC-backed firms to show how technological shocks to the cost of starting new firms have had a fundamental impact on the way in which investors manage their portfolios and the types of companies they choose to finance. The falling cost of experimentation makes abandonment options for investors much more valuable and this directly impacts the types of firms that investors are willing to finance, as well as the investment strategy they choose to use. In particular, we show how technological shocks to the cost of experimentation can play a central role in shaping both the rate and trajectory of startup innovation, by allowing more long shot bets to receive initial funding and thereby also reducing the chance of ‘false negatives’ in the economy. Nevertheless, this comes hand in hand with an investment strategy where several startups receive a small initial investment, but who do not get follow-on funding when intermediate information is negative. We show how this adaptation of investors towards a “spray and pray” investment strategy will tend bias VC investment towards startups where information is revealed quickly and cheaply and hence may adversely impact the extent to which more complex technologies, where information is revealed more slowly, are funded. In doing so we document the important feedback between technological change and financial intermediaries - technological shocks to investment opportunities require adaptation by investors, but this adaption has consequences for the future trajectory of innovation.

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VII. Figures and Tables

FIGURE 6. DIFFERENCE-IN-DIFFERENCE ESTIMATES: TREATED AND NON-TREATED

Notes: The figure plots the coefficients for the interaction terms ρ_t of financing year and the treated industry dummy from the following regression:

$$K_{it} = \beta_0 + \beta_1 \text{Treated}_i + \beta_2 \gamma_t + \sum_{t=2002}^{2010} \rho_t \text{Treated}_i \gamma_t + \epsilon_{it}.$$

The dependent variable K_{it} is the log of the first VC capital raised where the unit of observation is an entrepreneurial firm's first financing event. The 2006 interaction term is the excluded category, reported as zero in the figure. The vertical red lines represent the 95% confidence interval for the coefficient estimates with robust standard errors.

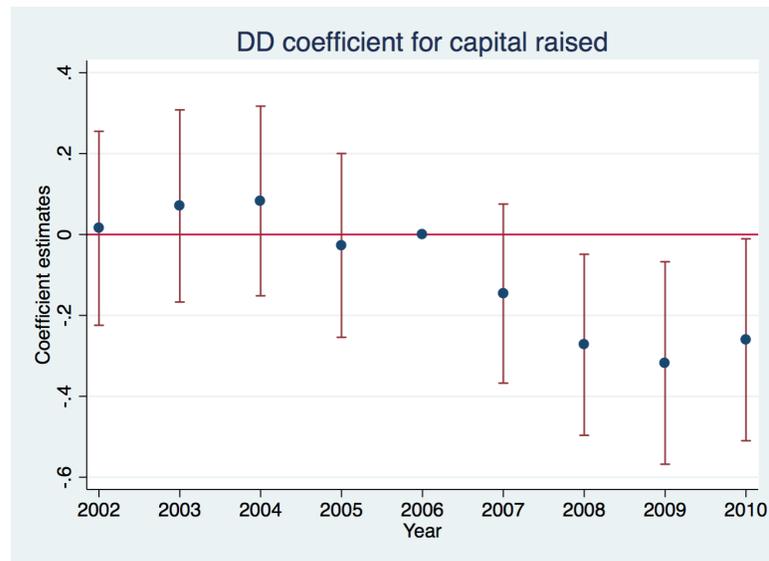


FIGURE 7. NEW VC-BACKED FIRMS IN TREATED INDUSTRIES

Notes: This figure reports the ratio of treated companies to untreated companies receiving a first, early stage financing as reported by VentureSource. A treated company is in one of the following industries (from VentureSource): “Business Support Services,” “Consumer Information Services,” “Financial Institutions and Services,” “Healthcare Services,” “Media and Content,” “Medical Software and Information Services,” “Software” and “Travel and Leisure.” A ratio of one implies that there were an equal amount of new entrepreneurial firms financed in that year in treated and untreated industries. The vertical red line represents the approximate date of the introduction of Amazon Web Services, our treatment event.

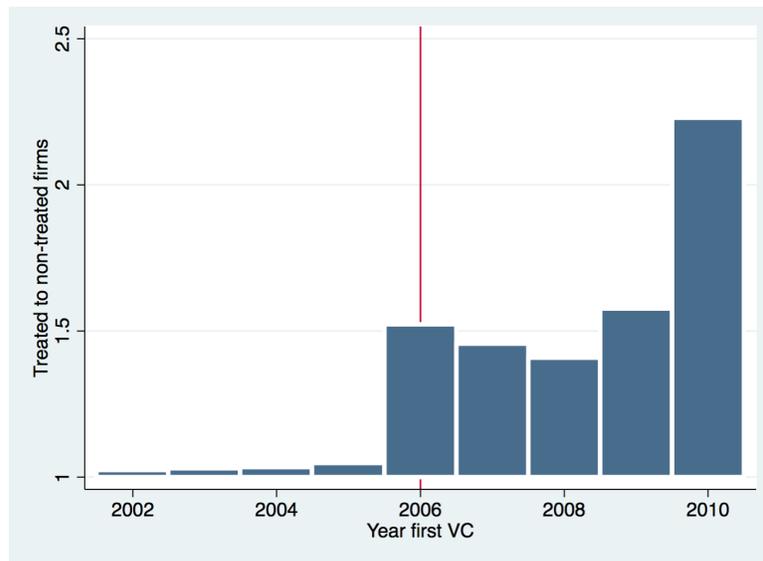


TABLE I—TREATMENT BY INDUSTRY

Notes: This table reports the fraction and number of treated firms and investments by industry. The sectors classified as “treated” are: “Business Support Services,” “Consumer Information Services,” “Financial Institutions and Services,” “Healthcare Services,” “Media and Content,” “Medical Software and Information Services,” “Software” and “Travel and Leisure.” These sectors are contained within the industries reported in the table.

Industry	Panel A	
	% “treated”	# Investments # firms
Biotechnology and health-care	0.08	3895 1884
Business and financial services	0.94	2804 1549
Consumer goods and services	0.74	3051 1742
Energy and Industrials	0.00	1168 640
Information Technology	0.62	6065 3158
Full dataset	0.50	16983 8973

TABLE II—DESCRIPTIVE STATISTICS

Notes: This table reports descriptive statistics on US-based startups that received Seed or Series A financing from an investor in the Venture Source database between 2002 and 2010. For these firms, we report data on the first financing event and the ultimate outcome of the startup as of March 2015. The sectors classified as “treated” are: “Business Support Services,” “Consumer Information Services,” “Financial Institutions and Services,” “Healthcare Services,” “Media and Content,” “Medical Software and Information Services,” “Software” and “Travel and Leisure.” The characteristics of firms and entrepreneurs are reported as of the date of first funding. “Average firm age” is the mean age of entrepreneurial firms at the time of first financing. “Average age founders” is the average age of the founding team at the time of first financing. “Share serial founders” is the fraction of firms that have at least one repeat founder on the founding team. “% failed” is the fraction of firms that went out of business by the end of 2014. “Exit value to total K ” is the reported exit valuation divided by the total capital raised by the entrepreneurial firm. The characteristics of firms, entrepreneurs and ultimate outcome are reported for the pre-period (2002-2005) so as to facilitate calculation of the magnitude of each response. The “# firms” reports the total number of firms for which we can calculate the variable.

Variable	# firms	Mean	Median
First capital (m)	7897	6.52	4.10
Firm age (yrs.)	8816	1.87	1.09
Team age (yrs.)	5722	41.28	41.00
Serial founder	7912	0.33	0.00
% failed	8973	0.35	0.00
% follow-on	8973	0.62	1.00
Step up in value	961	1.83	1.52
Exit value to capital	1428	6.41	2.63
% first board	5926	0.28	0.00

TABLE III—INITIAL FUNDING SIZE

Notes: This table reports results from OLS regressions where the dependent variable is the log of initial investment for the startup in which a given VC invested. A unit of observation is a entrepreneurial firm financing associated with an investor. VCs who are active in the pre-period are defined as those investors with at least three investments in the pre-2006 period. Industry fixed effects control for the five industries outlined in Table I. “Treated” industries are defined at a more granular-level than these industry classifications so there is within-industry variation in startups that are defined as “treated” vs. not. “Syndicate size” is the log of the number of investors in the financing and the three “Startup based in” are dummy variables for entrepreneurial firm headquarters state. “Year FE” indicate dummies for financing year, “Industry FE” are dummies for the five major industries and “VC firm FE” are VC firm fixed effects. Standard errors are clustered by VC-firm. Significance: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

	All VCs			VCs active in pre-period		
	(1)	(2)	(3)	(4)	(5)	(6)
Treated X Post-2005	-0.251*** (0.0634)	-0.227*** (0.0646)	-0.162*** (0.0360)	-0.285** (0.113)	-0.274** (0.114)	-0.141*** (0.0467)
Treated	0.0357 (0.0506)	0.0325 (0.0510)	-0.0671** (0.0311)	0.00681 (0.0614)	0.00772 (0.0605)	-0.103*** (0.0348)
Syndicate size	0.359*** (0.0202)	0.361*** (0.0200)	0.269*** (0.00910)	0.394*** (0.0374)	0.394*** (0.0372)	0.276*** (0.0113)
Startup based in CA	0.406*** (0.0774)	0.393*** (0.0767)	0.102*** (0.0314)	0.448*** (0.131)	0.440*** (0.130)	0.0637* (0.0383)
Startup based in MA	0.450*** (0.0803)	0.439*** (0.0799)	0.155*** (0.0377)	0.522*** (0.142)	0.518*** (0.142)	0.138*** (0.0519)
Startup based in NY	0.247*** (0.0742)	0.260*** (0.0738)	0.0755 (0.0589)	0.168 (0.149)	0.180 (0.148)	-0.0913 (0.0766)
Post-2005	0.0478 (0.0454)			0.159** (0.0685)		
Observations	15584	15584	15584	7738	7738	7738
Number startups	7897	7897	7897	5078	5078	5078
Number VCs	2657	2657	2657	506	506	506
R^2	0.132	0.143	0.137	0.153	0.157	0.152
Industry FE?	Y	Y	Y	Y	Y	Y
Year FE?	N	Y	Y	N	Y	Y
VC firm FE?	N	N	Y	N	N	Y

TABLE IV—INITIAL FUNDING SIZE: QUANTILE ESTIMATES

Notes: This table reports results from quantile regressions where the dependent variable is the log of initial investment for the startup in which a given VC invested. A unit of observation is a entrepreneurial firm financing associated with an investor. VCs who are active in the pre-period are defined as those investors with at least three investments prior to 2006. Industry fixed effects control for the five industries outlined in Table I. “Treated” industries are defined at a more granular-level than these industry classifications so there is within-industry variation in startups that are defined as “treated” vs. not (see Table I note). “Year FE” indicate dummies for financing year, “Industry FE” are dummies for the five major industries and “VC firm FE” are VC firm fixed effects. Bootstrapped standard errors (500 repetitions) are reported in parentheses. Significance: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

	All VCs			VCs active in pre-period		
	25th pctile (1)	Median (2)	75th pctile (3)	25th pctile (4)	Median (5)	75th pctile (6)
Treated X Post-2005	-0.241*** (0.0588)	-0.305*** (0.0518)	-0.189*** (0.0428)	-0.233** (0.103)	-0.135** (0.0675)	-0.100* (0.0553)
Treated	0.0186 (0.0591)	-0.0917** (0.0410)	-0.166*** (0.0323)	-0.0741 (0.0693)	-0.203*** (0.0487)	-0.225*** (0.0380)
Syndicate size	0.298*** (0.00913)	0.255*** (0.00750)	0.244*** (0.00920)	0.348*** (0.0161)	0.249*** (0.0128)	0.235*** (0.00884)
Startup based in CA	0.429*** (0.0328)	0.405*** (0.0257)	0.225*** (0.0228)	0.531*** (0.0575)	0.408*** (0.0368)	0.222*** (0.0262)
Startup based in MA	0.550*** (0.0452)	0.500*** (0.0424)	0.250*** (0.0340)	0.715*** (0.0643)	0.472*** (0.0464)	0.245*** (0.0378)
Startup based in NY	0.320*** (0.0558)	0.208*** (0.0618)	0.195*** (0.0755)	0.141 (0.116)	0.0725 (0.107)	0.0420 (0.0786)
Observations	15584	15584	15584	7738	7738	7738
Number startups	7897	7897	7897	5078	5078	5078
Number VCs	2657	2657	2657	506	506	506
R^2 / psuedo- R^2	0.175	0.174	0.170	0.183	0.180	0.175
Industry FE?	Y	Y	Y	Y	Y	Y
Year FE?	Y	Y	Y	Y	Y	Y
VC firm FE?	N	N	N	N	N	N

TABLE V—TOTAL INVESTMENTS BY INVESTORS

This table reports results from results of OLS and VC firm fixed effects regression total investments made by investors. Total investments are scaled by the number of investors in each first-round investment to ensure that entrepreneurial firms with more investors do not receive additional weight. A unit of observation is a quarter and industry, where industry is treated or non-treated as defined in Section IV. For columns (1) and (2), all VCs are included in the analysis in OLS and FE specification respectively. Columns (3) and (4) have the same specifications for the sample of VCs who have investments in the pre-period (i.e. “Active” VCs). “Treated” industries are defined at a more granular-level than these industry classifications so there is within-industry variation in startups that are defined as “treated” vs. not. “Year FE” indicate dummies for financing year and “VC firm FE” are VC firm fixed effects. Standard errors clustered by quarter are reported in parentheses. Significance: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

	Log total investments in quarter-industry			
	All VCs (1)	All VCs (2)	“Active” VCs (3)	“Active” VCs (4)
Treated X Post-2005	0.0320*** (0.00766)	0.0440*** (0.00832)	0.0469*** (0.0117)	0.0517*** (0.0111)
Treated	0.00763 (0.00569)	0.0114* (0.00673)	0.00803 (0.00631)	0.0127* (0.00730)
Observations	30592	30592	17219	17219
Number VCs	2824	2824	506	506
R^2	0.0250	0.0210	0.0281	0.0225
Industry FE?	N	N	N	N
Year FE?	Y	Y	Y	Y
VC firm FE?	N	Y	N	Y

TABLE VI—PORTFOLIO MANAGEMENT BY VCS: EARLY STAGE GOVERNANCE

Notes: This table reports results from results of OLS and VC firm fixed effects regression for the indicator of a board seat at the time of the firm’s first financing. A unit of observation is a entrepreneurial firm financing associated with an investor. VCs who are active (columns (3) and (4)) in the pre-period are defined as those investors with at least three investments in the pre-period. Industry fixed effects control for the five industries outlined in Table I. “Treated” industries are defined at a more granular-level than these industry classifications so there is within-industry variation in startups that are defined as “treated” vs. not. “Year FE” indicate dummies for financing year and “VC firm FE” are VC firm fixed effects. Standard errors are clustered by VC-firm are reported in parentheses. Significance: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

	All VCs (1)	All VCs (2)	“Active” VCs (3)	“Active” VCs (4)
Treated X Post-2005	-0.0302* (0.0172)	-0.0365** (0.0183)	-0.0564** (0.0264)	-0.0460* (0.0273)
Treated	0.0168 (0.0166)	-0.00292 (0.0158)	0.0483** (0.0215)	0.0141 (0.0234)
Syndicate size	0.0861*** (0.00374)	0.0649*** (0.00387)	0.105*** (0.00549)	0.0747*** (0.00541)
Startup based in CA	0.0429*** (0.0120)	0.00753 (0.00942)	0.0592*** (0.0188)	0.0125 (0.0165)
Startup based in MA	0.0626*** (0.0168)	0.0446** (0.0201)	0.0692*** (0.0231)	0.0578** (0.0273)
Startup based in NY	0.0517*** (0.0167)	0.0279* (0.0169)	0.0746** (0.0330)	0.0293 (0.0316)
Observations	10280	10280	4774	4774
Number startups	5926	5926	3470	3470
Number VCs	2165	2165	501	501
R^2	0.106	0.0714	0.127	0.0750
Industry FE?	Y	Y	Y	Y
Year FE?	Y	Y	Y	Y
VC firm FE?	N	Y	N	Y

TABLE VII—EX ANTE CHARACTERISTICS OF PORTFOLIO COMPANIES

Notes: This table reports results from results of VC firm fixed effects regression for three firm characteristics at the time of first financing. A unit of observation is a entrepreneurial firm financing associated with an investor. Columns (1) and (2) use the log of the firm age at first VC financing and columns (3) and (4) use the log of the average entrepreneurial team age at the time of financing. The final two columns use the dummy variable that is equal to one if at least one of the founders is a serial entrepreneur at the time of the financing event. Regressions in columns (1)-(4) use OLS. The final two columns use linear probability. VCs who are active in the pre-period (columns (2), (4) and (6)) are defined as those investors with at least three investments in the pre-period. Industry fixed effects control for the five industries outlined in Table I. “Treated” industries are defined at a more granular-level than these industry classifications so there is within-industry variation in startups that are defined as “treated” vs. not. “Year FE” indicate dummies for financing year, “Industry FE” are dummies for the five major industries and “VC firm FE” are VC firm fixed effects. Standard errors clustered by VC-firm reported in parentheses. Significance: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

	Log firm age		Log founding team age		Serial entrepreneur?	
	All VCs (1)	“Active” VCs (2)	All VCs (3)	“Active” VCs (4)	All VCs (5)	“Active” VCs (6)
Treated X Post-2005	-0.114* (0.0635)	-0.137* (0.0755)	-0.0481*** (0.0102)	-0.0419*** (0.0102)	-0.0273 (0.0168)	-0.0348 (0.0235)
Treated	0.128* (0.0676)	0.181*** (0.0563)	-0.0236*** (0.00650)	-0.0249*** (0.00840)	0.0417*** (0.0131)	0.0445** (0.0188)
Startup based in CA	-0.151*** (0.0355)	-0.0716 (0.0475)	-0.0488*** (0.00665)	-0.0491*** (0.00726)	0.0720*** (0.0137)	0.0597*** (0.0156)
Startup based in MA	-0.133** (0.0625)	-0.0875 (0.0776)	-0.0108* (0.00654)	-0.0158* (0.00931)	0.0548*** (0.0190)	0.0657** (0.0293)
Startup based in NY	-0.133** (0.0643)	-0.0175 (0.102)	-0.0666*** (0.00982)	-0.0831*** (0.0168)	0.0146 (0.0171)	-0.0281 (0.0263)
Observations	16795	8294	11216	5633	15304	7607
Number startups	8816	5570	5722	3732	7912	5050
Number VCs	2815	506	2174	500	2601	505
R^2	0.0110	0.0107	0.100	0.0927	0.0120	0.0120
Industry FE?	Y	Y	Y	Y	Y	Y
Year FE?	Y	Y	Y	Y	Y	Y
VC firm FE?	Y	Y	Y	Y	Y	Y

TABLE VIII—PORTFOLIO MANAGEMENT BY VCS: LIKELIHOOD OF STARTUP FAILURE

Notes: This table reports results from linear probability models for two outcome variables. A unit of observation is a entrepreneurial firm financing associated with an investor. Columns (1) and (2) use the indicator for the entrepreneurial firm having a subsequent exit or follow-on refinancing. Columns (3) and (4) use the dummy variable that is one if the firm failed by the end of the sample. VCs who are active (columns (2) and (4)) in the pre-period are defined as those investors with at least three investments in the pre-period. Industry fixed effects control for the five industries outlined in Table I. Industries are defined at a more granular-level than these industry classifications so there is within-industry variation in startups that are defined as “treated” vs. not (see note in Table I). “Year FE” indicate dummies for financing year, “Industry FE” are dummies for the five major industries and “VC firm FE” are VC firm fixed effects. Standard errors are clustered by VC-firm are reported in parentheses. Significance: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

	Follow on?		Failed?	
	All VCs (1)	“Active” VCs (2)	All VCs (3)	“Active” VCs (4)
Treated X Post-2005	-0.0191 (0.0175)	-0.0569** (0.0228)	0.0243 (0.0174)	0.0621*** (0.0228)
Treated	0.0286** (0.0135)	0.0405** (0.0177)	-0.105*** (0.0139)	-0.120*** (0.0185)
Startup based in CA	0.0421** (0.0177)	0.0211 (0.0152)	-0.0413*** (0.0156)	-0.0331** (0.0156)
Startup based in MA	0.0391** (0.0180)	0.0260 (0.0193)	-0.0650*** (0.0162)	-0.0626*** (0.0210)
Startup based in NY	0.0446** (0.0218)	0.0532* (0.0308)	-0.00899 (0.0209)	0.00890 (0.0304)
Observations	16983	8351	16983	8351
Number startups	8973	5626	8973	5626
Number VCs	2824	506	2824	506
R^2	0.00491	0.00586	0.00846	0.00824
Industry FE?	Y	Y	Y	Y
Year FE?	Y	Y	Y	Y
VC firm FE?	Y	Y	Y	Y

TABLE IX—PORTFOLIO MANAGEMENT BY VCS: VALUATIONS CONDITIONAL ON SUCCESS

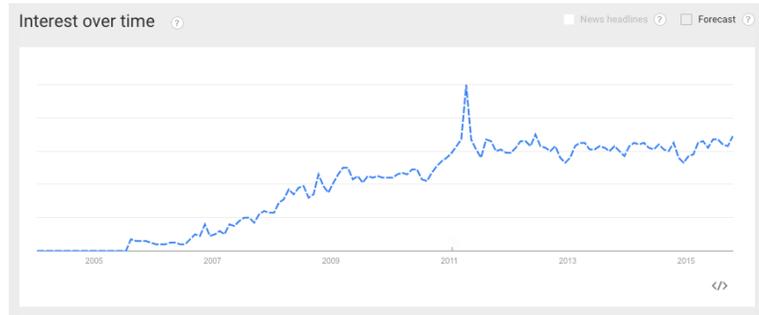
Notes: This table reports results from results of VC firm fixed effects regression for two outcome variables. A unit of observation is a entrepreneurial firm financing associated with an investor. Columns (1) and (2) use log of the ratio of the valuation of the next equity financing divided by the first (so requires both valuation and first round that was equity). Columns (3) and (4) use the log of the ratio of the final exit valuation (i.e. IPO valuation or acquisition price) to total capital invested in the firm at exit. VCs who are active (columns (2) and (4)) in the pre-period are defined as those investors with at least three investments prior to 2006. Industry fixed effects control for the five industries outlined in Table I. “Treated” industries are defined at a more granular-level than these industry classifications so there is within-industry variation in startups that are defined as “treated” vs. not. “Year FE” indicate dummies for financing year, “Industry FE” are dummies for the five major industries and “VC firm FE” are VC firm fixed effects. Standard errors are clustered by VC-firm are reported in parentheses. Significance: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

	Step up in valuation round 1 to round 2		Log exit value to capital raised (non-failed)	
	All VCs (1)	“Active” VCs (2)	All VCs (3)	“Active” VCs (4)
Treated X Post-2005	0.141* (0.0764)	0.182* (0.0946)	0.305** (0.120)	0.404** (0.163)
Treated	0.0129 (0.0477)	-0.0285 (0.0577)	0.256** (0.117)	0.210 (0.149)
Startup based in CA	0.123* (0.0696)	0.0315 (0.0688)	-0.111 (0.0785)	-0.0677 (0.128)
Startup based in MA	-0.0236 (0.0873)	-0.0706 (0.0832)	-0.234** (0.108)	-0.219 (0.159)
Startup based in NY	0.00293 (0.0679)	-0.00673 (0.122)	0.0290 (0.120)	0.0118 (0.225)
Observations	2237	1253	2351	1368
Number startups	961	721	1058	779
Number VCs	778	336	815	363
R^2	0.0476	0.0532	0.0385	0.0425
Industry FE?	Y	Y	Y	Y
Year FE?	Y	Y	Y	Y
VC firm FE?	Y	Y	Y	Y

A. Appendix

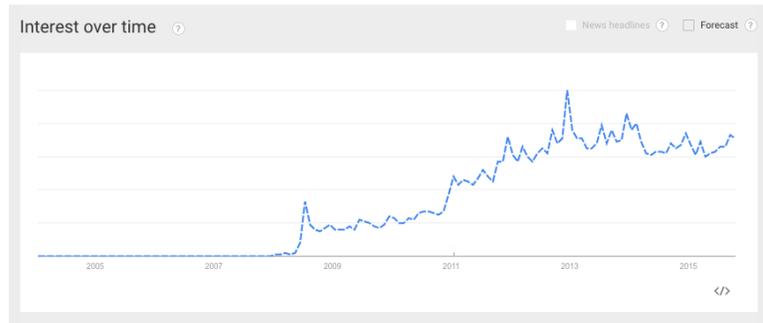
i. Tables and Figures

FIGURE 8. GOOGLE TRENDS DATA: AMAZON EC2



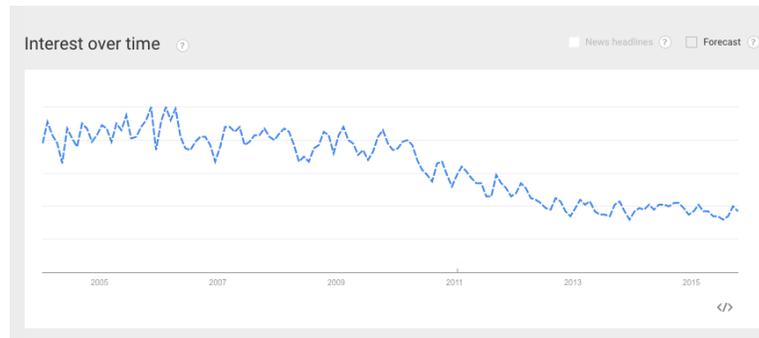
Notes: The figure presents the search term traffic for the phrase “Amazon Elastic Compute Cloud.”

FIGURE 9. GOOGLE TRENDS DATA: APP STORE



Notes: The figure presents the search term traffic for the phrase “App Store,” which is the marketplace for iPhone applications, a popular place for firms to sell their products.

FIGURE 10. GOOGLE TRENDS DATA: OPEN SOURCE SOFTWARE



Notes: The figure presents the search term traffic for the phrase “Open Source Software,” which includes languages such as Python, Ruby and PHP.

ii. *Matching between Entrepreneurs and Investors*

NO COMMITMENT

Using backward induction we start with the second period and first consider the case when the investor chooses not to commit. Conditional on a given α_1 the investor will invest in the second period as long as

$$V_j \alpha_j E[p_2 | j] - (1 - X) > 0 \quad \text{where } j \in \{S, F\}$$

This condition does not hold after failure even if $\alpha_F = 1$, therefore the investor will only invest after success in the first period. The minimum fraction the investor is willing to accept for an investment of $1 - X$ in the second period after success in the first period is

$$\underline{\alpha}_{2S} = \frac{1 - X}{V_S E[p_2 | S]}.$$

The entrepreneur, on the other hand, will continue with the business in the second period as long as,

$$V_j(1 - \alpha_j)E[p_2 | j] + u_E > u_F \quad \text{where } j \in \{S, F\}.$$

The entrepreneur will want to continue if the expected value from continuing is greater than the utility after failure, because the utility after failure is the outside option of the entrepreneur if she does not continue. The maximum fraction the entrepreneur will give up in the second period after success in the first period is

$$\overline{\alpha}_{2S} = 1 - \frac{u_F - u_E}{V_S E[p_2 | S]}.$$

Given both the minimum fraction the investor will accept, $\underline{\alpha}_{2S}$, as well as the maximum fraction the entrepreneur will give up, $\overline{\alpha}_{2S}$, an agreement may not be reached. An investor and entrepreneur are able to reach an agreement in the second period as long as

$$1 \geq \underline{\alpha}_{2S} \leq \overline{\alpha}_{2S} \geq 0 \quad \text{Agreement Conditions, } 2^{\text{nd}} \text{ period}$$

The middle inequality requirement is that there are gains from trade. However, those gains must also occur in a region that is feasible, i.e. the investor requires less than 100% ownership to be willing to invest, $1 \geq \underline{\alpha}_{2S}$, and the entrepreneur requires less than 100% ownership to be willing to continue, $\overline{\alpha}_{2S} \geq 0$.²⁴

We could find the maximum fraction the entrepreneur would be willing to give up after failure ($\overline{\alpha}_{2F}$), however, we already determined that the investor would require a share ($\underline{\alpha}_{2F}$) greater than 100% to invest in the second period, which is not economically viable. So no deal will be done after failure. If an agreement cannot be reached even after success then clearly the deal will never be funded. However, even those projects for which an

²⁴If not, the entrepreneur, for example, might be willing to give up 110% of the final payoff and the investor might be willing to invest to get this payoff, but it is clearly not economically feasible. For the same reason, even when there are gains from trade in the reasonable range, the resulting negotiation must yield a fraction such that $0 \leq \alpha_j \leq 1$ otherwise it is bounded by 0 or 1.

agreement could be reached after success may not be funded in the first period if the probability of success in the first period is too low. The following proposition determines the conditions for a potential agreement to be reached to fund the project in the first period. Given that the investor can forecast the second period dilution these conditions can be written in terms of the final fraction of the business the investor or entrepreneur needs to own in the successful state in order to be willing to start.

PROPOSITION 4: *The minimum total fraction the investor must receive is*

$$\underline{\alpha}_{S_N} = \frac{p_1(1 - X) + X}{p_1 V_S E[p_2 | S]}$$

and the maximum total fraction the entrepreneur is willing to give up is

$$\overline{\alpha}_{S_N} = 1 - \frac{(1 + p_1)(u_O - u_E) + (1 - p_1)(u_O - u_F)}{p_1 V_S E[p_2 | S]}$$

where the N subscript represents the fact that no agreement will be reached after failure.

See appendix A.v for proof. We use the N subscript because in the next section we consider the situation when investor chooses to commit to invest in the second period. This will result in an agreement to continue even after first period failure (A subscript for Agreement rather than N for No-agreement). Then we will compare the deals funded in each case. Given the second period fractions found above, the minimum and maximum total fractions imply minimum and maximum first period fractions (found in the appendix for the interested reader).

COMMITMENT

In this subsection we examine the alternative choice by an investor to commit with an assumed cost of early shutdown of c .

The following proposition solves for the minimum fraction the committed investor will accept in the second period and the maximum fraction the entrepreneur will give up in the second period. These will be used to determine if a deal can be reached.

PROPOSITION 5: *The minimum fraction the committed investor is willing to accept for an investment of $1 - X$ in the second period after success in the first period is*

$$\underline{\alpha}_{2S} = \frac{1 - X}{V_S E[p_2 | S]}.$$

However, after failure in the first period the minimum fraction the committed investor is willing to accept is

$$\underline{\alpha}_{2F} = \frac{1 - X - c}{V_F E[p_2 | F](1 - \alpha_1)} - \frac{\alpha_1}{1 - \alpha_1}.$$

The maximum fraction the entrepreneur will give up in the second period after success in the first period is

$$\overline{\alpha}_{2S} = 1 - \frac{u_F - u_E}{V_S E[p_2 | S]}.$$

After failure in the first period the maximum fraction the entrepreneur is willing to give up is

$$\overline{\alpha_{2F}} = 1 - \frac{u_F - u_E}{V_F E[p_2 | F](1 - \alpha_1)}.$$

The proof is in appendix A.iv. Both the investor and the entrepreneur must keep a large enough fraction in the second period to be willing to do a deal rather than choose their outside option. These fractions of course depend on whether or not the first period experiment worked.

After success in the first period the agreement conditions are always met. However, after failure in the first period the agreement conditions may or may not be met depending on the parameters of the investment, the investor and the entrepreneur.

LEMMA 1: *An agreement can be reached in the second period after failure in the first iff the investor is committed.*

PROOF:

A second period deal after failure can be reached if $\overline{\alpha_{2F}} - \underline{\alpha_{2F}} \geq 0$.

$$\overline{\alpha_{2F}} - \underline{\alpha_{2F}} = 1 - \frac{u_F - u_E}{V_F E[p_2 | F](1 - \alpha_1)} - \frac{1 - X - c}{V_F E[p_2 | F](1 - \alpha_1)} - \frac{\alpha_1}{1 - \alpha_1}.$$

$\overline{\alpha_{2F}} - \underline{\alpha_{2F}}$ is positive iff $V_F E[p_2 | F] - u_F + u_E - 1 - X + c \geq 0$. However, since the utility of the entrepreneur cannot be transferred to the investor, it must also be the case that $V_F E[p_2 | F] - (1 - X) + c \geq 0$. But if $V_F E[p_2 | F] - (1 - X) + c \geq 0$ then $V_F E[p_2 | F] - u_F + u_E - (1 - X) + c \geq 0$ because $u_F - u_E < 0$. QED

This lemma makes it clear that only a ‘committed’ investor will continue to fund the company after failure because $V_F E[p_2 | F] - (1 - X) < 0$.

We have now solved for both the minimum second period fraction the committed investor will accept, $\underline{\alpha_{2j}}$, as well as the maximum second period fraction the entrepreneur will give up, $\overline{\alpha_{2j}}$, and the conditions under which a second period deal will be done. If either party yields more than these fractions, then they would be better off accepting their outside, low-risk, opportunity rather than continuing the project in the second period.

Stepping back to the first period, a committed investor will invest and an entrepreneur will start the project with a committed investor only if they expect to end up with a large enough fraction after both first and second period negotiations.

PROPOSITION 6: *The minimum total fraction the investor is willing to accept is*

$$\alpha_{SA} = \frac{1 - (1 - p_1)V_F \alpha_F E[p_2 | F]}{p_1 V_S E[p_2 | S]},$$

and the maximum fraction the entrepreneur is willing to give up is

$$\overline{\alpha_{SA}} = 1 - \frac{2\Delta w_1 - (1 - p_1)E[p_2 | F]V_F(1 - \alpha_F)}{p_1 V_S E[p_2 | S]}$$

where the subscript A signifies that an agreement will be reached after first period failure. And where

$$\alpha_F = \gamma \left[\frac{1 - X - c}{V_F E[p_2 | F]} \right] + (1 - \gamma) \left[1 - \frac{\Delta u_F}{V_F E[p_2 | F]} \right]$$

The proof is in A.v, however, these are the relatively intuitive outcomes in each situation because each player must expect to make in the good state an amount that at least equals their expected cost plus their expected loss in the bad state.

Given the minimum and maximum fractions, we know the project will be started if

$$1 \geq \underline{\alpha}_{S_i} \leq \overline{\alpha}_{S_i} \geq 0 \quad \text{Agreement Conditions, } 1^{\text{st}} \text{ period,}$$

either with or without a second period agreement after failure ($i \in [A, N]$).

We have now calculated the minimum and maximum required by investors and entrepreneurs. With these fractions we can determine the types of projects for which investors will choose to commit.

iii. Commitment or the Guillotine

A deal can be done to begin the project if $\underline{\alpha}_{S_A} \leq \overline{\alpha}_{S_A}$, if the investor commits. Alternatively, a deal can be done to begin the project if $\underline{\alpha}_{S_N} \leq \overline{\alpha}_{S_N}$, assuming the project will be shut down after early failure. That is, a deal can get done if the lowest fraction the investor will accept, $\underline{\alpha}_{S_i}$ is less than the highest fraction the entrepreneur will give up, $\overline{\alpha}_{S_i}$. Therefore, given the decision by the investor to commit, a project can be started if $\overline{\alpha}_{S_A} - \underline{\alpha}_{S_A} \geq 0$, i.e., if

$$p_1 V_S E[p_2 | S] + (1 - p_1) V_F E[p_2 | F] - 2(u_O - u_E) - 1 \geq 0, \quad (\text{A-1})$$

or if $\overline{\alpha}_{S_N} - \underline{\alpha}_{S_N} \geq 0$, i.e., if

$$p_1 V_S E[p_2 | S] - 2(u_O - u_E) + (1 - p_1) \Delta u_F - p_1(1 - X) - X \geq 0. \quad (\text{A-2})$$

If we assume that the investor who generates the most surplus wins the deal then an investor will commit if $\overline{\alpha}_{S_A} - \underline{\alpha}_{S_A} \geq \overline{\alpha}_{S_N} - \underline{\alpha}_{S_N}$. Therefore, the following proposition demonstrates the three possibilities for any given project.

The proof is left to Appendix A.vii. Proposition 1 demonstrates the potential for a tradeoff between failure tolerance and the funding of a new venture. There is both a benefit of a sharp guillotine as well as a cost. Entrepreneurs do not like to be terminated ‘early’ and thus would rather receive an investment from a committed investor. This failure tolerance encourages innovative effort (as in Manso (2011); Holmstrom (1989); Aghion and Tirole (1994)), but a committed investor gives up the valuable real option to terminate the project early. Thus, the committed investor must receive a larger fraction of the pie if successful. While the entrepreneur would like a committed investor the commitment comes at a price. For some projects and entrepreneurs that price is so high that they would rather not do the deal. For others they would rather do the deal, but just not with a committed investor.

Essentially the utility of the entrepreneur can be enhanced by moving some of the payout in the success state to the early failure state. This is accomplished by giving a more failure tolerant VC a larger initial fraction in exchange for the commitment to fund the project in the bad state. If the entrepreneur is willing to pay enough in the good state to the investor to make that trade worth it to the investor then the deal can be done. However, there are deals for which this is true and deals for which this is not true. If the committed investor requires too much in order to be failure tolerant in the bad state, then

the deal may be done by a VC with a sharp guillotine.

iv. Proof of Proposition 5

Conditional on a given α_1 the investor will invest in the second period as long as

$$V_j \alpha_j E[p_2 | j] - (1 - X) > -c \quad \text{where } j \in \{S, F\}$$

As noted above, c , is the cost faced by the investor when he stops funding a project and it dies. Thus, the minimum fraction the investor will accept in the second period is

$$\underline{\alpha}_{2j} = \frac{(1 - x) - c}{V_j E[p_2 | j](1 - \alpha_1)} - \frac{\alpha_1}{1 - \alpha_1}.$$

Thus, an investor will not invest in the second period unless the project is NPV positive accounting for the cost of shutdown. This suggests that an investor who already owned a fraction of the business, α_1 , from the first period would be willing to take a lower minimum fraction in the second period than a new investor, and potentially accept even a negative fraction. However, there is a fraction η such that the investor is better off letting an outside investor invest (as long as an outside investor is willing to invest) rather than accept a smaller fraction. If $V_j E[p_2 | j] > (1 - X)$ (which is true for $j = S$) then an outside investor would invest for a fraction greater than or equal to $\frac{1-X}{V_S E[p_2 | S]}$. The fraction η that makes the investor indifferent between investing or not is the η such that

$$\alpha_1(1 - \eta)V_S E[p_2 | S] = (\eta + \alpha_1(1 - \eta))V_S E[p_2 | S] - (1 - X)$$

The left hand side is what the first period investor expects if a new investor purchases η in the second period. While the right hand side is the amount the first period investor expects if he purchases η in the second period. The η that makes this equality hold is $\eta = \frac{1-X}{V_S E[p_2 | S]}$. Note that η does not depend on c because the project continues either way. Thus, after success, an old investor is better off letting a new investor invest than accepting a fraction less than $\frac{1-X}{V_S E[p_2 | S]}$.²⁵ Thus, the correct minimum fraction that the investor will accept for an investment of $1 - X$ in the second period after success in the first period is

$$\underline{\alpha}_{2S} = \frac{1 - X}{V_S E[p_2 | S]}.$$

However, after failure in the first period then $V_F E[p_2 | F] < 1 - X$ and no new investor will invest. Potentially an old (committed) investor would still invest (to avoid paying c) and the minimum fraction he would accept is

$$\underline{\alpha}_{2F} = \frac{1 - X - c}{V_F E[p_2 | F](1 - \alpha_1)} - \frac{\alpha_1}{1 - \alpha_1}.$$

The entrepreneur, on the other hand, will continue with the business in the second

²⁵This assumes perfect capital markets that would allow a ‘switching’ of investors if entrepreneurs tried to extract too much. No results depend on this assumption but it makes the math easier and more intuitive, and we don’t want to drive any results off of financial market frictions.

period as long as,

$$V_j(1 - \alpha_j)E[p_2 | j] + u_E > u_F \quad \text{where } j \in \{S, F\}.$$

Since $\alpha_j = \alpha_{2j} + \alpha_1(1 - \alpha_{2j})$, for a given α_1 the maximum fraction the entrepreneur will give to the investor in the second period is

$$\overline{\alpha_{2j}} = 1 - \frac{u_F - u_E}{V_j E[p_2 | j](1 - \alpha_1)} \quad \forall j \in \{S, F\}.$$

Similarly to the investor, after success in the first period, there is a point at which the entrepreneur who already owns a fraction $1 - \alpha_1$ should quit and let the investors hire a new manager rather than take a smaller fraction. Thus, there is a η that makes the entrepreneur indifferent between staying and leaving:

$$(1 - \alpha_1)\eta V_S E[p_2 | S] + u_F = ((1 - \eta) + (1 - \alpha_1)\eta) V_S E[p_2 | S] + u_E$$

Thus, the correct maximum fraction the entrepreneur will give up in the second period after success in the first period is²⁶

$$\overline{\alpha_{2S}} = 1 - \frac{u_F - u_E}{V_S E[p_2 | S]}$$

However, after failure in the first period the maximum that the entrepreneur is willing to give up to keep the business alive is

$$\overline{\alpha_{2F}} = 1 - \frac{u_F - u_E}{V_F E[p_2 | F](1 - \alpha_1)}$$

The entrepreneur cannot credibly threaten to leave after failure unless he must give up more than $\overline{\alpha_{2F}}$, as his departure will just cause the business to be shut down.

v. Proof of Propositions 4 and 6

Bargaining will result in a fraction in the second period of $\alpha_{2j} = \gamma \alpha_{2j} + (1 - \gamma) \overline{\alpha_{2j}}$. For example, if the entrepreneur has all the bargaining power, $\gamma = 1$, then the investor must accept his minimum fraction, $\alpha_{2j} = \underline{\alpha_{2j}}$, while if the investor has all the bargaining power, $\gamma = 0$, then the entrepreneur must give up the maximum, $\alpha_{2j} = \overline{\alpha_{2j}}$. While if each has some bargaining power then they share the surplus created by the opportunity.

Given this, we can substitute into $\alpha_j = \alpha_{2j} + \alpha_1(1 - \alpha_{2j})$ and solve for the final fractions the investor and entrepreneur will obtain depending on success or failure at the first stage. Substituting we find $\alpha_j = \gamma \underline{\alpha_{2j}} + (1 - \gamma) \overline{\alpha_{2j}} + \alpha_1(1 - (\gamma \underline{\alpha_{2j}} + (1 - \gamma) \overline{\alpha_{2j}}))$. This can be rewritten as $\alpha_j = [\gamma \underline{\alpha_{2j}} + (1 - \gamma) \overline{\alpha_{2j}}](1 - \alpha_1) + \alpha_1$. Substituting in for $\underline{\alpha_{2j}}$ and $\overline{\alpha_{2j}}$ we find that

$$\alpha_S = \left[\gamma \frac{1 - X}{V_S E[p_2 | S]} + (1 - \gamma) \left[1 - \frac{u_F - u_E}{V_S E[p_2 | S]} \right] \right] (1 - \alpha_1) + \alpha_1 \quad (\text{A-3})$$

²⁶This requires the assumption of perfect labor markets that would allow a ‘switching’ of CEOs among entrepreneurial firms if investors tried to extract too much. No results depend on this assumption but it makes the math easier and more intuitive, and we don’t want to drive any results off of labor market frictions.

and α_F reduces to

$$\alpha_F = \gamma \left[\frac{1 - X - c}{V_F E[p_2 | F]} \right] + (1 - \gamma) \left[1 - \frac{u_F - u_E}{V_F E[p_2 | F]} \right] \quad (\text{A-4})$$

Of course, in both cases negotiations must result in a fraction between zero and one.²⁷ Note that α_F does not depend on the negotiations in the first period because after failure, renegotiation determines the final fractions.²⁸ Of course, investors and entrepreneurs will account for this in the first period when they decide whether or not to participate.²⁹ We solve for the first period fractions in appendix A.vi but these are not necessary for the proof.

The solution α_F is only correct *assuming* a deal can be reached between the investor and the entrepreneur in the second period (otherwise the company is shut down after early failure). Interesting outcomes will emerge both when an agreement can and cannot be reached as this will affect both the price of, and the willingness to begin, a project.

Stepping back to the first period, an investor will invest as long as

$$p_1 [V_S \alpha_S E[p_2 | S] - (1 - X)] - X + (1 - p_1) [V_F \alpha_F E[p_2 | F] - (1 - X)] \geq 0 \quad (\text{A-5})$$

if the 2nd period agreement conditions are met after failure. Or,

$$p_1 [V_S \alpha_S E[p_2 | S] - (1 - X)] - X - (1 - p_1)c \geq 0 \quad (\text{A-6})$$

if they are not.

The entrepreneur will choose to innovate and start the project if

$$p_1 [V_S (1 - \alpha_S) E[p_2 | S] + u_E] + u_E + (1 - p_1) [V_F (1 - \alpha_F) E[p_2 | F] + u_E] \geq 2u_O \quad (\text{A-7})$$

if the 2nd period agreement conditions are met after failure. Or,

$$p_1 [V_S (1 - \alpha_S) E[p_2 | S] + u_E] + u_E + (1 - p_1) u_F \geq 2u_O \quad (\text{A-8})$$

if they are not.

The four above equations can be used to solve for the minimum fractions needed by the investor and entrepreneur both when a deal after failure can be reached and when it cannot. If the agreement conditions in the 2nd period after failure are met, then the minimum fraction the investor is willing to receive in the successful state and still choose to invest in the project is found by solving equation (A-5) for the minimum α_S such that

²⁷Since negotiations must result in a fraction between zero and one, then if a deal can be done then if $\gamma < (u_F - u_E)/(Y(1+r) - c - V_F E[p_2 | F] + u_F - u_E)$ then $\alpha_F = 1$, or if $\gamma < -(u_F - u_E)/(Y(1+r) - V_S E[p_2 | S] + u_F - u_E)$ then $\alpha_S = 1$. Since $c \leq 1 - X$ the negotiations will never result in a fraction less than zero.

²⁸In actual venture capital deals so called ‘down rounds’ that occur after poor outcomes often result in a complete rearrangement of ownership fractions between the first round, second round and entrepreneur.

²⁹Alternatively we could assume that investors and entrepreneurs predetermine a split for for every first stage outcome. This would require complete contracts and verifiable states so seems less realistic but would not change the intuition or implications of our results.

the inequality holds:

$$\underline{\alpha}_{S_A} = \frac{1 - (1 - p_1)V_F\alpha_F E[p_2 | F]}{p_1 V_S E[p_2 | S]}$$

where the subscript A signifies that an agreement can be reached after first period failure. The maximum fraction the entrepreneur can give up in the successful state and still be willing to choose the entrepreneurial project is found by solving equation (A-7) for the maximum α_S such that the inequality holds:

$$\overline{\alpha}_{S_A} = 1 - \frac{2(u_O - u_E) - (1 - p_1)E[p_2 | F]V_F(1 - \alpha_F)}{p_1 V_S E[p_2 | S]}$$

where α_F is defined in equation (A-4) in both $\overline{\alpha}_{S_A}$ and $\underline{\alpha}_{S_A}$. Both $\overline{\alpha}_{S_A}$ and $\underline{\alpha}_{S_A}$ depend on the negotiations in the failed state, α_F , because the minimum share the players need to receive in the the good state to make them willing to choose the project depends on how badly they do in the bad state. If a second period agreement after failure cannot be reached then the minimum fraction of the investor and the maximum fraction of the entrepreneur are found by solving equations (A-6) and (A-8) respectively, to find

$$\underline{\alpha}_{S_N} = \frac{p_1(1 - X) + X}{p_1 V_S E[p_2 | S]}$$

and

$$\overline{\alpha}_{S_N} = 1 - \frac{(1 + p_1)(u_O - u_E) + (1 - p_1)(u_O - u_F)}{p_1 V_S E[p_2 | S]}$$

where the N subscript represents the fact that no agreement can be reached after failure.

vi. Derivation of first period fractions

The maximum and minimum required shares after first period success, $\overline{\alpha}_{S_i}$ and α_{S_i} , directly imply first period minimum and maximum fractions, $\overline{\alpha}_{1_i}$ and $\underline{\alpha}_{1_i}$ ($i \in [A, N]$), because we already know from above, equation (A-3), that

$$\alpha_S = \left[\gamma \frac{1 - X}{V_S E[p_2 | S]} + (1 - \gamma) \left(1 - \frac{u_F - u_E}{V_S E[p_2 | S]} \right) \right] (1 - \alpha_1) + \alpha_1$$

Thus, we can solve for the α_1 that just gives the investor his minimum α_S . Let Z equal the term in brackets in the equation above and we can solve for α_1 as a function of α_S .

$$\alpha_1 = \frac{\alpha_S - Z}{1 - Z} \tag{A-9}$$

Plugging in $\underline{\alpha}_{S_A}$ for α_S yields the minimum required investor fraction $\underline{\alpha}_{1_A}$:

$$\underline{\alpha}_{1_A} = \frac{\frac{1 - (1 - p_1)V_F\alpha_F E[p_2 | F]}{p_1 V_S E[p_2 | S]} - Z}{1 - Z}$$

as a function of α_F . And substituting in for α_F from equation (A-4) and Z from above yields,

$$\underline{\alpha}_{1A} = 1 - \frac{p_1 V_S E[p_2 | S] - p_1(1 - X) - X - (1 - p_1)\gamma c}{p_1(\gamma V_S E[p_2 | S] - \gamma(1 - X) + (1 - \gamma)(u_F - u_E))} - \frac{(1 - p_1)(1 - \gamma)(V_F E[p_2 | F] - (1 - X) - (u_F - u_E))}{p_1(\gamma V_S E[p_2 | S] - \gamma(1 - X) + (1 - \gamma)(u_F - u_E))}$$

This is the minimum fraction required by the investor assuming that a deal can be achieved in the second period after failure in the first period.³⁰ In equilibrium the investor's minimum depends on the entrepreneur's gains and costs because they must negotiate and participate. If instead, an agreement cannot be reached after failure in the first period then the project is stopped. In this case the minimum fraction required by the investor can be found by plugging α_{S_N} into equation (A-9) for α_S , where α_{S_N} is the minimum when no second period deal can be reached. In this case the minimum required investor fraction $\underline{\alpha}_{1N}$ is

$$\underline{\alpha}_{1N} = \frac{\frac{p_1(1-X)+X}{p_1 V_S E[p_2 | S]} - Z}{1 - Z}$$

or,

$$\underline{\alpha}_{1N} = 1 - \frac{p_1 V_S E[p_2 | S] - p_1(1 - X) - X}{p_1(\gamma V_S E[p_2 | S] - \gamma(1 - X) + (1 - \gamma)(u_F - u_E))}$$

We can similarly calculate the maximum fraction the entrepreneur is willing to give up in the first period. The maximum fraction can be found by plugging $\overline{\alpha}_{S_i}$ into equation (A-9) for α_{S_i} , where $\overline{\alpha}_{S_i}$ ($i \in [A, N]$) is the maximum when either a second period agreement after failure can (A) or cannot (N) be reached. When a second period agreement can be reached $\overline{\alpha}_{1A}$ is

$$\overline{\alpha}_{1A} = 1 - \frac{2(u_O - u_E) - (1 - p_1)E[p_2 | F]V_F(1 - \alpha_F)}{p_1(\gamma V_S E[p_2 | S] - \gamma Y(1 + r) + (1 - \gamma)(u_F - u_E))}$$

And when a second period deal after failure cannot be reached $\overline{\alpha}_{1N}$ is

$$\overline{\alpha}_{1N} = 1 - \frac{(1 + p_1)(u_O - u_E) + (1 - p_1)(u_O - u_F)}{p_1(\gamma V_S E[p_2 | S] - \gamma(1 - X) + (1 - \gamma)(u_F - u_E))}$$

vii. Proof of Proposition 1:

It is clearly possible that both $\overline{\alpha}_{S_A} - \alpha_{S_A} < 0$ and $\overline{\alpha}_{S_N} - \alpha_{S_N} < 0$. For example, a project with a low enough V_S and/or V_F could have both differences less than zero. Similarly, for a high enough V_S and/or V_F (or low X) both $\overline{\alpha}_{S_A} - \alpha_{S_A} > 0$ and $\overline{\alpha}_{S_N} - \alpha_{S_N} > 0$, even for c equal to the maximum c of $1 - X$. Thus, extremely bad projects will not be started and extremely good projects may be started by any type of investor.

³⁰Technical note: with extreme values it is possible that α_F would be greater than 1 or less than zero. In these cases α_F is bound by either zero or 1. This would cause the $\underline{\alpha}_1$ to increase or decrease. This dampens some of the effects in extreme cases but alters no results. To simplify the exposition we assume that parameters are in the reasonable range such that the investor and entrepreneur would not be willing to agree to a share greater than 1 or less than zero.

If either $\overline{\alpha_{S_A}} - \underline{\alpha_{S_A}} \geq 0$ or $\overline{\alpha_{S_N}} - \underline{\alpha_{S_N}} \geq 0$ or both then the investor will generate more surplus by committing if $\overline{\alpha_{S_A}} - \underline{\alpha_{S_A}} \geq \overline{\alpha_{S_N}} - \underline{\alpha_{S_N}}$ or vice versa. The difference between $\overline{\alpha_{S_A}} - \underline{\alpha_{S_A}}$ and $\overline{\alpha_{S_N}} - \underline{\alpha_{S_N}}$ is

$$\frac{(1-p_1)V_F E[p_2 | F] - (1-p_1)\Delta u_F - (1-p_1)(1-X)}{p_1 V_S E[p_2 | S]} \quad (\text{A-10})$$

Equation (A-10) may be positive or negative depending on the relative magnitudes of $V_F E[p_2 | F]$, Δu_F , and $(1-X)$. That is, projects for which the first stage experiment is cheap (X is small) and the utility impact on the entrepreneur from shutting down the project is low (Δu_F is small) and the expected value after failure is low ($V_F E[p_2 | F]$ is small) are more likely to be done by an uncommitted investor. QED

viii. Proof of Proposition 2 and Corollary 1:

From above we know that when Equation (A-10) is greater than zero then $\overline{\alpha_{S_A}} - \underline{\alpha_{S_A}} \geq \overline{\alpha_{S_N}} - \underline{\alpha_{S_N}}$ and the project creates more value if funded by a committed investor. This is more likely if $V_F E[p_2 | F]$ is larger, Δu_F is smaller, or $(1-X)$ is smaller.

The Corollary follows directly from the fact that if two projects have the same expected value, $p_1 V_S E[p_2 | S] + (1-p_1)V_F E[p_2 | F]$, and same probability of a successful experiment, p_1 , but a more valuable experiment ($V_S E[p_2 | S] - V_F E[p_2 | F]$ is larger) then $V_F E[p_2 | F]$ must be smaller. QED

ix. Proof of Proposition 3:

A project will be funded by a committed investor if $\overline{\alpha_{S_A}} - \underline{\alpha_{S_A}} \geq \overline{\alpha_{S_N}} - \underline{\alpha_{S_N}}$ or

$$(1-p_1)V_F E[p_2 | F] - (1-p_1)\Delta u_F - (1-p_1)(1-X) \geq 0 \quad (\text{A-11})$$

The derivative of this condition with respect to X is $(1-p_1)$. Thus a firm is more likely to switch type of funder with a fall in X if it has a small probability of first period success, p_1 . Furthermore, if X falls then $(1-p_1)(1-X)$ is larger and it takes a larger $V_F E[p_2 | F]$ for a committer to win. Thus, the projects that switch will be those with lower $V_F E[p_2 | F]$. For a given expected value if $V_F E[p_2 | F]$ is smaller then $V_S E[p_2 | S]$ must be larger and $V_S E[p_2 | S] - V_F E[p_2 | F]$ is larger so the project has a more valuable experiment. A project will be funded by an uncommitted investor rather than no investor if

$$p_1 V_S E[p_2 | S] - 2(u_O - u_E) + (1-p_1)\Delta u_F - p_1(1-X) - X \geq 0. \quad (\text{A-12})$$

The derivative of this condition with respect to X is $p_1 - 1$. Therefore an increase in X has a larger (more negative) impact if p_1 is small. These firms have a smaller $V_S E[p_2 | S]$ than those funded by an uncommitted investor before the change in X . However, before the change a committed investor would have funded this set of firms if they had a higher $V_F E[p_2 | F]$. This can be seen by noting that committed investors are willing to fund a project if $\overline{\alpha_{S_A}} - \underline{\alpha_{S_A}} \geq 0$, i.e., if

$$p_1 V_S E[p_2 | S] + (1-p_1)V_F E[p_2 | F] - 2(u_O - u_E) - 1 \geq 0, \quad (\text{A-13})$$

QED