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Past work has shown that failure tolerance by principals has the potential to stimulate innovation, but has not examined how this affects which projects principals will start. We demonstrate that failure tolerance has an equilibrium price — in terms of an investor's required share of equity — that increases in the level of radical innovation. Financiers with investment strategies that tolerate early failure will endogenously choose to fund less *radical innovations, while the most radical innovations (for whom the price of failure tolerance is too high) can only be started by investors who are* not *failure tolerant. Since policies to stimulate innovation must often be set before specific investments in innovative projects are made, this creates a tradeoff between a policy that encourages experimentation ex-post and one that funds experimental projects ex-ante. In equilibrium it is possible that all competing financiers choose to offer failure tolerant contracts to attract entrepreneurs, leaving no capital to fund the most radical, experimental projects in the economy. The impact of different innovation policies can help to explain who finances radical innovations, and when and where radical innovation occurs.*

Keywords: Financing Innovation, Failure Tolerance, Abandonment Options

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Innovation Policies

Investors, corporations and even governments who fund innovation must decide which projects to finance and when to withdraw their funding. A key insight from recent work is that a tolerance for failure may be important for innovation as it makes agents more willing to undertake exploratory projects that lead to innovation (Holmstrom, 1989; Aghion and Tirole, 1994; Manso, 2011). A number of empirical papers consider the impact of policies that reduce managerial myopia and allow managers to focus on long-run innovation (Burkart, Gromb and Panunzi, 1997; Myers, 2000; Acharya and Subramanian, 2009; Ferreira, Manso and Silva, 2011; Aghion, Reenen and Zingales, 2009).

Interestingly, however, many of the great innovations of our time have been commercialized by new ventures that are backed by venture capital investors, who tend to be remarkably intolerant of early failure (Hall and Woodward, 2010). For example, Kerr, Nanda and Rhodes-Kropf (2013) note that over the last 30 years, about 55% of startups that received VC funding were terminated at a loss, most often after early experimentation yielded negative information. Furthermore, Gompers and Lerner (2004) document the myriad control rights negotiated in standard venture capital contracts that allow investors to fire management and/or abandon the project (see also Sahlman (1990) and Hellmann (1998)). In fact, Hellmann and Puri (2002) and Kaplan, Sensoy and Stromberg (2009) show that even among firms that are 'successful', many end up with CEOs who are different from the founders.

How do we reconcile the fact that such radical innovations are commercialized by venture capital if failure tolerance is so important for innovation? In this paper, we propose a new way to think about failure tolerance that is related to, but distinct from prior work. Past work has considered the effect of failure tolerance on a particular project/agent and demonstrated the trade-off between an increased willingness to experiment at the cost of reduced effort. We consider the *selection* of projects by a more or less failure tolerant investor whose policy towards failure tolerance is is applied to all projects in a portfolio. We show how principals' innovation policies impact the types of projects they are willing to finance, and how in turn this may impact the nature of aggregate innovation that will be undertaken across different types of investing firms and regions.

Our alternate approach is relevant because the optimal level of failure tolerance varies from project to project, yet, in many if not most instances, a project-by-project optimization is not feasible for a principal engaged in funding innovation. For example, a government looking to stimulate innovation may pass laws making it harder to fire employees. This level of 'failure tolerance' will apply to all employees, regardless of the projects they are working on. Similarly, organizational structures, organizational culture, or a desire by investors to build a consistent reputation as entrepreneur friendly all result in firm-level policies towards failure tolerance. Put differently, the principal often has an 'innovation policy' that is set ex ante—one that is a blanket policy that covers all projects in the principal's portfolio. This policy may not be optimal for all projects and may affect which projects end up in the portfolio.

We therefore depart from the prior literature that has looked at the optimal solution for individual projects, and instead consider the ex ante strategic choice of a firm, investor or government looking to promote innovation but whose innovation policy applies to all its projects. Doing so highlights a central trade-off faced by principals when they pick their innovation policy. A policy that is more failure tolerant may encourage the agent to explore, but simultaneously destroys the value of the real option to abandon the project. In the real options literature (Gompers, 1995; Bergemann and Hege, 2005; Bergemann, Hege and Peng, 2008), innovation is achieved through experimentation – several novel ideas can be tried and only those that continue to produce positive information continue to receive funding. This idea has motivated the current thrust by several venture capital investors to fund the creation of a "minimum viable product" in order to test new entrepreneurial ideas as quickly and cheaply as possible, to "shut down failing projects fast and cheap", and only commit greater resources to improve the product after seeing early success.

Thus, a failure tolerant policy increases the entrepreneur's willingness to experiment but decreases the investors' willingness to fund experimentation. This is because, in equilibrium, failure tolerance has a price in the form of higher equity share for the failure tolerant investor. Failure tolerant investors, who must keep funding projects after bad news, must get a higher payoff after good news than an investor who was not failure tolerant and able to cut their losses. Entrepreneurs with projects involving potentially radical innovations, where the value of abandonment options are typically high, may be unwilling or unable to pay a high enough share to attract a failure tolerant investor. Thus, financiers who are more tolerant of early failure endogenously fund more incremental innovations, and the most radical innovations are either not funded at all, or are endogenously funded by financiers who have a sharp financial guillotine. In fact, we show that principals have to be careful, since a failure tolerant strategy meant to encourage innovation may have exactly the opposite effect than the one desired.

Thus, we predict that although failure tolerance can encourage incremental innovation, the most radical innovations in the economy will be funded by financiers with relatively limited failure tolerance, such as venture capitalists. Our model also demonstrates that some radical innovations can only be commercialized by principals who are not concerned with making NPV positive investments, such as for example, universities and government funded initiatives like the manhattan project or the lunar landing.

We then extend this idea to allow competing funders of innovation to set policies before they compete. We demonstrate that an equilibrium can arise in which *all* competing financiers choose to be failure tolerant in the attempt to attract entrepreneurs and thus no capital is available to fund the most radical innovations, even if there are entrepreneurs who want to find financing for such projects. Our model therefore highlights that the type of innovation undertaken in an economy may depend critically on the institutions that either facilitate or hinder the ability to terminate projects at an intermediate stage. The institutional funding environment for innovation is an endogenous equilibrium outcome that may result in places or times with no investors able to fund radical innovation. When this occurs, positive net present value but experimental projects will not be funded even though entrepreneurs are willing to start the firm.

This paper is related to prior work examining the role of principal agent relationships in the innovation process (e.g. Holmstrom (1989), Aghion and Tirole (1994), Hellmann and Thiele (2011) and Manso (2011)) as well as how the principle agent problem influences the decision to stop funding projects (e.g. Bergemann and Hege (2005), Cornelli and Yosha (2003) and Hellmann (1998)). We combine ideas from both literatures by considering the type of project an investor is willing to fund given their 'policy' (either chosen or due to inherent ability or culture) to end projects at an intermediate stage. A recent group of empirical papers has looked for and found a positive effect of failure tolerance on the intensive margin (e.g. Lerner and Wulf (2007), Azoulay, Zivin and Manso (2011), Acharya and Subramanian (2009), Ferreira, Manso and Silva (2011), Tian and Wang (2012)). Our ideas are consistent with these findings, although different from past theoretical work, as our point is that strategies that reduce short term accountability and thus encourage innovation on the intensive margin may *simultaneously* alter what financial backers are willing to fund, and thus reduce innovation at the extensive margin. Since previous empirical work has looked at the intensive margin, examining this latter effect seems to be a fruitful avenue for further empirical research. Our work is also related to research examining how organizational structure can have an impact on the ability and willingness of organizations to pursue radical innovations (March, 1991; Henderson, 1993; Henderson and Clark, 1990; Qian and Xu, 1998). Our model highlights the role of organizations as financiers of innovation and points to the fact that some of the documented drivers of incremental innovation in large corporations – such as bureaucratic institutions or soft budget constraints – can reinforce a tendency towards incremental innovation through effects at the extensive margin. This is because the inability to effective terminate exploratory projects that provide negative intermediate information can lead such firms to only finance exploratory projects that are more incremental in nature.

The tradeoff we explore also has implications for a wider array of situations than just R&D. In the context of a board choosing a CEO (or an academic institution deciding the length of the initial contract for new professors), the intuition presented here suggests that boards that provide long-term contracts with more tolerance for failure may find that they then choose a more experienced CEO who is a more known commodity. A board that makes it easy to fire the CEO is more likely to experiment by hiring a younger, less experienced CEO whose quality is less certain but whose potential may be great. Thus, the same result occurs in this context - the desire to alter the intensive margin to encourage experimentation alters the extensive margin on the willingness to select a more unconventional leader.

While our paper is theoretical in nature, we believe that it provides a number of potential empirical tests that will provide a more nuanced view on the role of failure tolerance for innovation. For example, recent work by Ewens and Fons-Rosen (2013) and Cerqueiro et al. (2013) have found initial support for the the idea that failure tolerance may encourage innovation at the intensive margin but discourage it at the extensive margin. Relatedly, case studies of corporate R&D have noted the importance of processes for "selecting, experimenting, funding and terminating new growth businesses" (Garvin and Levesque, 2005). Future work could provide a systematic analysis of a policy change at a corporation that becomes less failure tolerant and examine how this impacts project selection at the extensive margin. Our model would suggest that the policy of becoming less failure tolerant would allow corporations to start or select more novel projects.

The remainder of the paper is organized as follows. Section I develops a model of investing in innovative projects from both the financier's and entrepreneur's point of view. Section II solves for the deal between the financier and entrepreneur for different types of projects and levels of commitment. Section III endogenizes the choice of failure tolerance by the investor and determines the potential equilibria and how they depend on the the view of early failure in the labor market and by the entrepreneur. Section IV concludes.

I. 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.

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).[1] We build on this work by altering features of the problem to explore an important dimension in the decision to fund innovation.

[1]See Bergemann and Valimaki (2006) for a review of the economics literature on bandit problems.

A. Investor View

We model investment under uncertainty. A penniless entrepreneur seeks funding from investors for a risky project that requires capital for two periods or stages. The first stage of the project reveals information about the probability of success in the second stage.[2] The probability of 'success' (positive information) in the first stage is p_1 and reveals 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.[3]

The project requires capital X to complete the first stage of the project and Y to complete the second stage. The entrepreneur is assumed to have no capital while the investor has 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) on either X, Y or both. 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

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

[3]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).

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

We initially assume limited commitment, where the principal and the agent may agree on and bind themselves to short-term (one period) contracts, but cannot commit themselves to any future contracts. 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 (both X and Y) in the first period, may be shut down and Y returned to investors in period two.

Prior work has assumed an idealized investor who can write long-term contracts allowing them to commit to some projects and not to others. Our departure from this work allows us to compare investors who can never commit to committed investors introduced in the next section. This feature of our model creates a trade-off at the strategy decision level rather than a project by project choice.

We will demonstrate that the equilibrium share of the payoff owned by the investor in the final period, assuming an agreement can be reached for investment in both periods, depends on the outcome of the first period. 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. Remember that by choosing not to invest in the project in either period the investor earns a return of r per period on the money he does not invest in the risky project. We assume investors make all decisions to maximize net present value (which is equivalent to maximizing end of second period wealth).

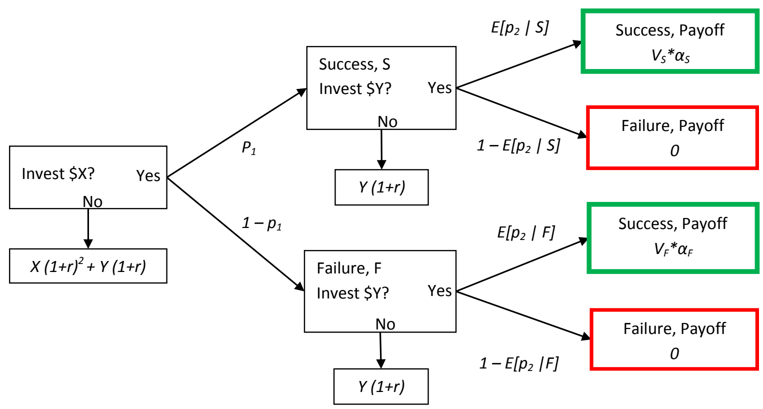

Figure 1. Extensive Form Representation of the Investor's Game Tree

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 and Y. Assuming that an investor chooses to fund the first period of required investment, the potential entrepreneur must choose whether or not to become 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 in both periods.[4]

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.[5]

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.

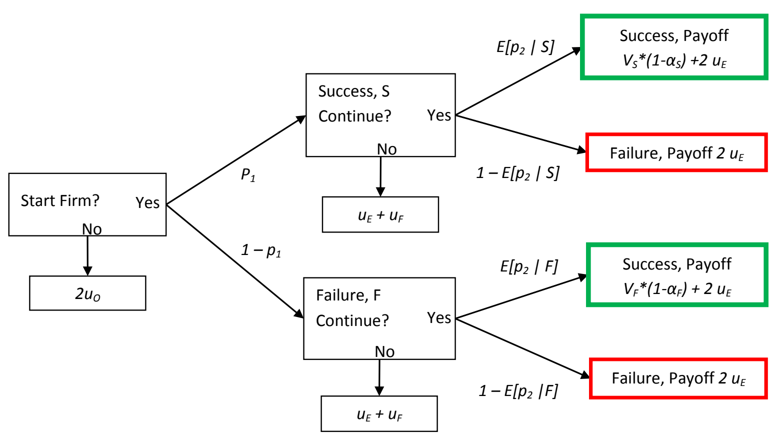

Figure 2. Extensive Form Representation of the Entrepreneur's Game Tree

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

[5]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.

II. The Deal Between the Entrepreneur and Investor

In this section we determine when the entrepreneur and investors will be able to find an acceptable deal. We do so by determining the minimum share both the entrepreneur and investor must own in order to choose to start the project.

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 full derivation of the final fractions owned under commitment and no commitment are shown in Appendix A. Here we provide the basic intuition of the results.

Note that conditional on a given α_1 the investor will invest in the second period as long as

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

This condition does not hold after failure even if $\alpha_F = 1$, therefore the investor will only invest after success in the first period.

We next introduce the notion of being failure tolerant by noting that under the assumption of incomplete contracts, there is potential value to an investor of a reputation as 'entrepreneurial friendly' or 'committed', who might then find it costly to shut down a project in the second period. For example, some venture capital investors have a reputation for being 'quick on the trigger' - a terminology that is used among the venture capital and entrepreneurial community and corresponds to empirical evidence on differences across VCs in exercising abandonment options (Guler, 2007). Relatedly, other VCs spend considerable effort on developing a reputation for being 'founder friendly', making strong statements such as their having never replaced a founder. An alternative way to conceptualize our notion of failure tolerance is that in the real world, all the requisite information from an experiment is rarely revealed in one instance. Rather, information sometimes trickles in, with many things going well but others going poorly. Variations across principals in how they treat these signals - whether they are quick to shut down or not - can also be thought of in our context as variation in failure tolerance. In this subsection we examine investors with an assumed (reputation) cost of early shutdown of c. Then in section III we allow investors to choose whether or not to have a committed reputation. We define a 'committed' investor as follows.

DEFINITION 1: *A committed investor has a* $c > c^* = Y(1+r) - V_F E[p_2 \mid F]$

With this definition we find the following lemma.

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

See Appendix C for proof. This lemma makes it clear that only a 'committed' investor will continue to fund the company after failure because $V_F E[p_2 \mid F] - Y(1+r) < 0$.[6]

Note that since an investor will need to take a larger share of the firm in a good state to make it worthwhile to continue investing after failure, the types of projects that can be funded with or without a committed investor are potentially different. We can, therefore, use the above inequalities to determine what types of projects actually can be started and the effects of failure tolerance and a sharp guillotine.

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

1) the project can only be started if the investor is committed,

[6]Furthermore, at $c = Y(1+r)$, the committed investor will continue to fund after failure since $V_F E[p_2 \mid F] > 0$. Thus, there is some c such that the investor is committed.

2) the project can only be started if the investor has a sharp guillotine (is uncommitted),

3) the project can be started with either a committed or uncommitted investor,

4) the project cannot be started.

The proof is left to Appendix C.iv. Proposition 1 demonstrates the potential for a tradeoff between failure tolerance and the launching of a new venture. While the potential entrepreneur would be more likely to choose to innovate with a committed investor, the commitment comes at the price of giving up a higher share of equity to the committed investor. For some projects and potential entrepreneurs that price is so high (or conversely their expected return from the lower share is so low) that they would rather not become an entrepreneur. For others, they would still choose the experimental path, but just not with a committed investor. That is, the monetary benefit they get from matching with an uncommitted investor outweighs their utility loss from possible early termination of the project. Thus, when we include the equilibrium cost of failure tolerance we see that it has the potential to both increase the probability that a potential entrepreneur chooses the innovative path and decrease it.

Essentially the utility of the potential entrepreneur can be enhanced (and innovation encouraged) 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 potential entrepreneur will choose the innovative path. This is the Manso (2011) intuition but at the extensive margin. Rather than encouraging innovative effort, in our set up failure tolerance encourages the entrepreneur to choose the innovative path (i.e., entrepreneurship) rather than the safe path (i.e., employment).

Manso (2011) has many interesting insights on failure tolerance, but differs from our work in a key aspect. Manso (2011) demonstrates how the optimal payments from the principal to the agent may involve leniency in the case of bad interim outcomes. This reduces incentives for effort but simultaneously induces the agent to experiment.[7] In Manso (2011), however, after poor information the project is *always stopped.* The agent goes back to producing in the previous manner — i.e. to exploitation — and there is no one who must continue to fund a negative NPV project. Thus, the Manso (2011) model applies generally to any situation where the agent is innovating around the task they would otherwise do and go back to it if the innovation fails.[8] We focus instead on the choice of both the principal and the agent to become involved, and potentially stay involved, in a new project that may not have a default option to fall back on – such as developing a cure for a disease when none exists. Negotiation around investment means that failure tolerance comes at a cost to the entrepreneur. Thus, as the next section shows, if the committed investor requires too much in order to be failure tolerant in the bad state, then a fundamentally innovative project may more likely be done by a VC with a sharp guillotine who has no failure tolerance.

A. *Who Funds Experimentation?*

The central question is which projects are more likely to be done by a committed or uncommitted investor? We can see that projects with higher payoffs, V_S or V_F, or lower costs, Y and X, are more likely to be done, but when considering the difference between a committed and an uncommitted investor we must look at the value of the early experiment.

In our model the first stage is an experiment that provides information about the pro-

[7]Hellmann and Thiele (2011) also suggest that low powered incentives may induce low effort on standard tasks but encourage experimentation.

[8]A secretary who tries for a better way to do a task. A line worker who tries to improve the production line. A surgeon who can either be encouraged to spend time doing surgery or inventing a new tool for surgery, but if the tool does not work he goes back to surgery. Etc.

bability of success in the second stage. 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 $V_F E[p_2 \mid F]$. 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. One special case is 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 a more informative first stage.

While a more informative first stage is a logical definition of a more experimental project, increasing $V_S E[p_2 \mid S] - V_F E[p_2 \mid F]$ might simultaneously increase or decrease the total expected value of the project. When we look at the effects from a more informative first stage we want to make sure that we hold constant any change in expected value. That is, we want to separate the effects of more information from the experiment and simply a higher expected value. Therefore, we define a project as having a more informative first stage in a mean preserving way as follows.

DEFINITION 2: *MIFS—A project has a more informative first stage in a mean preserving way if $V_S E[p_2 \mid S] - V_F E[p_2 \mid F]$ is larger for a given p_1, and expected payoff, $p_1 V_S E[p_2 \mid S] + (1 - p_1) V_F E[p_2 \mid F]$.*

We use the MIFS comparison definition because it reflects a difference in 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.[9] However, this

[9]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 have a more informative first stage. We are not ruling this possibilities out, rather we are just isolating the effect of the experiment.

kind of difference 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.

Note that the notion of MIFS has a relation to, but is not the same as, increasing risk. For example, we could increase risk while holding the information learned from the experiment constant by decreasing both $E[p_2 \mid S]$ and $E[p_2 \mid F]$ and increasing V_S and V_F. This increase in risk would increase the overall risk of the project but would not impact the importance of the first stage experiment.

With this definition we can establish the following proposition

PROPOSITION 2: *A MIFS project is more likely to be funded by an uncommitted investor. A MIFS project can potentially only be funded by an uncommitted investor.*

PROOF:

See Appendix C.v

Proposition 2 makes it clear that the more valuable the information learned from the experiment, the more important it is to be able to act on it. A committed investor cannot act on the information and must fund the project anyway while an uncommitted investor can use the information to terminate the project. Therefore, an increase in failure tolerance decreases an investors willingness to fund projects with MIFS experiments.

Figure 3 demonstrates the ideas in propositions 1 and 2. Projects with a given expected payoff after success in the first period (Y-axis) or failure in the first period (X-axis) fall into different regions or groups. We only examine projects above the 45° line because it is not economically reasonable for the expected value after failure to be greater than the expected value after success. In the upper left diagram the small dashed lines that run parallel to

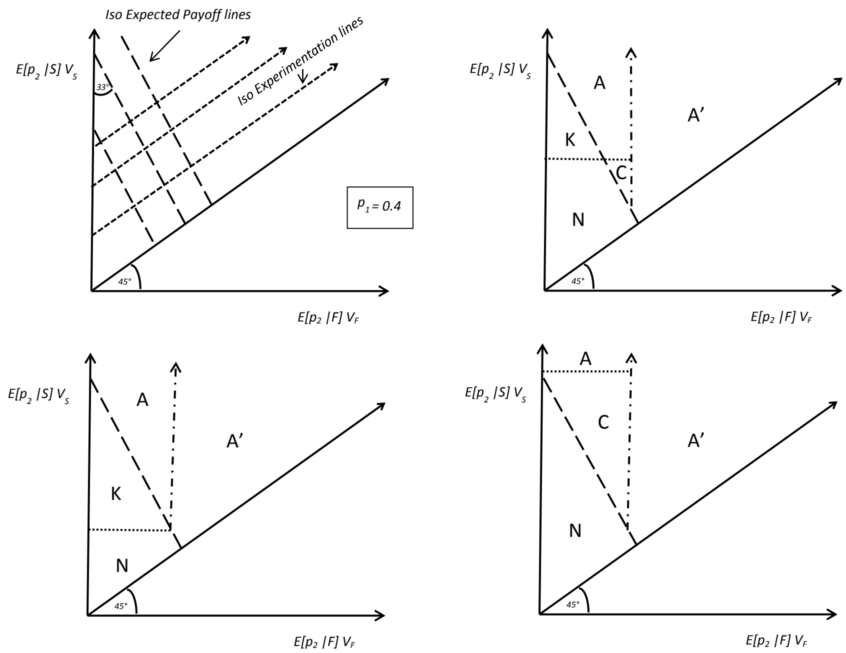

FIGURE 3. INVESTOR REGIONS: N = NO INVESTORS, C = ONLY COMMITTED INVESTORS, K = ONLY KILLER INVESTORS, A = ALL INVESTORS, A' = ALL INVEST, NEITHER KILLS

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 can be thought of as equally experimental. Moving northeast along an Iso Experimentation line increases the project's value without changing the value of the information learned in the first stage.

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.[10] Projects to the northwest along an Iso Expected Payoff line are MIFS projects, but have the same expected value.

The diagram also reinforces that risk is distinct from our notion of experimentation. Each point in the diagram could represent a more or less risky project. A project with a higher V_S and V_F but lower $E[p_2 \mid S]$ and $E[p_2 \mid F]$ would be much more risky but could

[10]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.

have the same $V_S E[p_2 \mid S]$ and $V_F E[p_2 \mid F]$ as an alternative less risky project. Thus, these two different projects would be on the same Iso Experimentation and Iso Expected Payoff line with very different risk.

In the remaining three diagrams in Figure 3 we see the regions discussed in proposition 1. Above the large dashed line, entrepreneurs can reach an agreement with a committed investor. Committed investors will not invest in projects below the large dashed line and can invest in all projects above this line. This line has the same slope as an Iso Expected Payoff Line because with commitment the project generates the full ex ante expected value. However, with an uncommitted investor the project is stopped after failure in the first period. Thus, the uncommitted investor's expected payoff is independent of $V_F E[p_2 \mid F]$. Therefore, uncommitted investors will invest in all projects above the horizontal dotted line. The vertical line with both a dot and dash is the line where $V_F E[p_2 \mid F] = Y(1+r)$. Projects to the right of this line (region A') have a high enough expected value after failure in the first period that no investor would ever kill the project, (i.e., refuse to invest after failure in the first stage), so we focus our attention to the left of this line.[11]

Where, or whether the dotted and dashed lines cross depends on the other parameters in the problem $(c, u_O, u_E, u_F, r, X, Y)$ that are held constant in each diagram. If the lines cross, as in the upper right diagram, we see five regions. Entrepreneurs with projects with high enough expected values can reach agreements with either type of investor (region A) and those with low enough expected values cannot find investors (region N). However, projects with mid level expected values may only be able to reach an agreement with one of the two types of investors. This displays the intuition of proposition 2. We see that projects with a given level of expected payoff are more likely to be funded only by a uncommitted investors (region K) if they are have a MIFS and more likely to be funded

[11] We have assumed throughout the paper that $V_F E[p_2 \mid F] < Y(1+r)$ to focus on the interesting cases where commitment matters.

only by a committed investor (region C) if they are less experimental, i.e. have a less informative first stage.

Proposition 2 seems contrary to the notion that failure tolerance increases innovation (Holmstrom (1989), Aghion and Tirole (1994) and Manso (2011)), but actually fits both with this intuition and with the many real world examples. The source of many of the great innovations of our time come both from academia or government labs, places with great failure tolerance but with no criteria for NPV-positive innovation, and from venture capitalist investments, a group that cares a lot about the NPV of their investments, but is often reviled by entrepreneurs for their quickness to shut down a firm. On the other hand, many have argued that large corporations, that also need to worry about the NPV of their investments, engage in more incremental innovation and are slow to terminate poorly progressing projects.[12] How can we reconcile these differences?

Our model helps explain this by highlighting that having a strategy of a sharp guillotine allows investors to back the projects for which experimentation is very important. Proposition 2 tells us that principals whose capital budgeting process or bureaucratic constraints may make them slow to terminate projects with initially negative information, will tend to fund projects that are ex ante less experimental (and so wont need to terminate them if intermediate results are not good). Others, such as VCs, who are generally faster with the financial guillotine, will, on average, fund things with greater learning from early experiments and terminate those that don't work out.[13] Thus, even though bureaucratic corporations will have *encouraged* more innovation they will only have *funded* the less experimental projects and will therefore progress toward incremental improvements. On the

[12]For example, systematic studies of R&D practices in the U.S. report that large companies tend to focus R&D on less uncertain, less novel projects more likely to focus on cost reductions or product improvement than new product ideas (e.g. Henderson (1993), Henderson and Clark (1990), Scherer (1991), Scherer (1992), Jewkes, Sawers and Stillerman (1969) and Nelson, Peck and Kalachek (1967)).

[13]Hall and Woodward (2010) report that about 50% of the venture-capital backed startups in their sample had zero-value exits

other hand, VCs will have discouraged some entrepreneurs from starting projects ex ante. However, ex post they will have funded the most experimental projects! Relatedly, failure tolerance can induce entrepreneurs to engage in experimentation, but the price of being a failure tolerant investor who cares about NPV may be too high - so that institutions such as academia and the government may also be places that end up financing a lot of radical experimentation, just not in an NPV positive way.

Recent work, Chemmanur, Loutskina and Tian (2012), has reported that corporate venture capitalists seem to be more failure tolerant than regular venture capitals. Interestingly, corporate venture capitalists do not seem to have had adequate financial performance but Dushnitsky and Lenox (2006) has shown that corporations benefit in non-pecuniary ways (see theory by Fulghieri and Sevilir (2009)). Our theory suggests that as the need for financial return diminishes, investors can become more failure tolerant and promote more radical innovation.

Of course there are several reasons why VCs might differ from corporations in terms of the projects they select and how they choose to advance them (Kortum and Lerner, 2000). There are also other drivers of the choice of when to terminate a project, including agency issues, which are supressed in our model but can play an important role in driving outcomes, (Guedj and Scharfstein, 2006; Gromb and Scharfstein, 2002). One way to empirically examine the choices at the extensive margin is to look for exogenous changes in the value of abandonment options - which can alter the tradeoff investors face in terms of encouraging innovation vs. making abandonment options more valuable. For example, Ewens, Nanda and Rhodes-Kropf (2016) document how the introduction of Amazon Web Services differentially lowered the cost of early experiments in certain industries — by making it possible to 'rent' hardware rather than buy it — and study the effect this had on the startups that VCs backed. Consistent with the predictions in this model, Ewens, Nanda and Rhodes-Kropf (2016) find that in sectors that benefited most from a falling cost of experimentation (which made a failure intolerant strategy much more attractive), investors began to select firms that were ex ante less conventional (e.g., younger teams, with fewer serial entrepreneurs), were more likely to terminate their investments after an initial round of financing, but exited their investments at higher values in the fewer instances that they were successful. That is, Ewens, Nanda and Rhodes-Kropf (2016) find evidence consistent with a 'shift' in policy among VCs having an impact on which startups were selected by VC investors. Recent work looking at the way in which project directors at the US Department of Energy's The Advanced Research Project Agency - Energy (ARPA-E) chose and managed radical innovations is also consistent with our model (Goldstein and Kearney, 2016). Goldstein and Kearney (2016) find that a distinctive feature of the program was the 'active program management' by ARPA-E directors, who were willing to over-ride the recommendations of judges in terms of selecting the most radical innovations, but simultaneously being disciplined in shutting down further funding for projects that did not demonstrate intermediate success. Doing one of these without the other would likely adversely impact the outcomes, the commitment to shut down poorly performing projects allowed them to take more risky 'bets'. Similarly, recent work by Ewens and Fons-Rosen (2013) and Cerqueiro et al. (2013) have found initial support for the the idea that failure tolerance may encourage innovation at the intensive margin but discourage it at the extensive margin.

At a more speculative level, our model also suggests that corporations that want to retain and fund more radical innovations likely need to become *less* failure tolerant. Case study evidence and our discussions with heads of R&D or Strategy at large corporations suggest that they were looking to get more disciplined in shutting down projects in the hope of selecting more speculative investments (Garvin and Levesque, 2005). Further work in this domain may look for cross sectional variation across principals or a policy shift that made corporations more, or less failure tolerant and examine how their selection of projects changed at the extensive margin.[14]

Remember that the notion of increasing experimentation is not the same as increasing risk. Thus, our point is not that more failure tolerant investors, such as corporations, will not do risky projects. Rather they will be less likely to take on projects where a great deal of the project value comes from the ability to terminate it if intermediate information is negative.

It is also important to note that in our model the entrepreneur and investor have the same information about the project. However, one might imagine that failure tolerant contracts might attract entrepreneurs with worse projects or alternatively might attract lazy entrepreneurs more likely to generate bad intermediate information. While we do not model this, it would seem to magnify our effect as failure tolerant investors would have to work with clearly distinguishable high quality entrepreneurs and avoid unconventional inexperienced entrepreneurs. This would be another force driving them away from the most radical projects.

In general there are likely to be other costs and benefits of failure tolerance such as those modeled by Manso (2011). While past work has modeled some of these tradeoffs on the intensive margin our point is that there are tradeoffs on the extensive margin that affect what deals different 'investors' will choose to fund. An investor with an intolerant reputation will not be able to fund a project that creates more value with failure tolerance. While an investor who is naturally very failure tolerant (or desires that reputation) will know to stay away from projects that require a sharp guillotine.

[14] Interestingly, Seru (2011) reports that mergers reduce innovation. This may be because the larger the corporation the more failure tolerant it becomes and thus endogenously the less willing it becomes to fund innovation.

III. Investors choice of commitment level

In this section we close the model by endogenizing the choice by the investor to become committed or not. We show first that both a committed and uncommitted strategy may be optimal and may coexist. However, we also show the potential for different equilibrium investing environments, and why in some environments no investor is willing to fund radical experiments. This demonstrates how the type of innovation undertaken in an economy may depend on the financial institutions that exist in equilibrium.

We model the process of the match between investors and entrepreneurs using a version of the classic search model of Diamond-Mortensen-Pissarides (for examples see Diamond (1993) and Mortensen and Pissarides (1994) and for a review see Petrongolo and Pissarides (2001)).[15] This allows the profits of the investors to vary depending on how many others have chosen to be committed or quick with the guillotine. In order for some investors to choose to be committed while others choose to be uncommitted, the expected profits from choosing either type of policy must be the same in equilibrium. If not, investors will switch from one type to the other, raising profits for one type and lowering them for the other, until either there are no investors of one type or until the profits equate.

We document that no one policy - being committed or uncommitted - is superior: Investors are after profits, not innovation per se, and thus prices and levels of competition adjust so that it can be equally profitable to be a committed investor who attracts entrepreneurs, but must require a higher fraction of the company, or an uncommitted investor who is less desirable to entrepreneurs but who asks for a smaller fraction of the company. Thus, each type of entrepreneur completes a deal with a different type of investor. However, it is also interesting to note that an equilibrium can arise where no investor chooses

[15]For a complete development of the model see Pissarides (1990). A search and Nash bargaining combination was recently used by Inderst and Müller (2004) in examining venture investing.

to be uncommitted even though there are some entrepreneurs with positive NPV projects willing to do a deal with such investors.

The formal proof is left to appendix C.vii but the intuition is as follows. As the fear, or stigma, of early failure increases, the surplus created with an uncommitted investor falls. This lowers the profits to being uncommitted so investors exit and become committed investors until the profits from either choice are again equivalent. However, there comes a point where even if an uncommitted investor gets all the surplus from a deal, they would rather be a committed investor even if all other investors are committed (competitive forces are not as bad for profits as no commitment). At this point no investor will choose to be uncommitted.

Thus, economies with high aversion to early entrepreneurial failure may endogenously contain no investor willing to *fund* the type of investments that create more surplus with an uncommitted investor. Note that this equilibrium can occur even if there are entrepreneurs looking for funding that create more total surplus if funded by an uncommitted investor. It may be the case, however, that with high general aversion to early failure all investors find it more profitable to form a reputation as committed to attract entrepreneurs and thus look for projects that create more surplus with a committed investor.

The type of project that wont get funded in this economy are those with very low NPV after failure in the first period. These are the projects for which experimentation matters greatly. Note that it is NOT the high risk projects that do not get funded - the probability of success in the first period p_1 does not affect the funding condition. Rather, it is those projects that are NPV positive before the experiment but are significantly NPV negative if the early experiment failed. These type of experimental projects will not receive funding from committed investors.

To the extent that such projects, characterized by very diffuse priors early on, where experiments can reveal if they have potential or not, are associated with radical innovations, this result can help explain the dearth of radical innovations emerging from countries in Europe and Japan, even though entrepreneurs from those countries contribute to radical innovations in the US. Many believe that the stigma of failure is much higher in these cultures, but it would seem that at least some entrepreneurs would be willing to take the risk. However, what our equilibrium implies is that even those entrepreneurs that are willing to start very experimental projects may find no investor willing to *fund* that level of experimentation. This is a key insight – the institutional funding environment for innovation is an endogenous equilibrium outcome that may result in places or times with no investors able to fund radical innovation even though the projects are individually NPV positive - it is just not NPV positive to be an investor with a reputation as being "quick on the trigger" if things do not go well. In equilibrium, all investors choose to be committed investors to attract the large mass of entrepreneurs who are willing to pay for commitment (those with less experimental projects). Thus, when a project arrives that needs an investor with a sharp guillotine to fund it (or it is NPV negative) there is no investor able to do it! In this equilibrium, financial intermediaries, such as venture capitalists, can only fund projects that are less experimental.

This secondary point of our model is related to Landier (2002) but adds an important dimension.[16] Financiers in our model are not passive, but instead make an endogenous choice that creates an institutional environment that will not fund experimentation. That is, financial institutions may in fact make it hard for even those few entrepreneurs willing to overcome the stigma of failure because they cannot find funding. Thus, we are not just explaining why some countries have less radical innovation but rather why they have virtually none—even those entrepreneurs who are willing to take a risk discover a funding

[16]Gromb and Scharfstein (2002) have a similar combination of labor market and organizational form in their model but with differences in the explicit costs and benefits.

market that sends them to other locations to find funding.

To see this distinction more clearly, note that in Landier's model, entrepreneurs in countries with high failure stigma find capital to be *cheaper*. However, the complaint from entrepreneurs in many parts of the world is that they cannot find funding at all. European entrepreneurs, and even those in parts of the United States, complain that they must go to the U.S. or specifically to Silicon Valley to get their ideas funded. For example, Skype, a huge venture backed success, was started by European entrepreneurs Niklas Zennstrm and Janus Friis and based in Luxembourg but received its early funding from US venture capitalists (Bessemer Venture partners and Draper Fisher Jurvetson). Our model builds on Landier (2002) to show that the problem is two-sided; venture capitalists look for less experimental projects to form reputations as failure tolerant because most entrepreneurs want a more failure tolerant backer. But doing so potentially results in an equilibrium with *no* investor willing to fund radical experiments even if they are NPV positive and the entrepreneur is willing to take the risk. Martin Varsavsky, one of Europe's leading technology entrepreneurs recently said in an interview with Fortune magazine that "Europeans must accept that success in the tech startup world comes through trial and error. European [investors] prefer great plans that don't fail."[17]

IV. Conclusion

While past work has examined optimal amount of failure tolerance at the individual project level, this idealized planner who adjusts the level of failure tolerance on a project-by-project basis may not occur in many situations. Our contribution is to instead consider the ex ante strategic choice of a firm, investor or government aiming to promote innovation or generate profits. While this paper develops a theoretical model, we also outline several

[17] http://tech.fortune.cnn.com/2012/08/14/europe-vc/

testable predictions and potentially fruitful areas where further empirical work could deepen our understanding of the relationship between failure tolerance and innovation at the organizational level.

We show that a financial strategy of failure tolerance adopted in the attempt to promote innovation encourages agents to start projects but simultaneously reduces the principal's willingness to fund experimental projects. By combining this idea with past work on failure tolerance we see that an increase in failure tolerance may increase innovative behavior at the intensive margin but may simultaneously decrease the willingness of funders to back innovation, thus reducing innovation at the extensive margin. In fact, caution is required since an increase in failure tolerance by the principal in an attempt to promote innovation could alter and even reduce total innovation.

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A. Appendix A: Model of Deal Between the Entrepreneur and Investor

In this section we determine when the entrepreneur and investors will be able to find an acceptable deal. We do so by determining the minimum share both the entrepreneur and investor must own in order to choose to start the project.

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, $\alpha_j = \alpha_{2j} + \alpha_1(1 - \alpha_{2j})$.

i. No Commitment

Using backward induction we start with the second period. Conditional on a given α_1 the investor will invest in the second period as long as

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

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 Y in the second period after success in the first period is

$$\underline{\alpha_{2S}} = \frac{Y(1+r)}{V_S E[p_2 \mid S]}. \tag{A-1}$$

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

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

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

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

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, $\overline{\alpha_{2S}} \geq 0$.[18]

[18] If not, the entrepreneur, for example, might be willing to give up 110% of the final payoff and the investor

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

$$\underline{\alpha_{S_N}} = \frac{p_1 Y(1+r) + X(1+r)^2}{p_1 V_S E[p_2 \mid S]}$$

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 C.ii for proof. We use the N subscript because in the next section we consider the situation when reputation concerns result in an agreement to continue even after first period failure (A subscript for Agreement and 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).

ii. Commitment

With the assumption of incomplete contracts there is potential value to an investor of a reputation as 'entrepreneurial friendly' or 'committed', who might then find it costly to shut down a project in the second period. Or alternatively, there might be value in a bureaucratic institution that has a limited ability to shut down a project once started. In this subsection we examine investors with an assumed (reputation) cost of early shutdown of c. Then in section III we allow investors to choose whether or not to have a committed reputation.

When investors have a early shutdown cost of c then the minimum fraction they are willing to accept after first period success is the same as before, equation (A-1), and the maximum fraction the entrepreneur will give up is also the same, equation (A-2).[19] An investor who has an early shut down cost may be willing to invest in the second period

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.

[19] See appendix C.i

even if the first period is a failure. After failure in the first period the minimum fraction the investor with shutdown costs c is willing to accept is

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

And 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 derivation of the above equations is in appendix C.i. Intuitively, 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 depend on whether or not the first period experiment worked and the cost of shutdown.

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. We define a 'committed' investor as follows.

DEFINITION 3: *A committed investor has a* $c > c^* = Y(1+r) - V_F E[p_2 \mid F]$

With this definition we find the following lemma.

LEMMA 2: *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 $\overline{\alpha_{2F}} - \underline{\alpha_{2F}} \geq 0$.

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

$\overline{\alpha_{2F}} - \underline{\alpha_{2F}}$ is positive iff $V_F E[p_2 \mid F] - u_F + u_E - Y(1+r) + c \geq 0$. However, since the utility of the entrepreneur cannot be transferred to the investor, it must also be the case that $V_F E[p_2 \mid F] - Y(1+r) + c \geq 0$. But if $V_F E[p_2 \mid F] - Y(1+r) + c \geq 0$ then $V_F E[p_2 \mid F] - u_F + u_E - Y(1+r) + c \geq 0$ 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 $V_F E[p_2 \mid F] - Y(1+r) < 0$.[20]

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.

The following proposition determines the conditions under which a project will be funded in the first period. Since the investor can forecast the second period dilution, the conditions for agreement can be written in terms of the *final* fraction of the business the investor and

[20]Furthermore, at $c = Y(1+r)$, the committed investor will continue to fund after failure since $V_F E[p_2 \mid F] > 0$. Thus, there is some c such that the investor is committed.

entrepreneur must own to be willing to start the project. That is, 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 4: *The minimum total fraction the investor is willing to accept is*

$$\underline{\alpha_{S_A}} = \frac{Y(1+r) + X(1+r)^2 - (1-p_1)V_F\alpha_F E[p_2 \mid F]}{p_1 V_S E[p_2 \mid S]},$$

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

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

The proof is in C.ii. The intuition is that 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 what kinds of deals will be done by the different types of player.

iii. Commitment or the Guillotine

A deal can be done to begin the project if $\underline{\alpha_{S_A}} \leq \overline{\alpha_{S_A}}$, assuming an agreement will be reached to continue the project even after early failure. 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 that a second period agreement after failure will or will not be reached, a project can be started if $\overline{\alpha_{S_A}} - \underline{\alpha_{S_A}} \geq 0$, i.e., if

$$p_1 V_S E[p_2 \mid S] + (1-p_1)V_F E[p_2 \mid F] - 2(u_O - u_E) - Y(1+r) - X(1+r)^2 \geq 0, \quad \text{(A-3)}$$

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

$$p_1 V_S E[p_2 \mid S] - 2(u_O - u_E) + (1-p_1)\Delta u_F - p_1 Y(1+r) - X(1+r)^2 \geq 0. \qquad \text{(A-4)}$$

Note that since an investor will need to take a larger share of the firm in a good state to make it worthwhile to continue investing after failure, the types of projects that can be funded with or without a committed investor are potentially different. We can, therefore, use the above inequalities to determine what types of projects actually can be started and the effects of failure tolerance and a sharp guillotine. This is done in Proposition 1.

B. Appendix B: Model of Investors choice of commitment level

In this section we model the endogenous choice by the investor to become committed or not. We show first that both a committed and uncommitted strategy may be optimal and may coexist. However, we also show the potential for different equilibrium investing environments, and why in some environments no investor is willing to fund radical experiments. This demonstrates how the type of innovation undertaken in an economy may depend on the financial institutions that exist in equilibrium.

i. *The Search for Investments and Investors*

We model the process of the match between investors and entrepreneurs using a version of the classic search model of Diamond-Mortensen-Pissarides (for examples see Diamond (1993) and Mortensen and Pissarides (1994) and for a review see Petrongolo and Pissarides (2001)).[21] This allows the profits of the investors to vary depending on how many others have chosen to be committed or quick with the guillotine.

We assume that there are a measure of of investors, M_I, who must choose between having a sharp guillotine, $c = 0$, (type K) or committing to fund the next round (type C). Simultaneously we assume that there are a measure of entrepreneurs, M_e, with one of two types of projects, type A and B. Type A projects occur with probability ϕ, while the type B projects occur with probability $1 - \phi$. As is standard in search models, we define $\theta \equiv M_I/M_e$. This ratio is important because the relative availability of each type will determine the probability of deal opportunities and therefore influence each firm's bargaining ability and choice of what type of investor to become.

Given the availability of investors and entrepreneurs, the number of negotiations to do a deal each period is given by the matching function $\psi(M_I, M_e)$.[22] Each individual investor experiences the same probability of finding an entrepreneur each period, and vice versa. Thus we define the probability that an investor finds an entrepreneur in any period as

$$\psi(M_I, M_e)/M_I = \psi(1, \frac{M_e}{M_I}) \equiv q_I(\theta), \tag{A-5}$$

By the properties of the matching function, $q_I'(\theta) \leq 0$, the elasticity of $q_I(\theta)$ is between zero and unity, and q_I satisfies standard Inada conditions. Thus, an investor is more likely to meet an entrepreneur if the ratio of investors to entrepreneurs is low. From an entrepreneurs point of view the probability of finding an investor is $\theta q_I(\theta) \equiv q_e(\theta)$. This differs from the viewpoint of investors because of the difference in their relative scarcity. $q_e'(\theta) \geq 0$, thus entrepreneurs are more likely to meet investors if the ratio of investors to entrepreneurs is high.

[21] For a complete development of the model see Pissarides (1990). A search and Nash bargaining combination was recently used by Inderst and Müller (2004) in examining venture investing.

[22] This function is assumed to be increasing in both arguments, concave, and homogenous of degree one. This last assumption ensures that the probability of deal opportunities depends only on the relative scarcity of the investors to entrepreneurs, θ, which in turn means that the overall size of the market does not impact investors or entrepreneurs in a different manner.

We assume that the measure of each type of investor and project is unchanging. Therefore, the expected profit from searching is the same at any point in time. Formally, this stationarity requires the simultaneous creation of more investors to replace those out of money and more entrepreneurs to replace those who found funding.[23] We can think of these as new funds, new entrepreneurial ideas or old projects returning for more money.[24]

When an investor and an entrepreneur find each other they must negotiate over any surplus created and settle on an α_S. The surplus created if the investor is committed is,

$$\begin{aligned}&\xi_C(p_1, V_S, V_F, E[p_2 \mid S], E[p_2 \mid F], X, Y, r, u_O, u_E, u_L)\\&\quad = p_1 V_S E[p_2 \mid S] + (1-p_1)V_F E[p_2 \mid F] - 2(u_O - u_E) - Y(1+r) - X(1+r)^2. \quad \text{(A-6)}\end{aligned}$$

While the surplus created if the investor is not committed is

$$\begin{aligned}&\xi_K(p_1, V_S, V_F, E[p_2 \mid S], E[p_2 \mid F], X, Y, r, u_O, u_E, u_L)\\&\quad = p_1 V_S E[p_2 \mid S] - 2(u_O - u_E) + (1-p_1)\Delta u_F - p_1 Y(1+r) - X(1+r)^2. \quad \text{(A-7)}\end{aligned}$$

With an abuse of notation we will refer to the surplus created by investments in type A projects as either ξ_{CA} or ξ_{KA} depending on whether the investor is type C or type K, and the surplus in type B projects as either ξ_{CB} or ξ_{KB}.

The set of possible agreements is $\Pi = \{(\pi_{gf}, \pi_{fg}) : 0 \leq \pi_{gf} \leq \xi_{gf} \text{ and } \pi_{fg} = \xi_{gf} - \pi_{gf}\}$, where π_{gf} is the share of the expected surplus of the project earned by the investor and π_{fg} is the share of the expected surplus of the project earned by the entrepreneur, where $g \in [K, C]$ and $f \in [A, B]$.

In equilibrium, if an investor and entrepreneur find each other it is possible to strike a deal as long as the utility from a deal is greater than the outside opportunity for either. If an investor or entrepreneur rejects a deal then they return to searching for another partner which has an expected value of π_K, π_C, π_A, or π_B depending on the player.

This matching model will demonstrate the potential for different venture capital industry outcomes. Although we have reduced the project space down to two projects, this variation is enough to demonstrate important insights.

To determine how firms share the surplus generated by the project we use the Nash bargaining solution, which in this case is just the solution to

$$\max_{(\pi_{gf}, \pi_{fg}) \in \Pi} (\pi_{gf} - \pi_g)(\pi_{fg} - \pi_f). \quad \text{(A-8)}$$

The well known solution to the bargaining problem is presented in the following Lemma.[25]

LEMMA 3: *In equilibrium the resulting share of the surplus for an investor of type $g \in [K, C]$ investing in a project of type $f \in [A, B]$ is*

$$\pi_{gf} = \frac{1}{2}(\xi_{gf} - \pi_f + \pi_g), \quad \text{(A-9)}$$

[23] Let m_j denote the rate of creation of new type j players (investors or entrepreneurs). Stationarity requires the inflows to equal the outflows. Therefore, $m_j = q_j(\theta)M_j$.

[24] In the context of a labor search model, this assumption would be odd, since labor models are focused on the rate of unemployment. There is no analog in venture capital investing, since we are not interested in the 'rate' that deals stay undone.

[25] The generalized Nash bargaining solution is a simple extension and available upon request.

while the resulting share of the surplus for the entrepreneur is $\pi_{fg} = \xi_{gf} - \pi_{gf}$ *where the* π_g, π_f *are the disagreement expected values and* ξ_{gf} *is defined by equations (A-6) and (A-7).*

Given the above assumptions we can write the expected profits that both types of investors and the entrepreneurs, with either type of project, expect to receive if they search for the other.

$$\pi_g = \frac{q_I(\theta)\left[\phi \max\left(\pi_{gA}, \pi_g\right) + (1-\phi)\max\left(\pi_{gB}, \pi_g\right)\right]}{1+r} + \frac{1-q_I(\theta)}{1+r}\pi_g \tag{A-10}$$

If we postulate that ω fraction of investors choose to be uncommitted or type K, then

$$\pi_f = \frac{q_e(\theta)\left[\omega \max\left(\pi_{fK}, \pi_f\right) + (1-\omega)\max\left(\pi_{fC}, \pi_f\right)\right]}{1+r} + \frac{1-q_e(\theta)}{1+r}\pi_f, \tag{A-11}$$

where $g \in [K, C]$ and $f \in [A, B]$. These profit functions are also the disagreement utility of each type during a deal negotiation. With these equations we now have enough to solve the model.

We present the solution to the matching model in the following proposition.

PROPOSITION 5: *If search costs are low relative to the value created by joining B projects with a type K* $\frac{2r}{(1-\phi)q_I(\theta)+\omega q_e(\theta)} < \frac{\xi_{KB}-\xi_{CB}}{\xi_{CB}}$ *and A projects with a type C* $\frac{2r}{\phi q_I(\theta)+(1-\omega)q_e(\theta)} < \frac{\xi_{CA}-\xi_{KA}}{\xi_{KA}}$*, then at the equilibrium* ω*,* $1 > \omega* > 0$*, there is assortative matching and type C investors invest in A type projects and type K investors invest in B type projects. Furthermore, the equilibrium profits of investors who commit (C) or don't commit (K) are*

$$\pi_K = \frac{(1-\phi)q_I(\theta)}{2r + (1-\phi)q_I(\theta) + \omega q_e(\theta)}\xi_{KB} \tag{A-12}$$

$$\pi_C = \frac{\phi q_I(\theta)}{2r + \phi q_I(\theta) + (1-\omega)q_e(\theta)}\xi_{CA} \tag{A-13}$$

And the profits of the entrepreneurs with type A or B projects are

$$\pi_A = \frac{(1-\omega)q_e(\theta)}{2r + \phi q_I(\theta) + (1-\omega)q_e(\theta)}\xi_{CA} \tag{A-14}$$

$$\pi_B = \frac{\omega q_e(\theta)}{2r + (1-\phi)q_I(\theta) + \omega q_e(\theta)}\xi_{KB} \tag{A-15}$$

We leave the proof to the appendix (C.vi). The point of this set up is to have an equilibrium in which the level of competition from other investors determines the profits from being a committed or uncommitted investor. In this search and matching model the fraction each investor or entrepreneur gets is endogenously determined by each players ability to find another investor or investment. The result is an intuitive equilibrium in which each player gets a fraction of the total surplus created in a deal, ξ_{pf}, that depends on their ability to locate someone else with which to do a deal.

It is interesting to note that even though entrepreneurs would prefer a committed investor, and investors would prefer to be able to exercise their abandonment option in a project, there may be a role for both types of investors since commitment is priced in equilibrium.

In order for some investors to choose to be type K while others choose to be type C the expected profits from choosing either type must be the same in equilibrium. If not, investors will switch from one type to the other, raising profits for one type and lowering them for the other, until either there are no investors of one type or until the profits equate. Therefore, the equilibrium ω is the $\omega = \omega^*$ such that the profits from either choice are equivalent.

COROLLARY 1: *The equilibrium fraction of investors who choose to be killers is* $0 \leq \omega * \leq 1$ *where*

$$\omega^* = \frac{(2r + \phi q_I(\theta) + q_e(\theta))(1-\phi)q_I(\theta)\xi_{KB} - (2r + (1-\phi)q_I(\theta))\phi q_I(\theta)\xi_{CA}}{q_e(\theta)(1-\phi)q_I(\theta)\xi_{KB} + q_e(\theta)\phi q_I(\theta)\xi_{CA}} \qquad \text{(A-16)}$$

This corollary elucidates the important insight that there are many parameter realization that would result in equilibria in which some investors choose endogenously to be type K while others simultaneously choose to be type C. It is not that one choice is superior. Investors are after profits not innovation and thus prices and levels of competition adjust so that in many cases it can be equally profitable to be a committed investor who attracts entrepreneurs, but must require a higher fraction of the company, or an uncommitted investor who is less desirable to entrepreneurs but who asks for a smaller fraction of the company. Thus, each type of entrepreneur completes a deal with a different type of investor.

However, it is also interesting to note that there are some equilibria in which no investor chooses to be type K. The following corollary, points out that whether or not it is profitable to be type K depends on the level of entrepreneurial aversion to early failure.

COROLLARY 2: *The equilibrium fraction of of type K investors, ω^*, is a decreasing function of the average entrepreneurial aversion to early failure. Furthermore, for high enough average entrepreneurial aversion to early failure the equilibrium fraction of investors who choose to be type K, ω^*, may be zero even though there is a positive measure of projects that create more value with type K investors ($M_e(1-\phi) > 0$).*

The formal proof left to appendix C.vii but the intuition is as follows. As the fear, or stigma, of early failure increases the surplus created with an uncommitted investor falls. This lowers the profits to being uncommitted so investors exit and become committed investors until the profits from either choice are again equivalent. However, there comes a point where even if an uncommitted investor gets all the surplus from a deal, they would rather be a committed investor even if all other investors are committed (competitive forces are not as bad for profits as no commitment). At this point no investor will choose to be type K.

Thus, economies with high aversion to early entrepreneurial failure may endogenously contain no investor willing to *fund* the type of investments that create more surplus with an uncommitted investor. Note that this equilibrium can occur even if there are entrepreneurs looking for funding that create more total surplus if funded by an uncommitted investor. It may be the case, however, that with high general aversion to early failure all investors find it more profitable to form a reputation as committed to attract entrepreneurs and thus look for projects that create more surplus with a committed investor.

The type of project that wont get funded in this economy are those such that $\xi_K > \xi_C$. This is true if equation (A-6) > equation (A-7), or

$$V_F E[p_2 \mid F] - Y(1+r) < \Delta u_F \tag{A-17}$$

As we can see, the projects that wont get funded are those with very low NPV after failure in the first period. These are the projects for which experimentation mattered greatly. Note that it is NOT the high risk projects that do not get funded - the probability of success in the first period p_1 does not affect the funding condition. Rather, it is those projects that are NPV positive before the experiment but are significantly NPV negative if the early experiment failed. These type of experimental projects cannot receive funding and as described in Section III

C. Appendix C: Proofs of Propositions

i. Derivation of Max and Min Required Fractions

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

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

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

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

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 $V_j E[p_2 \mid j] > Y(1+r)$ (which is true for $j = S$) then an outside investor would invest for a fraction greater than or equal to $\frac{Y(1+r)}{V_S E[p_2|S]}$. The fraction η that makes the investor indifferent between investing or not is the η such that

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

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 $\eta = \frac{Y(1+r)}{V_S E[p_2|S]}$. 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 $\frac{Y(1+r)}{V_S E[p_2|S]}$.[26] Thus, the correct minimum fraction that the

[26]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.

investor will accept for an investment of Y in the second period after success in the first period is

$$\underline{\alpha_{2S}} = \frac{Y(1+r)}{V_S E[p_2 \mid S]}.$$

However, after failure in the first period then $V_F E[p_2 \mid F] < Y(1+r)$ 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

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

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

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

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[27]

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

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.

[27]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.

ii. Proof of Propositions 3 and 4

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

$$\alpha_S = \left[\gamma\frac{Y(1+r)}{V_S E[p_2 \mid S]} + (1-\gamma)\left[1 - \frac{u_F - u_E}{V_S E[p_2 \mid S]}\right]\right](1-\alpha_1) + \alpha_1 \tag{A-18}$$

and α_F reduces to

$$\alpha_F = \gamma\left[\frac{Y(1+r) - c}{V_F E[p_2 \mid F]}\right] + (1-\gamma)\left[1 - \frac{u_F - u_E}{V_F E[p_2 \mid F]}\right] \tag{A-19}$$

Of course, in both cases negotiations must result in a fraction between zero and one.[28] Note that α_F does not depend on the negotiations in the first period because after failure, renegotiation determines the final fractions.[29] Of course, investors and entrepreneurs will account for this in the first period when they decide whether or not to participate.[30] We solve for the first period fractions in appendix C.iii 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

$$\begin{aligned} &p_1[V_S\alpha_S E[p_2 \mid S] - Y(1+r)] - X(1+r)^2 \\ &\qquad + (1-p_1)[V_F\alpha_F E[p_2 \mid F] - Y(1+r)] \geq 0 \end{aligned} \tag{A-20}$$

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

$$p_1[V_S\alpha_S E[p_2 \mid S] - Y(1+r)] - X(1+r)^2 - (1-p_1)c \geq 0 \tag{A-21}$$

if they are not.

The entrepreneur will choose to innovate and start the project if

[28]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 $c \leq Y(1+r)$ the negotiations will never result in a fraction less than zero.

[29]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.

[30]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.

$$p_1[V_S(1-\alpha_S)E[p_2 \mid S]+u_E]+u_E \\ +(1-p_1)[V_F(1-\alpha_F)E[p_2 \mid F]+u_E] \geq 2u_O \quad \text{(A-22)}$$

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

$$p_1[V_S(1-\alpha_S)E[p_2 \mid S]+u_E]+u_E+(1-p_1)u_F \geq 2u_O \quad \text{(A-23)}$$

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-20) for the minimum α_S such that the inequality holds:

$$\underline{\alpha_{S_A}} = \frac{Y(1+r)+X(1+r)^2-(1-p_1)V_F\alpha_F E[p_2 \mid F]}{p_1 V_S E[p_2 \mid S]}$$

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-22) 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-19) 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-21) and (A-23) respectively, to find

$$\underline{\alpha_{S_N}} = \frac{p_1 Y(1+r)+X(1+r)^2}{p_1 V_S E[p_2 \mid S]}$$

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.

iii. 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 $\underline{\alpha_{1_i}}$ $(i \in [A, N])$, because we already know from above, equation (A-18), that

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

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.

$$\alpha_1 = \frac{\alpha_S - Z}{1 - Z} \tag{A-24}$$

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

$$\underline{\alpha_{1_A}} = \frac{\frac{Y(1+r)+X(1+r)^2-(1-p_1)V_F\alpha_F E[p_2|F]}{p_1 V_S E[p_2|S]} - Z}{1 - Z}$$

as a function of α_F. And substituting in for α_F from equation (A-19) and Z from above yields,

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

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.[31] 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-24) 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

$$\underline{\alpha_{1_N}} = \frac{\frac{p_1 Y(1+r)+X(1+r)^2}{p_1 V_S E[p_2|S]} - Z}{1 - Z}$$

or,

$$\underline{\alpha_{1_N}} = 1 - \frac{p_1 V_S E[p_2 \mid S] - p_1 Y(1+r) - X(1+r)^2}{p_1(\gamma V_S E[p_2 \mid S] - \gamma Y(1+r) + (1-\gamma)(u_F - u_E))}$$

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-24) 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

[31]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

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

iv. 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 (or high X) could have both differences less than zero for any positive c (i.e., independent of the failure tolerance of the investor). 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 $Y(1+r)$. Thus, extremely bad projects will not be started and extremely good projects will be started by any type of investor.

Committed investors, who will reach an agreement after early failure, will start the project if $\overline{\alpha_{S_A}} - \underline{\alpha_{S_A}} \geq 0$. Uncommitted investors, who will kill the project after early failure, will start the project if $\overline{\alpha_{S_N}} - \underline{\alpha_{S_N}} \geq 0$. The difference between $\overline{\alpha_{S_A}} - \underline{\alpha_{S_A}}$ and $\overline{\alpha_{S_N}} - \underline{\alpha_{S_N}}$ is

$$\frac{(1-p_1)V_F E[p_2 \mid F] - (1-p_1)\Delta u_F - (1-p_1)Y(1+r)}{p_1 V_S E[p_2 \mid S]} \tag{A-25}$$

For an uncommitted investor, equation (A-25) may be positive or negative depending on the relative magnitudes of $V_F E[p_2 \mid F]$, Δu_F, and $Y(1+r)$. If it is positive, then for some parameters $\overline{\alpha_{S_A}} - \underline{\alpha_{S_A}} \geq 0$ while $\overline{\alpha_{S_N}} - \underline{\alpha_{S_N}} < 0$. In these cases the project can only be funded by a committed investor. If the difference in equation (A-25) is negative then for some parameters $\overline{\alpha_{S_A}} - \underline{\alpha_{S_A}} < 0$ while $\overline{\alpha_{S_N}} - \underline{\alpha_{S_N}} \geq 0$. In these cases the project can only be funded by an uncommitted investor. QED

v. Proof of Proposition 2:

A project can be funded by a committed investor if $\overline{\alpha_{S_A}} - \underline{\alpha_{S_A}} \geq 0$. For two projects with the same expected payout, $\overline{\alpha_{S_A}} - \underline{\alpha_{S_A}}$ has the same sign, i.e., both projects either can or cannot be funded and changing $V_S E[p_2 \mid S] - V_F E[p_2 \mid F]$ does not change that. This can be seen by noting that the numerator of equation (A-3) is unaffected by changes in $V_S E[p_2 \mid S] - V_F E[p_2 \mid F]$ as long as $p_1 V_S E[p_2 \mid S] + (1-p_1)V_F E[p_2 \mid F]$ does not change.

A project can be funded by an uncommitted investor if $\overline{\alpha_{S_N}} - \underline{\alpha_{S_N}} \geq 0$. If $V_S E[p_2 \mid S] - V_F E[p_2 \mid F]$ increases but p_1, and the expected payout, $p_1 V_S E[p_2 \mid S] + (1-p_1)V_F E[p_2 \mid F]$, stay the same, then $V_S E[p_2 \mid S]$ must have increased and $V_F E[p_2 \mid F]$ must have decreased. In which case $\overline{\alpha_{S_N}} - \underline{\alpha_{S_N}}$ increased (see equation (A-4)) and the difference between $\overline{\alpha_{S_A}} - \underline{\alpha_{S_A}}$ and $\overline{\alpha_{S_N}} - \underline{\alpha_{S_N}}$ (equation (A-25)) decreased. Therefore, there are a larger set of parameters such that $\overline{\alpha_{S_A}} - \underline{\alpha_{S_A}} < 0$ while $\overline{\alpha_{S_N}} - \underline{\alpha_{S_N}} \geq 0$, i.e., the project can only be funded by an uncommitted investor. QED *vi. Proof of Proposition 5:*

Let $g \in [K, C]$ represent the investor type investing in a project of type $f \in [A, B]$, and let ω represent the fraction of investors that choose to be killers (K) rather than committed (C). Also, let π_g and π_f represent the expected profits of the investor and entrepreneur respectively before they find a partner, while π_{gf} and π_{fg} represent their respective expected profits conditional on doing a deal with a partner of type f or g respectively.

We begin with equation (A-10) and assume that $\pi_C < \pi_{CA}$, $\pi_C > \pi_{CB}$, $\pi_K < \pi_{KB}$, $\pi_K > \pi_{KA}$, which we later verify in equilibrium. Thus,

$$\pi_K = \frac{q_I(\theta)\left[\phi\pi_K + (1-\phi)\pi_{KB}\right]}{1+r} + \frac{1-q_I(\theta)}{1+r}\pi_K \tag{A-26}$$

$$\pi_C = \frac{q_I(\theta)\left[\phi\pi_{CA} + (1-\phi)\pi_C\right]}{1+r} + \frac{1-q_I(\theta)}{1+r}\pi_C \tag{A-27}$$

Next we use equation (A-11) and assume that $\pi_A < \pi_{AC}$, $\pi_A > \pi_{BC}$, $\pi_B < \pi_{BK}$, $\pi_B > \pi_{BC}$, which we also verify in equilibrium.

$$\pi_A = \frac{q_e(\theta)\left[\omega\pi_A + (1-\omega)\pi_{AC}\right]}{1+r} + \frac{1-q_e(\theta)}{1+r}\pi_A \tag{A-28}$$

$$\pi_B = \frac{q_e(\theta)\left[\omega\pi_{BK} + (1-\omega)\pi_B\right]}{1+r} + \frac{1-q_e(\theta)}{1+r}\pi_B \tag{A-29}$$

Using Lemma 3 and solving we find

$$\pi_K = \frac{(1-\phi)q_I(\theta)}{2r + (1-\phi)q_I(\theta)}\left[\xi_{KB} - \pi_B\right] \tag{A-30}$$

$$\pi_C = \frac{\phi q_I(\theta)}{2r + \phi q_I(\theta)}\left[\xi_{CA} - \pi_A\right] \tag{A-31}$$

$$\pi_A = \frac{(1-\omega)q_e(\theta)}{2r + (1-\omega)q_e(\theta)}\left[\xi_{CA} - \pi_C\right] \tag{A-32}$$

$$\pi_B = \frac{\omega q_e(\theta)}{2r + \omega q_e(\theta)}\left[\xi_{KB} - \pi_K\right] \tag{A-33}$$

Therefore, with 4 equations and 4 unknowns we can solve for π_K, π_C, π_A, and π_B.

$$\pi_K = \frac{(1-\phi)q_I(\theta)}{2r + (1-\phi)q_I(\theta) + \omega q_e(\theta)}\xi_{KB} \tag{A-34}$$

$$\pi_C = \frac{\phi q_I(\theta)}{2r + \phi q_I(\theta) + (1-\omega)q_e(\theta)}\xi_{CA} \tag{A-35}$$

$$\pi_A = \frac{(1-\omega)q_e(\theta)}{2r + \phi q_I(\theta) + (1-\omega)q_e(\theta)}\xi_{CA} \tag{A-36}$$

$$\pi_B = \frac{\omega q_e(\theta)}{2r + (1-\phi)q_I(\theta) + \omega q_e(\theta)}\xi_{KB} \tag{A-37}$$

These are the equilibrium profits, but we must confirm that $\pi_{CB} < \pi_C < \pi_{CA}$ and $\pi_{KA} < \pi_K < \pi_{KB}$ as well as $\pi_{AK} < \pi_A < \pi_{AC}$ and $\pi_{BC} < \pi_B < \pi_{BK}$.

Lemma 3 tells us that $\pi_{gf} = \frac{1}{2}(\xi_{gf} - \pi_f + \pi_g)$ and $\pi_{fg} = \xi_{gf} - \pi_{gf}$. Thus checking all the inequalities just above reduces to checking that $\xi_{CB} - \pi_B < \pi_C < \xi_{CA} - \pi_A$ and that $\xi_{KA} - \pi_A < \pi_K < \xi_{KB} - \pi_B$. Substituting for π_K, π_C, π_A, and π_B from above we see that it is always the case that $\pi_C < \xi_{CA} - \pi_A$ and $\pi_K < \xi_{KB} - \pi_B$ as long as ξ_{KB} and ξ_{CA} are positive (i.e. a deal creates value). Furthermore, since at the equilibrium $\omega = \omega^*$ it must be the cast that $\pi_C = \pi_K$, therefore, $\xi_{CB} - \pi_B < \pi_C$ as long as

$$\frac{2r}{(1-\phi)q_I(\theta) + \omega q_e(\theta)} < \frac{\xi_{KB} - \xi_{CB}}{\xi_{CB}} \tag{A-38}$$

and $\xi_{KA} - \pi_A < \pi_K$ as long as

$$\frac{2r}{\phi q_I(\theta) + (1-\omega) q_e(\theta)} < \frac{\xi_{CA} - \xi_{KA}}{\xi_{KA}} \tag{A-39}$$

vii. Proof of Corollary 2:

Since $\partial \pi_K/\partial\omega < 0$ and $\partial\pi_C/\partial\omega > 0$, single crossing is insured and ω^* is determined the point at which $\pi_K = \pi_C$ using the results from proposition 5. As corollary 1 notes this results in

$$\omega^* = \frac{(2r + \phi q_I(\theta) + q_e(\theta))(1-\phi)q_I(\theta)\xi_{KB} - (2r + (1-\phi)q_I(\theta))\phi q_I(\theta)\xi_{CA}}{q_e(\theta)(1-\phi)q_I(\theta)\xi_{KB} + q_e(\theta)\phi q_I(\theta)\xi_{CA}} \tag{A-40}$$

Or, $\omega^* = 1$ if $\pi_K(1) > \pi_C(1)$ or $\omega^* = 0$ if $\pi_K(0) > \pi_C(0)$.

As the fear or stigma of early failure decreases, Δu_F increases. Using equations (A-6) and (A-7) we find that $\frac{\partial \xi_{Cf}}{\partial \Delta u_F} = 0$ and $\frac{\partial \xi_{Kf}}{\partial \Delta u_F} = (1 - p_1) > 0$. Therefor,

$$\begin{aligned}\frac{\partial \omega^*}{\partial \Delta u_F} = &\frac{(q_e(\theta)(1-\phi)q_I(\theta)\xi_{KB})(2r + \phi q_I(\theta) + q_e(\theta))(1-\phi)q_I(\theta)\frac{\partial \xi_{KB}}{\partial \Delta u_F}}{(q_e(\theta)(1-\phi)q_I(\theta)\xi_{KB} + q_e(\theta)\phi q_I(\theta)\xi_{CA})^2}\\
&+ \frac{(q_e(\theta)\phi q_I(\theta)\xi_{CA})(2r + \phi q_I(\theta) + q_e(\theta))(1-\phi)q_I(\theta)\frac{\partial \xi_{KB}}{\partial \Delta u_F}}{(q_e(\theta)(1-\phi)q_I(\theta)\xi_{KB} + q_e(\theta)\phi q_I(\theta)\xi_{CA})^2}\\
&- \frac{[(2r + \phi q_I(\theta) + q_e(\theta))(1-\phi)q_I(\theta)\xi_{KB}]q_e(\theta)(1-\phi)q_I(\theta)\frac{\partial \xi_{KB}}{\partial \Delta u_F}}{(q_e(\theta)(1-\phi)q_I(\theta)\xi_{KB} + q_e(\theta)\phi q_I(\theta)\xi_{CA})^2}\\
&+ \frac{[(2r + (1-\phi)q_I(\theta))\phi q_I(\theta)\xi_{CA}]q_e(\theta)(1-\phi)q_I(\theta)\frac{\partial \xi_{KB}}{\partial \Delta u_F}}{(q_e(\theta)(1-\phi)q_I(\theta)\xi_{KB} + q_e(\theta)\phi q_I(\theta)\xi_{CA})^2}\end{aligned} \tag{A-41}$$

And since the first and third terms are the same but with opposite sign this reduces to

$$\begin{aligned}\frac{\partial \omega^*}{\partial \Delta u_F} = &\frac{(q_e(\theta)\phi q_I(\theta)\xi_{CA})(2r + \phi q_I(\theta) + q_e(\theta))(1-\phi)q_I(\theta)\frac{\partial \xi_{KB}}{\partial \Delta u_F}}{(q_e(\theta)(1-\phi)q_I(\theta)\xi_{KB} + q_e(\theta)\phi q_I(\theta)\xi_{CA})^2}\\
&+ \frac{[(2r + (1-\phi)q_I(\theta))\phi q_I(\theta)\xi_{CA}]q_e(\theta)(1-\phi)q_I(\theta)\frac{\partial \xi_{KB}}{\partial \Delta u_F}}{(q_e(\theta)(1-\phi)q_I(\theta)\xi_{KB} + q_e(\theta)\phi q_I(\theta)\xi_{CA})^2}\end{aligned} \tag{A-42}$$

which is positive since both terms are positive. The proves the first part of the corollary.

No investor chooses to be a killer if

$$(2r + \phi q_I(\theta) + q_e(\theta))(1-\phi)q_I(\theta)\xi_{KB} \leq (2r + (1-\phi)q_I(\theta))\phi q_I(\theta)\xi_{CA} \tag{A-43}$$

Since the above solved for $\frac{\partial \omega^*}{\partial \Delta u_F} > 0$ it is easy to see that Δu_F is not in the numerator of $\frac{\partial \omega^*}{\partial \Delta u_F}$ and therefore the second derivative of ω^* with respect to Δu_F is negative everywhere. Therefore, for small enough Δu_F condition (A-43) holds and no investor chooses to be a killer. Note that condition (A-43) can hold even though $\xi_{KB} > 0$ and even though $\phi < 1$ so there are projects that create more surplus with a killer as an investor.