Entrepreneurship and the Cost of Experimentation

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We study how technological change impacts the nature of venture-capital backed entrepreneurship in the US, through its effect on the falling cost of experimentation for startup firms. Using a theoretical model and rich data, we are able to both document and provide a framework for understanding the increased prevalence of investors who "spray and pray" – investing a little money in several startups run by teams of young and unproven entrepreneurs, with a lower probability of following-on their investments. Consistent with the model, we find that these patterns to be strongest in industry segments where technological change has led the cost of starting a business to fall most sharply in recent years.

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I. Introduction

Entrepreneurship is increasingly seen as central to productivity growth and to the process of creative destruction (Aghion and Howitt (1992); King and Levine (1993)), and a growing literature has aimed to understand the institutional and organizational factors that reduce financing constraints for entrepreneurs and facilitate the founding and growth of new ventures. In particular, recent work has highlighted the importance of economic experimentation (Rosenberg (1994); Stern (2005)) in driving forward the process of creative destruction, since most new ventures will fail (Kerr and Nanda (2009); Hall and Woodward (2010)), and it is extremely difficult to predict, ex ante, whether a particular innovation or venture is likely to succeed (Fleming (2001); Kerr, Nanda and Rhodes-Kropf (2014)).

Much of the literature on reducing frictions associated with economic experimentation has focused on legal, cultural or institutional factors that might impact the entry of new firms. Relatively little academic research has examined the role that technological change plays in changing the cost of experimentation around the founding of new firms – and the effect that this has on nature of innovation and entrepreneurship in the economy. This seems like a major gap in our understanding of entrepreneurship for at least two reasons. First, as we outline in greater detail below, a number of technological developments that have made the early experiments by startups significantly cheaper in recent years.[1] While anecdotal accounts of this phenomenon have been documented in the press and the managerial implications popularized in frameworks such as the "lean startup model", we are

[1] In particular, the advent of cloud computing has meant that startups no longer need to buy expensive hardware when starting-up. This process has been accelerated since 2005, after the advent of Amazon Elastic Compute Cloud (Amazon EC2) and has led the fixed costs of starting a business to fall by an order of magnitude in the last few years.

not aware of any systematic work examining how the changing cost of starting businesses is impacting the nature of economic experimentation and the types of businesses being financed in the economy.

Second, and more importantly from a theoretical standpoint, the changing cost of experimentation has the potential to radically impact the way in which investors manage their portfolios and the types of companies they choose to finance. This is because investors backing startups engaged in the early stages of innovation face an important tradeoff (Manso (2011)): on the one hand, they want to tolerate early failure by entrepreneurs to encourage the entrepreneurs to engage in risky experimentation – thereby increasing the chances of radical innovation (Acharya and Subramanian (2009); Tian and Wang (2012)). On the other hand, however, failure tolerance requires investors to forgo abandonment options, and hence makes them less likely to fund the risky experimentation (Guler (2007*b*) Guler (2007*a*), Nanda and Rhodes-Kropf (2013), Cerqueiro et al. (2013)). 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 use the "financial guillotine" 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 has allowed 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 where one can learn a lot about the ultimate outcome of the project from an initial investment in the startup. Second, we show that the only profitable way to finance these projects is for investors to manage their portfolio with a "sharp guillotine" – that is, to invest in a number of startups in order to learn about their potential, most of which are terminated after the initial financing and hence a much smaller proportion receives follow-on funding. Finally, the model shows that the portfolios of existing investors who choose not to change to becoming less failure tolerant can in fact become *less* risky. This is because the most risky projects that would have been funded by these investors prior to the fall in the cost of experimentation will now be more profitably funded either by new entrants or existing investors who switch to managing their portfolios with more of a "guillotine" strategy. Hence the projects that remain to be funded by the committed or failure tolerant investors investors will be the most conservative set of investments being made by VCs.

Our model helps to rationalize two seemingly opposing views that have emerged about the venture capital industry in recent years. On the one hand, there is a view that some investors are more willing take a series of long-shot bets on completely unproven founding teams and business models, but are far less tolerant of early failure by these startups. On the other hand, there is a view that existing VCs have become extremely risk averse and are not truly funding radical innovation. For example, Scott McNealy, founder of Sun Microsystems has argued that "VCs are acting like business schools, which no longer take kids right out college but wait two to four years until they've proven themselves. They're basically saying,'We're not going to take a chance, we'll let the angels do that and vet them first."' Our model shows that both aspects of the financing landscape can emerge from the same phenomenon of the falling cost of experimentation combined with organizational inertia that leads some incumbent VCs move to later stage or less risky investments.

We build on our theoretical model to also examine predictions about the characteristics of the venture capital portfolios using rich data on venture capital investments and the portfolio companies. 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 portfolio strategies of VCs in the 2006-2010 period compared to that in the 2001-2005 period. A differences in differences estimation approach suggests that on average, investors are more likely to back unproven founding teams in the post period when the startup is in an industry segment that benefited from Amazon's EC2 services. In these sectors, VCs back younger founders who are less likely to be serial entrepreneurs. They also invest less in these startups and are much less likely to follow-on their investment compared to their investments in other industry segments. Our results suggest that the falling cost of experimentation has helped to democratize entry, particularly among young, unproven founding teams and has led to a new class of investors who have entered to fund such startups using a "guillotine strategy." In ongoing work, we are studying the heterogeneity in the investor response, to also understand whether the average effects are masking variation where (consistent with the model) some investors have in fact become more risk averse following the shock.

Our results are related to a growing literature that examines how changes to the environment of financial intermediaries has follow-on effects in the real economy. The rest of the paper is structured as follows. In Section 2, we develop a model of investment to highlight how the cost of experimentation will impact the type of entrepreneurs who are backed and the investment strategies of investors. In Section 3, we describe the data and the estimation strategy, including a mapping from the model to testable hypotheses. Section 4 outlines our results and Section 5 concludes.

II. A Model of Investment

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.[2]

A. Investor View

The first stage of the project reveals information about the probability of success in the second stage.[4] The probability of 'success' (positive information) in the first stage is p_1 and reveals the information S, while 'failure' reveals F. Success in the second stage yields a payoff of V_S or V_F depending on what happened in the first stage, but occurs with a probability that is unknown and whose expectation depends on the information revealed by the first stage. Failure in the second stage yields a payoff of zero.

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 outcome of the first stage. Let $E[p_2|S]$ denote the expectation of p_2 conditional on success in the first stage, while $E[p_2|F]$ denotes the expectation of p_2 conditional on failure in the first stage.[5]

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

[2]This basic set up is a two-armed bandit problem. There has been a great deal of work modeling innovation that has used some from 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).[3] We build on this work by altering features of the problem to explore the effect of a reduction in the cost of early experimentation.

[4]This might be the building of a prototype or the FDA regulated Phase I trials on the path of a new drug. Etc.

[5]One 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).

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 then it is NPV negative in the second period, i.e., $E[p_2|F] * V_F < 1 - X$. And if the project 'succeeds' in the first period then it is NPV positive in the second period, i.e., $E[p_2|S] * V_S > 1 - X$.

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

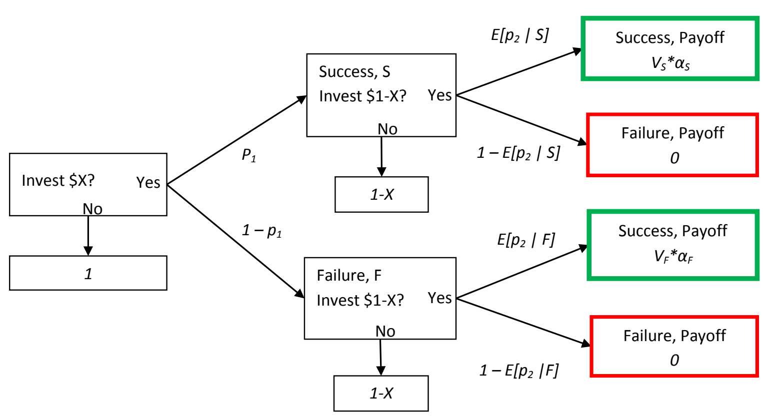

FIGURE 1. EXTENSIVE FORM REPRESENTATION OF THE INVESTOR'S GAME TREE

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, X. Assuming that an investor chooses 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 they generate utility of u_E in both periods. Alternatively, if they choose not to become an entrepreneur in the first period then we assume that no entrepreneurial opportunity arises in the second period so they generate 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 their outside option in the second period. We assume $\Delta u_F = u_F - u_E < 0$, which represents the disutility felt by a failed entrepreneur. The more negative Δu_F is, the worse entrepreneurial experience in a failed project is perceived.[6]

Given success or failure in the first period the entrepreneur updates their expectation about the probability the project is a 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.

[6]Entrepreneurs 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.

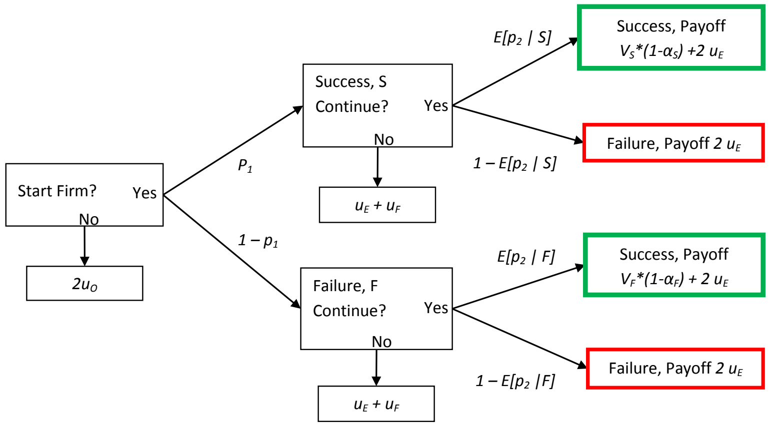

FIGURE 2. EXTENSIVE FORM REPRESENTATION OF THE ENTREPRENEUR'S GAME TREE

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. An investor who commits is assumed to face of cost of c if they fail to fund the project in the second period.[7] Negotiations will result in a final fraction owned by the entrepreneur if the first period was a success of $1 - \alpha_S$, and $1 - \alpha_F$ if the first period was a failure.[8]

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

[7]We assume $c > 1 - X - V_F E[p_2 \mid F]$ to focus on the interesting case when commitment has value.
[8]The entrepreneur could also receive side payments from the investor. This changes no results and so is suppressed.

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 and investment from an investor who commits to being failure tolerant. This failure tolerance encourages innovative effort, 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.

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.

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

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

The question is then – which projects are more likely to be done by a committed or uncommitted investor? The answer depends on whether $\overline{\alpha_{S_A}} - \underline{\alpha_{S_A}} \geq \overline{\alpha_{S_N}} - \underline{\alpha_{S_N}}$. The following proposition demonstrates the three aspects of a project the alter the commitment of the funder.

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

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 lower (X is smaller).*

PROOF:

See Appendix A.vii

The point that an entrepreneur with a larger disutility from early termination will more likely get funding from a committed investor is intuitive and has been discussed above. The other two points relate to the value and cost of 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 valuable experiment. $V_S E[p_2 \mid S] - V_F E[p_2 \mid F]$ is larger if the experiment revealed more about what might happen in the future. In an extreme one might have an experiment that demonstrated nothing, i.e., $V_S E[p_2 \mid S] = V_F E[p_2 \mid F]$. 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 $V_S E[p_2 \mid S]$ would be much larger than $V_F E[p_2 \mid F]$.

Potentially, the experiment could reveal whether or not the project is worthless ($V_S E[p_2 \mid S] - V_F E[p_2 \mid F] = V_S E[p_2 \mid S]$). Thus, $V_S E[p_2 \mid S] - V_F E[p_2 \mid F]$ is the amount or quality of the information revealed by the experiment.[9]

For two projects that have the same expected value, $p_1 V_S E[p_2 \mid S] + (1-p_1) V_F E[p_2 \mid F]$ and the same probability of a successful experiment, p_1 we will refer to the one for which $V_S E[p_2 \mid S] - V_F E[p_2 \mid F]$ is larger as having the more valuable experiment.[10] This yields the following corollary.

COROLLARY 1: *A project with a more valuable experiment is more likely to be funded by an uncommitted investor.*

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

What is then interesting is to consider what happens when 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*

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

[10] We 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 $V_S E[p_2 \mid S] - V_F E[p_2 \mid F]$ is larger *and* the expected value is larger. For example, if $E[p_2 \mid F]$ is always zero, then the only way to increase $V_S E[p_2 \mid S] - V_F E[p_2 \mid F]$ is to increase $V_S E[p_2 \mid S]$. 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.

receive funding from an uncommitted investor.

- *A project is more likely to change funding type, or switch from unfunded to funded, if it has a smaller probability of success in the first stage,* p_1 *or have more valuable experiments*
- *The projects that are now funded have expected values after failure that are too low to have been funded by a committer, but with the drop in cost of the first stage experiment can now be funded by and uncommitted investor.*

PROOF:

See Appendix A.viii

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 valuable experiments and lower probabilities of first stage success, i.e. they have a larger fraction of their value imbedded 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 valuable experiment.

Thus, the prediction that stems from Proposition 3 is 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 valuable 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 perviously 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 valuable experiments. These firms can now get funded in the first period because the price of the option to see the first stage outcome fell.

Figure 3 helps 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.

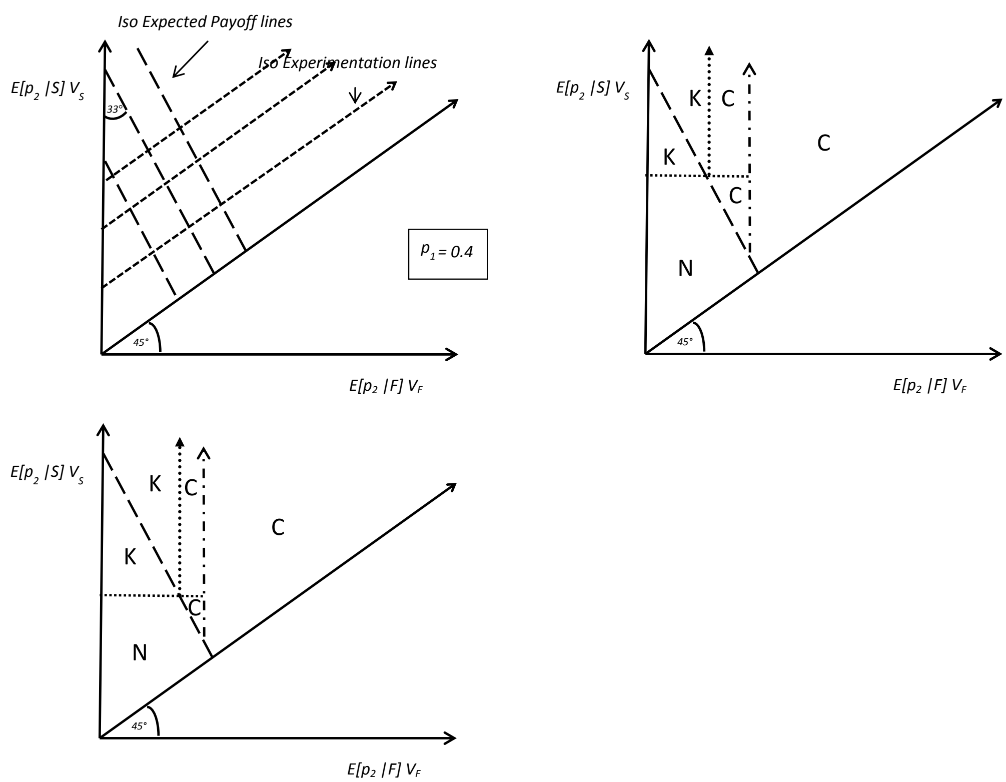

FIGURE 3. INVESTOR REGIONS: N = NO INVESTORS, C = COMMITTED INVESTOR, K = KILLER INVESTOR

In the upper left diagram the small dashed lines that run parallel to the 45° line are Iso Experimentation lines, i.e., along these lines $V_S E[p_2 \mid S] - V_F E[p_2 \mid F]$ is constant.

These projects have an equally valuable experiment. Moving northeast along an Iso Experimentation line increases the project's value without changing the degree to which it is experimental.

The large dashed lines are Iso Expected Payoff lines. These projects have the same ex ante expected payoff, $p_1 V_S E[p_2 \mid S] + (1-p_1) V_F E[p_2 \mid F]$. They have a negative slope that is defined by the probability of success in the first period p_1.[11] Projects to the northwest along an Iso Expected Payoff line are more experimental, but have the same expected value.

In the remaining three diagrams in Figure 3 we see the regions discussed in proposition 1. The large dashed line is defined by equation (A-1). Above this line $\overline{\alpha_{S_A}} - \underline{\alpha_{S_A}} \geq 0$, so 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, or killer, investor the project is stopped after failure in the first period. Thus, the killer investor's expected payoff is independent of $V_F E[p_2 \mid F]$. Therefore, uncommitted investors could invest in all projects above the horizontal dotted line. This line is defined by equation (A-2) because a killer and an entrepreneur can reach an agreement as long as $\overline{\alpha_{S_N}} - \underline{\alpha_{S_N}} \geq 0$. The vertical line with both a dot and dash is the line where $V_F E[p_2 \mid F] = 1 - X$. 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 kill the project, so we focus our attention to the left of this line.[12]

[11]In 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.

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

Finally, the point at which the horizontal dotted line crosses the vertical line with both dots and dashes bifurcates the graph. This line is defined by the points where $\overline{\alpha_{S_A}} - \underline{\alpha_{S_A}} = \overline{\alpha_{S_N}} - \underline{\alpha_{S_N}}$. At points to the left of a vertical 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 each diagram. If the lines cross, as in the upper right diagram, we see six regions. Entrepreneurs with projects with low enough expected values cannot find investors (region N). Those with high enough expected values but projects with more valuable experiments reach agreements with uncommitted or killer investors (this are the K regions). The lower K region is the set of projects that a committed investor would never fund and the upper K region is the set of projects a committed investor could fund but the uncommitted investor creates more value. 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 are projects 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. 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 a killer (region K) if they are more experimental and more likely to be funded only by a committed investor (region C) if they are less experimental.

If the cost of experimentation falls then the horizontal dashed line shifts lower and the vertical dotted line shifts to the right. This demonstrates the effect in proposition 3. The lower horizontal dotted line means the firms now above this line 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 a killer and not by a committed investor.

F. Reputation as a Committed Investor

In our idealized setup an investor can choose to commit or not for each project (this is essentially the assumption of complete contracts). However, one might think that firms cannot easily both commit and terminate early. It could be that some investors are less able to kill a project once started due to organizational, cultural or bias related reasons. For example, Qian and Xu (1998) argue that the inability to stop funding projects is endemic to bureaucratic systems such as large corporations or governments. Alternatively, some investors in new projects are often unable to commit to fund the project in the future even if they desire to make such a commitment. For example, corporations cannot write contracts with themselves and thus always retain the right to terminate a project. Venture capital investors have strong control provisions for many standard incomplete contracting reasons and are unable to give up the power to shut down the firm and return any remaining money if they wish to do so in the future. Thus, even a project that receives full funding in the first period, may be shut down and 1-X returned to investors in period two.

If investors cannot easily both commit and terminate early then they must choose. In which case, if the cost of early experimentation falls there is an opportunity to enter the market as an investor more focused on early termination. Old investors with a more committed reputation could potentially switch to this type of investing but may find it difficult to change their business model. Thus, one would expect that a drop in cost of experimentation would create the opportunity for new investing firms to enter the VC market with a more aggressive style. For a given amount of capital to invest they would invest in more early stage projects with lower expected values, and fund fewer of them at the second stage.

If investors had to choose to be either a killer or a committed investor their portfolios would differ. Consider two specific VCs, one of whom who has chosen to be a killer and the other who is a committed investor. Assume each has $\$Z$ to invest. As 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.

A committed or uncommitted investor who finds an investment must invest X, however, they have a different expectations about the need to invest $1-X$. The committed investor must invest $1-X$ if the first stage experiment fails (because the market will not), and 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. While the uncommitted investor will make at most Z/X investments and expect to make at least $Z/((X+p_1(1-X))$ investments. For all $X < 1$ and $p_1 < 1$, $Z/X > Z/(1-p_1(1-X))$ and $Z/((X+p_1(1-X)) > Z$.

Therefore, we would expect on average for committed investors to take on a smaller number of less experimental projects while the uncommitted investors take on a larger number of more experimental projects. Note that both strategies may be expected to be equally profitable. The committed investors own a larger fraction of fewer projects that are more likely to succeed but have to invest more in them. While uncommitted investors own a smaller fraction of more projects and only invest more when it is profitable to do so. Thus, if X were to fall the new entrants would take on more projects and provide follow on funding to fewer of them.

In summary, if investors cannot be both killers and committers (because commitment takes a reputation as a committer) then then these two approaches will not happen in the same firm. A fall in the cost of the experimentation may lead some investors to switch to having a "guillotine" strategy, while others may stay committed and hence will become more risk average. It will also lead to new funders at the extensive margin with a guillotine strategy – one where they performed cheaper first stage experiments in lower average quality projects with greater experimental value and hence terminated more projects after the initial investment.

III. Data and Estimation Strategy

Our analysis is based on data from Dow Jones VentureSource. This data-set, along with Thompson Venture Economics, forms the basis of most academic papers on venture capital. Research comparing the two databases has noted that Venture Source is less likely to omit deals, a fact that is important when looking at first financings.

The unit of analysis in our data is an investor-startup pair. We focus our analysis on all US-based startups receiving financing between 2001 and 2010. We keep the first instance of an investor-firm pair for these startups, which implies that we have the first financing event for each investor in each startup that was financed over that period. As we describe later, our analyses are also done with subsamples that only include the investor firm pairs in the very first financing for the startup.

In order to get data on founder characteristics, we match a novel database of founders and their backgrounds developed by Ewens and Fons-Rosen (2013) to the startups in our dataset, and build on it using web searches, biographies in Capital IQ, LinkedIn public profiles and information from company websites. As can be seen in Table 1, we do not yet have complete coverage of founder age. Our data coverage corresponds to 4,368 or 12,185 financings. We are in the process of building it up further, including getting data on the entrepreneurs' educational backgrounds and university affiliations to develop a sense of 'pedigree'. A full description of the variables used in the regressions and the detailed industry-level breakdown is outlined in Tables 7 and 8.

A. Hypotheses and Estimation Strategy

Our model generates two sets of testable hypotheses.

The first set of testable hypotheses relate to the fact that if there is a fall in the cost of experimentation, we would expect investors to respond in certain ways that can be measured in terms of their portfolio strategy and the composition of the investments. We use the timing of Amazon's cloud computing services as the technology shock, and therefore compare VCs' investments from 2006-2010 with the investments from 2001-2005, and comparing the pre and post periods for industry segments more impacted by the technology shock with those less impacted by the shock. We refer to industry segments more impacted by the shock as "lean" industries.

$$Y_{jit} = \beta_1 LeanXPost + \beta_2 Z_{jt} + \beta_3 X_i + \rho_j + \gamma_t + \nu_{jit} \tag{1}$$

where ρ_j is the investor fixed effect, Z_{jt} are time-varying investor controls, X_i are entrepreneurial firm characteristics at the time of the investment, including detailed industry segment fixed effects and γ_t are year fixed effects corresponding to the year of the investment. Our main coefficient of interest is the interaction between *Lean* and *Post*. Note that since we have industry segment fixed effects and year fixed effects, the main effects of *Lean* and *Post* are not identified).

The sample of analysis includes all first financings into a startup by each investor between 2001 and 2010 for all investors with at least investment prior to the beginning of the sample and one investment on or after 2010. Thus, the β_1 estimate represents the within-VC dynamics of the dependent variable Y_{jit}. We estimate four different Y_{jit}. Two of the variables correspond to the financing strategy of the VC: the dollars invested by the VC in that round of financing, the probability that the startup will raise another round of financing within two years of the financing event. For both these variables, we expect that β_1 will be negative, as we expect investments in Lean industries in the post period to need less money, but also be less likely to receive follow on financing.

The other two variables correspond to the composition of the VC's portfolio: the average age of the founding team at the time of the investment and a dummy for whether there is a serial entrepreneur in the founding team at the time of the investment. Again, we expect β_1 to be negative, as the model highlights that these are more risky, experimental projects and hence we would expect that on average, they are started by younger teams with less entrepreneurial experience.

The second set of testable hypotheses relate to the heterogeneity of the response by the investors. While on average, the falling cost of experimentation leads to the predictions above, we expect that some VCs may not be able to change their investment strategies. This will leave room for new entrants but will also imply that the VCs who do not shift to taking advantage of the more valuable real options will end up investing in situations where real options are less valuable – that is, for less risky firms and at less risky stages of the startup. We are yet to fully explore these latter set of hypotheses fully, but we do expect that compared to the average incumbent VCs (that are comprised of those that switched and those that didn't) the average new entrant will run their portfolio more more like a guillotine investor.

IV. Results

A. Pre-Post comparison for existing VCs

Table 2 outlines the first set of results outlined in the hypotheses above, where the dependent variable is the log of the amount invested by the VC in the round. Columns 1-4 focus on all first financings while columns 5 and 6 focus on two measures of early stage financing.

Columns 1 and 2 do not include year fixed effects, allowing the coefficient on the Post dummy to be identified. The insignificant result on the Post dummy highlights that although lean industries experienced a strong decline in the financing for a startup (negative coefficient on the interaction between Post and Lean), this was not true for the non-Lean industries. Columns 3 and 4 include add year fixed effects and columns 5 and 6 restrict the sample to only early stage rounds. In each case, the coefficient is stable and suggests about a 10% decline in the capital raised by startups in lean industries in the post period relative to capital raised startups in non-lean industries. Tables 3-5 provide a similar picture. In each of these tables and consistent with the hypotheses outlined above, we seem to find consistent results that VCs are less likely to follow on, and seem to be backing younger and less experienced founding teams. Figures 4 and 5 provide the yearly dynamic specifications for these regressions.

It is worth stressing that all the regressions reported in Tables 2-5 include venture-capital investor fixed effects, fixed effects for 20 industries and round-level fixed effects. These fixed effects are important in ruling out some obvious explanations for the findings. For example, it could be that the results were driven by changes at the extensive margin – where entry by a new set of investors may have led them to invest in a different set of projects and hence impact the average results. While we do find these results (reported in Table 6, below), the results in Tables 2-5 cannot be explained by this because they are restricted to the set of VCs that consistently invested over the period 2001 to 2010 and moreover, the inclusion of VC fixed effects implies that the results are ‘within-VC’ rather than across VC.

Similarly, the results are not being driven by shifts in the types of industries that are more or less active in the post vs. pre period, or variation in that may be driven by more rounds of a certain type being done in the post vs. pre period due to say the number of funds that closed in those years. To the extent that unobserved heterogeneity is driving the results, it would need to be related to the same VCs changing the way they invest in lean industries in the post period through a mechanism not related to the changing cost of experimentation. For example, a pure fall in the cost of running businesses could lead VCs to replicate their portfolio many times but should not necessarily lead them to take on riskier investments with a smaller change of following on a the backing of less experienced teams.

B. Across Investor Heterogeneity

As outlined in the hypothesis section above, our model suggests that a shock to the cost of experimentation could lead to three sets of changes. First, some investors could switch strategies to managing their portfolios with a sharper guillotine. This is the average effect we are found in Tables 2-5. Second, even if on average investors choose to switch as we have found, some investors may not be able to or may not want to switch strategies. The model suggests that the overall set of projects these investors will back could in fact become less risky. Third, since existing investors are a mix of the first and second type, a comparison on new entrants to incumbents will show entrants to be managing their portfolio with a sharper guillotine.

We are still working to establish the heterogeneity in the outcomes along the lines of the second point above, and have some suggestive evidence for the third point in Table 6. In Table 6, we restrict the sample to the post period, and compare the portfolio strategies and characteristics of VCs who had made investments prior to 2006 with the strategies and characteristics of VCs who were raising their first fund in the post period. We seem to find strong evidence that the entrants are different. Although the interactions with the Lean dummy are large and negative, the standard errors are equally large, leading the results to not be statistically significant. We need to do more to establish that this is a robust result and not simply due to differences between new funds and older funds in any time period, versus a particular set of factors that leads new funds between 2006 and 2010 to be different, driven by the fall in the cost of experimentation.

V. Conclusion

The 2000s have been a period of flux for the venture capital industry, driven in part by poor returns and in part by a dramatic fall in the cost of starting new businesses, that has changed the trade-off between the need for failure tolerance and the need for starting a number of new projects and only reinvesting in a few. In particular, a fall in the cost of financing has made it possible for investors in put in a little money into backing more risky and unproven founding teams, but reinvest in a smaller fraction of them. This has the impact of democratizing entry for entrepreneurs, but also means that it increases the rate of churn among startups. Our initial empirical results are consistent with the model – we find that the results are strongest among precisely the industry segments that were most impacted by the technological shock arising from Amazon making its EC2 services available for startups.

Although anecdotal evidence is consistent with the model's prediction that this shock may make VCs more risk averse and lead them to back safer startups, we have not yet found consistent systematic evidence with this view. We are currently working to expand our analyses to look at this aspect of the model in greater detail.

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VI. Figures and Tables

Figure 4. Capital invested in first financings: incumbents

Notes: Figure reports the year fixed effect coefficients from a VC fixed effect (conditional on a "lean" industry) regression where the dependent variable is a dummy for a follow on financing event.

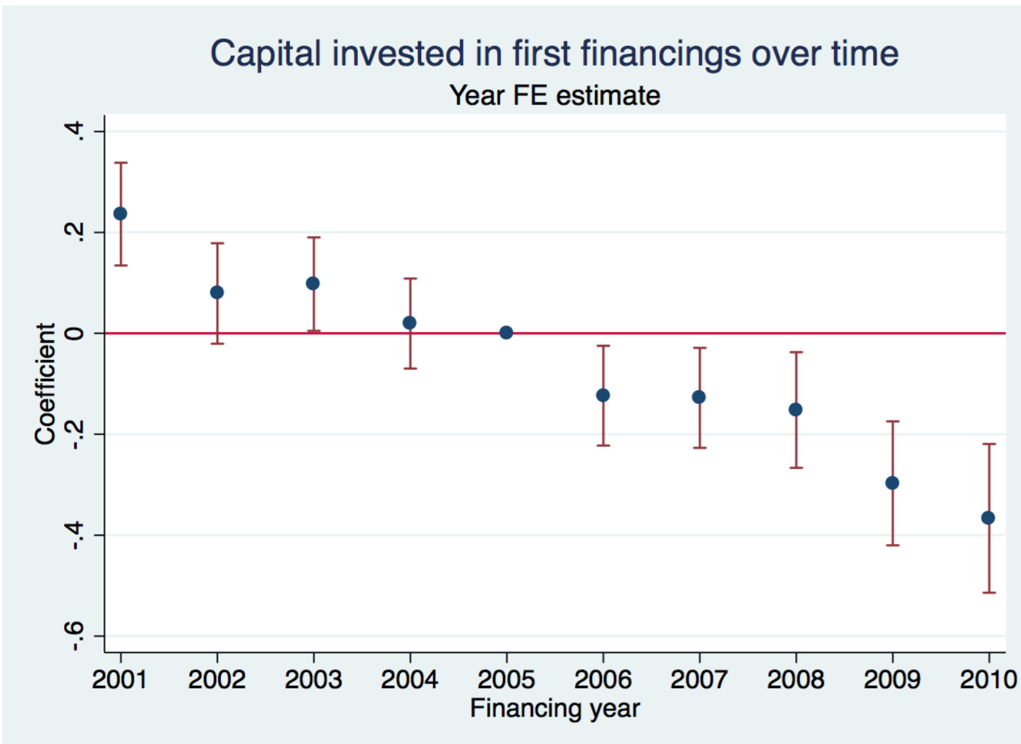

Figure 5. Propensity follow-on: incumbents

Notes: Figure reports the year fixed effect coefficients (conditional on a "lean" industry) from a VC fixed effect regression where the dependent variable is a dummy for a follow on financing event.

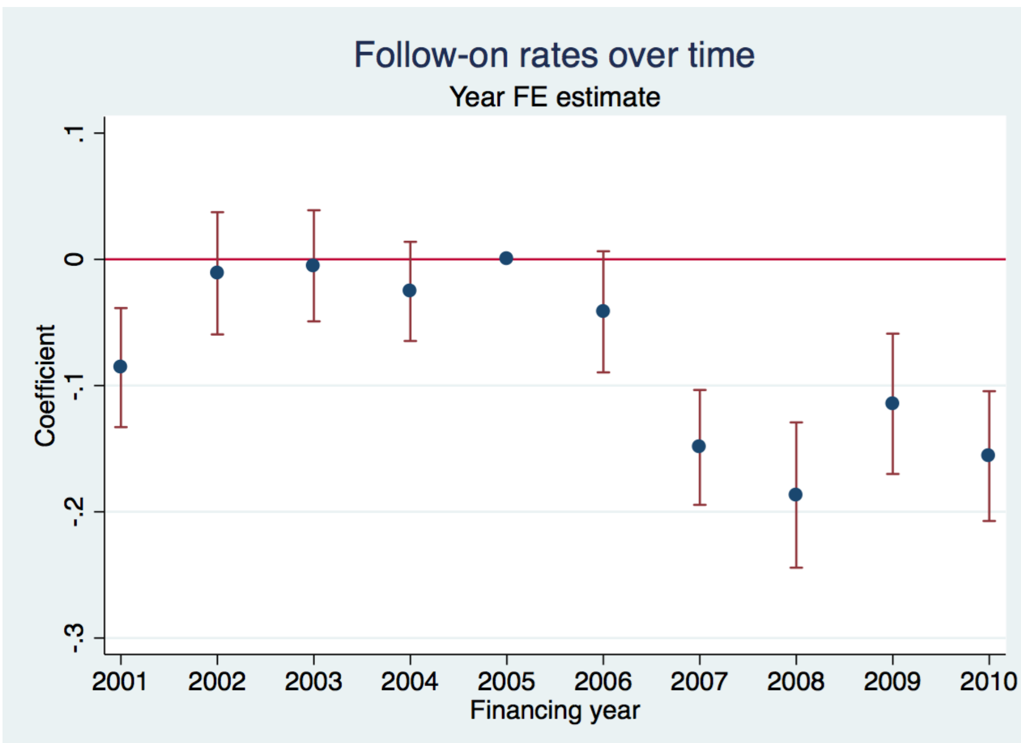

Table 1—Comparing investment behavior of incumbent VCs: 2001 - 2010

Notes: Table compares the investment characteristics of VCs with at least one pre-2005 over time. T-test reports the two-sided results. The founder age at first financings are separated because the sample of VCs differs due to missing data. All variables are defined in Table 7 Significance: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

	Pre-2005	Post-2005	Diff/s.e.
Log capital raised	2.315	1.937	0.377***
			0.0209
Follow on?	0.512	0.475	0.0371***
			0.00951
Serial founder	0.161	0.216	-0.0554***
			0.00734
Observations	7206	4979	12185
Number VCs	397	299	696
Founder age at financing	39.724	37.832	1.8921***
			(.262)
Observations	3071	1297	4368

Table 2—Intensive margin: first capital raised

Notes: Table reports the regression of log capital raised in a VC fixed effects regressions for all first time financings made in an entrepreneurial firm. The columns "All financings" include all investor-financing pairs where the investor is a venture capitalist and active from 2001 - 2010. "Early stage" examines only first time financings by the investor in early stage ("Seed," "Angel," "Series A" and "Bridge") and "First round" only considers the first financing of the entrepreneurial firm by any investor. "All VCs" includes all investors, while "> 25 inv." requires the investor to have at least 25 investments over the sample period. Fixed effects for the VC are included along with dummies for financing year ("Year FE"), industry ("Industry FE", see Table 8) and stage ("Stage FE") which are for first through fourth and greater rounds. "Post-2005" is a dummy for financings on or after 2005, "lean" is a dummy for the subset of industries defined as low-capital above and "Syndicate size" is a count of the number of investors in the financing. "CA/MA/NY" are dummies for the location of the entrepreneurial firm and "Firm age" is the log of the firm age in years at the time of the financing. "VC experience" is the log of total deals done by the investor as of the financing. Standard errors clustered at the VC firm reported in parentheses. Significance: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

	Log first capital raised					
	All financings				Early stage	First round
	All VCs	> 25 inv.	All VCs	> 25 inv.	All VCs	All VCs
Post-2005 X lean	-0.0838**	-0.0979**	-0.0776**	-0.0923**	-0.111**	-0.117*
	(0.0369)	(0.0403)	(0.0362)	(0.0396)	(0.0546)	(0.0608)
Post-2005	0.0173	0.0300				
	(0.0315)	(0.0351)				
CA	-0.0127	-0.0372	-0.0117	-0.0362	-0.0450	-0.0457
	(0.0258)	(0.0286)	(0.0258)	(0.0285)	(0.0423)	(0.0477)
MA	0.00412	-0.00219	0.00680	0.00182	-0.0245	0.0699
	(0.0306)	(0.0337)	(0.0305)	(0.0336)	(0.0501)	(0.0601)
NY	-0.0632	-0.117*	-0.0483	-0.0997	-0.0667	-0.0860
	(0.0567)	(0.0635)	(0.0546)	(0.0612)	(0.0685)	(0.0795)
Syndicate size	0.646***	0.630***	0.646***	0.631***	0.670***	0.710***
	(0.0250)	(0.0278)	(0.0251)	(0.0280)	(0.0342)	(0.0365)
Firm age (yrs. log)	0.121***	0.133***	0.122***	0.135***	0.111***	0.116***
	(0.00976)	(0.0106)	(0.00967)	(0.0105)	(0.0108)	(0.0114)
VC experience (log)	-0.171***	-0.186***	-0.0487	-0.0672	0.0219	0.0138
	(0.0329)	(0.0399)	(0.0415)	(0.0480)	(0.0490)	(0.0550)
Observations	11656	9567	11656	9567	6509	5077
R^2	0.513	0.496	0.518	0.500	0.448	0.452
# VCs	485	237	485	237	464	440
# Firms	6126	5386	6126	5386	4296	3477
# financings	8278	7069	8278	7069	4464	3477
VC FE?	Y	Y	Y	Y	Y	Y
Year FE?	N	N	Y	Y	Y	Y
Industry FE?	Y	Y	Y	Y	Y	Y
Stage FE?	Y	Y	Y	Y	Y	N

Table 3—Intensive margin: follow-on

Notes: Table reports the regression of follow-on propensity in a VC fixed effects regressions for all first time financings made in an entrepreneurial firm. A follow-on financing occurs if a new, non-exit equity or debt financing occurs within 2 years (0 otherwise). The columns "All financings" include all investor-financing pairs where the investor is a venture capitalist and active from 2001 - 2010. "Early stage" examines only first time financings by the investor in early stage ("Seed," "Angel," "Series A" and "Bridge") and "First round" only considers the first financing of the entrepreneurial firm by any investor. "All VCs" includes all investors, while "> 25 inv." requires the investor to have at least 25 investments over the sample period. Fixed effects for the VC are included along with dummies for financing year ("Year FE"), industry ("Industry FE", see Table 8) and stage ("Stage FE") which are for first through fourth and greater rounds. "Post-2005" is a dummy for financings on or after 2005, "lean" is a dummy for the subset of industries defined as low-capital above and "Syndicate size" is a count of the number of investors in the financing. "CA/MA/NY" are dummies for the location of the entrepreneurial firm and "Firm age" is the log of the firm age in years at the time of the financing. "VC experience" is the log of total deals done by the investor as of the financing. Standard errors clustered at the VC firm reported in parentheses. Significance: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

	Follow on?					
	All financings				Early stage	First round
	All VCs	> 25 inv.	All VCs	> 25 inv.	All VCs	All VCs
Post-2005 X lean	-0.0833***	-0.0886***	-0.0762***	-0.0812***	-0.120***	-0.0824**
	(0.0230)	(0.0250)	(0.0231)	(0.0249)	(0.0312)	(0.0360)
Post-2005	-0.0200	-0.00988				
	(0.0174)	(0.0186)				
Capital invested (log)	-0.0123**	-0.0136**	-0.0129**	-0.0144**	-0.0244***	-0.0261***
	(0.00579)	(0.00625)	(0.00572)	(0.00616)	(0.00745)	(0.00799)
Syndicate size	-0.0251**	-0.0302***	-0.0250**	-0.0301***	-0.0254*	-0.0206
	(0.0103)	(0.0112)	(0.0105)	(0.0114)	(0.0146)	(0.0175)
Firm age (yrs. log)	-0.0336***	-0.0316***	-0.0336***	-0.0318***	-0.0219***	-0.0164**
	(0.00487)	(0.00528)	(0.00491)	(0.00533)	(0.00572)	(0.00646)
VC experience (log)	0.00216	-0.0102	-0.0189	-0.0227	0.0281	0.0452
	(0.0167)	(0.0196)	(0.0213)	(0.0252)	(0.0295)	(0.0394)
CA	0.0315**	0.0258*	0.0301**	0.0244*	0.00438	0.00740
	(0.0128)	(0.0138)	(0.0127)	(0.0138)	(0.0184)	(0.0221)
MA	0.0168	0.0107	0.0164	0.00982	0.0107	0.0498*
	(0.0172)	(0.0183)	(0.0169)	(0.0180)	(0.0241)	(0.0282)
NY	0.0721***	0.0828***	0.0719***	0.0827***	0.0535	0.0498
	(0.0278)	(0.0292)	(0.0277)	(0.0290)	(0.0390)	(0.0466)
Observations	10546	8931	10546	8931	5937	4625
R^2	0.095	0.079	0.102	0.086	0.129	0.148
# VCs	384	219	384	219	376	360
# Firms	5874	5256	5874	5256	4078	3272
# financings	7785	6794	7785	6794	4228	3272
VC FE?	Y	Y	Y	Y	Y	Y
Year FE?	N	N	Y	Y	Y	Y
Industry FE?	Y	Y	Y	Y	Y	Y
Stage FE?	Y	Y	Y	Y	Y	N

Table 4—Intensive margin: founder age

Notes: Table reports the regression of founder age (or average founding team age) in a VC fixed effects regressions for all first time financings made in an entrepreneurial firm. Founder age is in years and is as of the first financing associated with the investor. The columns "All financings" include all investor-financing pairs where the investor is a venture capitalist and active from 2001 - 2010. "Early stage" examines only first time financings by the investor in early stage ("Seed," "Angel," "Series A" and "Bridge") and "First round" only considers the first financing of the entrepreneurial firm by any investor. "All VCs" includes all investors, while "> 25 inv." requires the investor to have at least 25 investments over the sample period. Fixed effects for the VC are included along with dummies for financing year ("Year FE"), industry ("Industry FE", see Table 8) and stage ("Stage FE") which are for first through fourth and greater rounds. "Post-2005" is a dummy for financings on or after 2005, "lean" is a dummy for the subset of industries defined as low-capital above and "Syndicate size" is a count of the number of investors in the financing. "CA/MA/NY" are dummies for the location of the entrepreneurial firm and "Firm age" is the log of the firm age in years at the time of the financing. "VC experience" is the log of total deals done by the investor as of the financing. Standard errors clustered at the VC firm reported in parentheses. Significance: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

	Founder age at first financing					
	All financings				Early stage	First round
	All VCs	> 25 inv.	All VCs	> 25 inv.	All VCs	All VCs
Post-2005 X lean	-1.269**	-1.402**	-1.177**	-1.333**	-0.700	-0.761
	(0.533)	(0.561)	(0.541)	(0.569)	(0.709)	(0.802)
Post-2005	0.899**	1.026**				
	(0.445)	(0.471)				
Capital invested (log)	0.717***	0.748***	0.761***	0.794***	0.843***	0.749***
	(0.172)	(0.185)	(0.175)	(0.188)	(0.205)	(0.219)
Syndicate size	0.0527	0.0884	0.126	0.159	0.0239	0.125
	(0.301)	(0.318)	(0.302)	(0.318)	(0.331)	(0.362)
Firm age (yrs. log)	0.407***	0.353***	0.366***	0.310**	0.204	0.192
	(0.125)	(0.130)	(0.122)	(0.126)	(0.135)	(0.142)
VC experience (log)	1.729***	1.875***	0.517	0.731	0.101	0.0245
	(0.433)	(0.490)	(0.547)	(0.607)	(0.619)	(0.641)
CA	-0.852**	-0.893**	-0.867**	-0.918**	-1.340***	-1.155**
	(0.347)	(0.355)	(0.352)	(0.360)	(0.459)	(0.511)
MA	-0.0802	-0.0133	-0.167	-0.0899	-0.394	-0.484
	(0.501)	(0.512)	(0.501)	(0.511)	(0.656)	(0.761)
NY	-2.916***	-2.750***	-2.905***	-2.747***	-3.207***	-2.749***
	(0.525)	(0.510)	(0.523)	(0.509)	(0.724)	(0.822)
Observations	3804	3324	3804	3324	2723	2320
R^2	0.248	0.221	0.252	0.226	0.278	0.279
# VCs	356	217	356	217	335	313
# Firms	2103	1935	2103	1935	1867	1628
# financings	2859	2561	2859	2561	1935	1628
VC FE?	Y	Y	Y	Y	Y	Y
Year FE?	N	N	Y	Y	Y	Y
Industry FE?	Y	Y	Y	Y	Y	Y
Stage FE?	Y	Y	Y	Y	Y	N

Table 5—Intensive margin: serial entrepreneur

Notes: Table reports the regression of a dummy for at least one serial entrepreneur in a VC fixed effects regressions for all first time financings made in an entrepreneurial firm. The dependent variable is 1 if at least one of the founders have previous founding experience. The columns "All financings" include all investor-financing pairs where the investor is a venture capitalist and active from 2001 - 2010. "Early stage" examines only first time financings by the investor in early stage ("Seed," "Angel," "Series A" and "Bridge") and "First round" only considers the first financing of the entrepreneurial firm by any investor. "All VCs" includes all investors, while "> 25 inv." requires the investor to have at least 25 investments over the sample period. Fixed effects for the VC are included along with dummies for financing year ("Year FE"), industry ("Industry FE", see Table 8) and stage ("Stage FE") which are for first through fourth and greater rounds. "Post-2005" is a dummy for financings on or after 2005, "lean" is a dummy for the subset of industries defined as low-capital above and "Syndicate size" is a count of the number of investors in the financing. "CA/MA/NY" are dummies for the location of the entrepreneurial firm and "Firm age" is the log of the firm age in years at the time of the financing. "VC experience" is the log of total deals done by the investor as of the financing. Standard errors clustered at the VC firm reported in parentheses. Significance: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

	Serial entrepreneur?					
	All financings				Early stage	First round
	All VCs	> 25 inv.	All VCs	> 25 inv.	All VCs	All VCs
Post-2005 X lean	-0.0592***	-0.0620***	-0.0519***	-0.0545***	-0.0543**	-0.0521*
	(0.0164)	(0.0176)	(0.0161)	(0.0171)	(0.0237)	(0.0290)
Post-2005	0.0139	0.0204				
	(0.0139)	(0.0149)				
Capital invested (log)	0.00914**	0.0122**	0.00801*	0.0109**	0.00443	0.00500
	(0.00455)	(0.00498)	(0.00453)	(0.00494)	(0.00655)	(0.00751)
Syndicate size	0.0254***	0.0232**	0.0280***	0.0263***	0.0216*	0.0307**
	(0.00826)	(0.00923)	(0.00825)	(0.00924)	(0.0120)	(0.0146)
Firm age (yrs. log)	-0.0481***	-0.0488***	-0.0489***	-0.0497***	-0.0373***	-0.0355***
	(0.00424)	(0.00460)	(0.00429)	(0.00465)	(0.00503)	(0.00556)
VC experience (log)	0.0612***	0.0546***	0.00147	-0.00518	0.0363	0.0299
	(0.0131)	(0.0156)	(0.0150)	(0.0178)	(0.0231)	(0.0268)
CA	0.0581***	0.0617***	0.0566***	0.0602***	0.0550***	0.0751***
	(0.0117)	(0.0127)	(0.0117)	(0.0128)	(0.0176)	(0.0216)
MA	0.0217	0.0301	0.0218	0.0294	0.0251	0.0462
	(0.0166)	(0.0183)	(0.0166)	(0.0183)	(0.0235)	(0.0296)
NY	0.0314	0.0211	0.0307	0.0204	0.0233	0.0127
	(0.0202)	(0.0218)	(0.0205)	(0.0221)	(0.0266)	(0.0352)
Observations	10546	8931	10546	8931	5937	4625
R^2	0.108	0.099	0.114	0.105	0.120	0.129
# VCs	384	219	384	219	376	360
# Firms	5874	5256	5874	5256	4078	3272
# financings	7785	6794	7785	6794	4228	3272
VC FE?	Y	Y	Y	Y	Y	Y
Year FE?	N	N	Y	Y	Y	Y
Industry FE?	Y	Y	Y	Y	Y	Y
Stage FE?	Y	Y	Y	Y	Y	N

Table 6—Extensive margin: differences in incumbents and entrants

Notes: Table reports cross-sectional regressions of the same dependent variables in Tables 2-5 where a unit of observation is a VC and early stage first financing between 2005 and 2010. "All new entrants" is 1 if all the investors in a financing syndicate entered the market on or after 2005. "Lean" is as defined above and "Capital invested (log)" is the total capital provided by the specific VC in the syndicate. All other controls are as defined in Table 2. "Round type FE" are fixed effects for the round classifications "Seed," "Angel," "Series A" and "Bridge." Standard errors clustered at the VC firm reported in parentheses. Significance: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

	Log raised	Log raised	Follow-on?	Follow-on?	Founder age	Founder age	Serial?	Serial?
All new entrants	-0.582***	-0.511***	-0.0792***	-0.0558*	-0.680	-0.0375	-0.0494***	-0.0486**
	(0.0704)	(0.0866)	(0.0240)	(0.0300)	(0.484)	(0.682)	(0.0141)	(0.0218)
All entrants X lean		-0.135		-0.0446		-1.146		-0.00160
		(0.0856)		(0.0317)		(0.705)		(0.0281)
Capital invested (log)			0.0130**	0.0127*	1.121***	1.103***	0.0188***	0.0187***
			(0.00649)	(0.00650)	(0.174)	(0.174)	(0.00535)	(0.00536)
Firm age (yrs. log)	0.0352***	0.0349***	-0.0293***	-0.0294***	0.281**	0.281**	-0.0310***	-0.0310***
	(0.0112)	(0.0112)	(0.00507)	(0.00507)	(0.130)	(0.129)	(0.00442)	(0.00442)
Syndicate size	0.583***	0.583***	0.0302**	0.0301**	0.891***	0.891***	0.0307**	0.0307**
	(0.0387)	(0.0387)	(0.0153)	(0.0153)	(0.326)	(0.327)	(0.0125)	(0.0125)
CA	0.259***	0.258***	0.0458***	0.0458***	-1.405***	-1.409***	0.0737***	0.0737***
	(0.0557)	(0.0557)	(0.0176)	(0.0176)	(0.396)	(0.396)	(0.0142)	(0.0142)
MA	0.303***	0.302***	0.0559**	0.0556**	-0.302	-0.324	0.0517**	0.0517**
	(0.0705)	(0.0701)	(0.0246)	(0.0247)	(0.619)	(0.620)	(0.0233)	(0.0233)
NY	0.198***	0.196***	0.0663**	0.0657**	-2.742***	-2.766***	0.0311	0.0311
	(0.0671)	(0.0673)	(0.0308)	(0.0309)	(0.589)	(0.591)	(0.0213)	(0.0213)
Observations	4856	4856	4845	4845	2463	2463	4845	4845
R^2	0.456	0.457	0.049	0.049	0.173	0.174	0.035	0.035
# VCs	860	860	860	860	622	622	860	860
# Firms	3157	3157	3153	3153	1580	1580	3153	3153
# financings	3157	3157	3153	3153	1580	1580	3153	3153
VC FE?	N	N	N	N	N	N	N	N
Year FE?	Y	Y	Y	Y	Y	Y	Y	Y
Industry FE?	Y	Y	Y	Y	Y	Y	Y	Y
Round type FE?	Y	Y	Y	Y	Y	Y	Y	Y

VII. Additional tables

Table 7—Variable description

Notes: Table describes the variables used in the analysis throughout the paper.

Variable	Definition
Follow on	Dummy variable equal to one of the current financing had a subsequent non-exit capital infusion within two years. For the VC-level regressions, the variable is one if the VC investor in the financing participated in the subsequent non-exit financing.
Serial founder	Dummy variable equal to one if the founder of the current firm was ever observed as founder prior to the current firm founding.
Log first K	The log of the capital raised in the first early stage financing.
Pre-2005 VCs?	A dummy equal to one if the financing has all (or none) VCs who have at least one pre-2005 investment.
Financing year	The year of the first early stage financing of the entrepreneurial firm.
Syndicate size	The total number of investors or angel groups associated with the financing
Firm age at first financing	Age in years of the entrepreneurial firm at its first financing event.
Log total VC experience	The log of the total investments made by the VC as of the financing event. For the main empirical analysis comparing pre- and post-2005 VCs, this number is normalized within each group by the average experience (then logged).
Founder age	The age of the founder at either firm founding or the firm's first financing (if available). For founding teams, the number reports the average age across co-founders.
CA/MA/NY	State fixed effects for California, Massachusetts and New York.
Lean?	A dummy variable equal to one if the entrepreneurial firm's industry is in one of the "lean" industries: "Business Support Service," "Consumer Information Services," "Financial Institutions and Services," "Healthcare Services," "Media and Content," "Medical Software and Information Services," "Software," and "Travel and Leisure."

Table 8—Industry classifications

Notes: Table lists the twenty industry classifications in VentureSource that are the levels for industry controls used in the paper.

Classification
Biopharmaceuticals
Business Support Services
Communications and Networking
Construction and Civil Engineering
Consumer Information Services
Electronics and Computer Hardware
Financial Institutions and Services
Food and Beverage
Healthcare Services
Household and Office Goods
Media and Content
Medical Devices and Equipment
Medical Software and Information Serv.
Personal Goods
Retailers
Semiconductors
Software
Travel and Leisure
Vehicles and Parts
Wholesale Trade and Shipping

Appendix for "Entrepreneurship and the Cost of Experimentation"

A. Appendix

i. *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

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

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

$$\underline{\alpha_{2S}} = \frac{1 - X}{V_S E[p_2 \mid S]}.$$

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

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

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

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

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

$$1 \geq \underline{\alpha_{2S}} \leq \overline{\alpha_{2S}} \geq 0 \qquad \textit{Agreement Conditions}, \ \ 2^{nd} \textit{period}$$

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, $\overline{\alpha_{2S}} \geq 0$.[1]

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 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 1: *The minimum total fraction the investor must receive is*

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

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

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

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

See appendix A.iv 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.

[1] If 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 $0 \leq \alpha_{2j} \leq 1$ otherwise it is bounded by 0 or 1.

PROPOSITION 2: *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*

$$\underline{\alpha_{2S}} = \frac{1 - X}{V_S E[p_2 \mid S]}.$$

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

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

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

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

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

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

The proof is in appendix A.iii. 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 $\overline{\alpha_{2F}} - \underline{\alpha_{2F}} \geq 0$.

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

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

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

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

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

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

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

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

The proof is in A.iv, 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

$$1 \geq \underline{\alpha_{S_i}} \leq \overline{\alpha_{S_i}} \geq 0 \qquad \textit{Agreement Conditions}, \quad 1^{st} \textit{ period},$$

either with our 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.

ii. 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 with 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

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

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

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

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.vi. 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 and 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.

iii. Proof of Proposition 2

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

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

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

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

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 that accept a smaller fraction. If $V_j E[p_2 \mid j] > (1-X)$ (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

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

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

$$\underline{\alpha_{2S}} = \frac{1-X}{V_S E[p_2 \mid S]}.$$

However, after failure in the first period then $V_F E[p_2 \mid F] < 1-X$ 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

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

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

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

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

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

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:

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

Thus, the correct maximum fraction the entrepreneur will give up in the second period after success in the first period is[3]

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

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

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

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.

[2]This 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.

[3]This 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.

iv. *Proof of Propositions 1 and 3*

Bargaining will result in a fraction in the second period of $\alpha_{2j} = \gamma\underline{\alpha_{2j}} + (1-\gamma)\overline{\alpha_{2j}}$. 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

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

and α_F reduces to

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

Of course, in both cases negotiations must result in a fraction between zero and one.[4] Note that α_F does not depend on the negotiations in the first period because after failure, renegotiation determines the final fractions.[5] Of course, investors and entrepreneurs will account for this in the first period when they decide whether or not to participate.[6] We solve for the first period fractions in appendix A.v 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

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

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

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

if they are not.

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

[5] In 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.

[6] Alternatively 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 entrepreneur will choose to innovate and start the project if

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

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

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

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 the inequality holds:

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

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:

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

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

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

and

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

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

v. Derivation of first period fractions

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

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

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,

$$\underline{\alpha_{1_A}} = 1 - \frac{p_1 V_S E[p_2 \mid S] - p_1(1-X) - X - (1-p_1)\gamma c}{p_1(\gamma V_S E[p_2 \mid S] - \gamma(1-X) + (1-\gamma)(u_F - u_E))} - \frac{(1-p_1)(1-\gamma)(V_F E[p_2 \mid F] - (1-X) - (u_F - u_E))}{p_1(\gamma V_S E[p_2 \mid S] - \gamma(1-X) + (1-\gamma)(u_F - u_E))}$$

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.[7] 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 $\underline{\alpha_{S_N}}$ into equation (A-9) for α_S, where $\underline{\alpha_{S_N}}$ is the minimum when no second period deal can be reached. In this case the minimum required investor fraction $\underline{\alpha_{1_N}}$ is

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

or,

$$\underline{\alpha_{1_N}} = 1 - \frac{p_1 V_S E[p_2 \mid S] - p_1(1-X) - X}{p_1(\gamma V_S E[p_2 \mid S] - \gamma(1-X) + (1-\gamma)(u_F - u_E))}$$

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

[7]Technical 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.

reached $\overline{\alpha_{1_A}}$ is

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

And when a second period deal after failure cannot be reached $\overline{\alpha_{1_N}}$ is

$$\overline{\alpha_{1_N}} = 1 - \frac{(1+p_1)(u_O - u_E) + (1-p_1)(u_O - u_F)}{p_1(\gamma V_S E[p_2 \mid S] - \gamma(1-X) + (1-\gamma)(u_F - u_E))}$$

vi. Proof of Proposition 1:

It is clearly possible that both $\overline{\alpha_{S_A}} - \underline{\alpha_{S_A}} < 0$ and $\overline{\alpha_{S_N}} - \underline{\alpha_{S_N}} < 0$. 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 $\overline{\alpha_{S_A}} - \underline{\alpha_{S_A}} > 0$ and $\overline{\alpha_{S_N}} - \underline{\alpha_{S_N}} > 0$, 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.

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

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

Equation (A-10) may be positive or negative depending on the relative magnitudes of $V_F E[p_2 \mid F]$, 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 ($V_F E[p_2 \mid F]$ is small) are more likely to be done by an uncommitted investor. QED

vii. 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 $V_F E[p_2 \mid F]$ 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, $p_1 V_S E[p_2 \mid S] + (1-p_1)V_F E[p_2 \mid F]$, and same probability of a successful experiment, p_1, but a more valuable experiment ($V_S E[p_2 \mid S] - V_F E[p_2 \mid F]$ is larger) then $V_F E[p_2 \mid F]$ must be smaller. QED

viii. 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

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

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 $V_F E[p_2 \mid F]$ for a committer to win. Thus, the projects that switch will be those with lower $V_F E[p_2 \mid F]$. For a given expected value if $V_F E[p_2 \mid F]$ is smaller then $V_S E[p_2 \mid S]$ must be larger and $V_S E[p_2 \mid S] - V_F E[p_2 \mid F]$ is larger so the project has a more valuable experiment.

A project will be funded by an uncommitted investor rather than no investor if

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

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 $V_S E[p_2 \mid S]$ 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 $V_F E[p_2 \mid F]$. 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

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

QED

B. References

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