Essays on Innovation

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ABSTRACT
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This dissertation analyzes problems related to barriers to innovation.

In the first chapter, “Delegation and Learning”, I study an agency problem which is common in many contexts involving financing of innovation. Consider the example of an entrepreneur, who has an idea but not the money to implement it, and an investor, who has the money but not the idea. In such a case, how should a financial contract between the investor and the entrepreneur look like? How much money should the investor provide the entrepreneur? How should the surplus be divided between them in case the idea turns out to be profitable? There are certain common elements in situations such as these. First, there is an element of learning. This is because initially it is unknown if the idea is profitable or not and hence the idea has to be tried out in the market and both the investor and entrepreneur learn about the profitability of the idea from observing market outcomes. Second, there is an element of delegation in the above situation. This is because decision rights regarding where and when should the idea be tried out is typically in the hands of the entrepreneur and he knows his idea better than the investor. Finally, the preferences of the investor and the entrepreneur might not be aligned. For instance, the investor may receive private benefits, monetary or reputational, from launching products even when these are not profitable. In such a case, how should a contract that incentivizes the entrepreneur to act in the investor’s interest look like?

To study these issues, I develop a model in which a principal contracts with an agent whose ability is uncertain. Ability is learnt from the agent’s performance in projects that the principal finances over time. Success however also depends on the quality of the project at hand, and quality is privately observed by the agent who is biased towards implementation. I characterize the optimal sequence of rewards in a relationship that tolerates an endogenously
determined finite number of failures and incentivizes the agent to implement only good projects by specifying rewards for success as a function of past failures. The fact that success becomes less likely over time suggests that rewards for success should increase with past failures. However, this also means that the agent can earn a rent from belief manipulation by deviating and implementing a bad project which is sure to fail. I show that this belief-manipulation rent decreases with past failures and implies that optimal rewards are front-loaded. The optimal contract resembles the arrangements used in venture capital, where entrepreneurs must give up equity share in exchange for further funding following failure.

In the second chapter, “Informal Risk Sharing and Index Insurance: Theory with Experimental Evidence”, written with Francis Annan, we study when does informal risk sharing act as barrier or support to the take-up of an innovative index-based weather insurance? We evaluate this substitutability or complementarity interaction by considering the case of an individual who endogenously chooses to join a group and make decisions about index insurance. The presence of an individual in a risk sharing arrangement reduces his risk aversion, termed “Effective Risk Aversion” — a sufficient statistic for index decision making. Our analysis establishes that such reduction in risk aversion can lead to either reduced or increased take up of index insurance. These results provide alternative explanations for two empirical puzzles: unexpectedly low take-up for index insurance and demand being particularly low for the most risk averse. Experimental evidence based on data from a panel of field trials in India, lends support for several testable hypotheses that emerge from our baseline analysis.

In the third chapter, “Investment Timing, Moral Hazard and Overconfidence”, I study how overconfidence and financial frictions impact entrepreneurs by shaping their incentives to learn. I consider a real option model in which an entrepreneur learns about the quality of project he has, prior to implementation. Success depends on the quality of the project as well as the unknown ability of the entrepreneur. The possibility of the entrepreneur diverting investor funds to his private uses, creates a moral hazard problem which leads
to delayed investment and over-experimentation. An entrepreneur who is overconfident regarding his ability, under-experiments and invests earlier compared to an entrepreneur who has accurate beliefs regarding his ability. Such overconfidence on behalf of the entrepreneur creates inefficiencies when projects are self financed, but reduces inefficiencies due to moral hazard in case of funding by investors.
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Chapter 1

Delegation and Learning

Bikramaditya Datta¹

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1.1 Introduction

Consider a firm that evaluates entering a new business. The firm puts a manager in charge and finances projects related to this business, such as designing prototypes or testing specific markets. The manager is better informed about the quality of the projects - that is, their chances of succeeding - but his interests may not align with those of the firm. For instance, the manager might be present biased or have a taste for empire building, thus deriving a larger benefit from implementing projects compared to the firm. Moreover, there is uncertainty about the manager’s fit to lead the firm’s operations in the new business, and therefore about his ability to make projects succeed. In such situations, how much funding should the firm place at the manager’s disposal and how can the firm incentivize the manager to work in its interest?

Learning often involves delegation. A firm while learning about the profitability of entering a new business, often starts small and delegates decision-making to a manager. The agency problem in the above scenario is related to the fact that the manager usually has better information about the quality of projects in which he can invest, but has incentives different from that of the firm. The firm would like the manager to wait for good projects and only take those up. The manager on the other hand, benefits from working on projects regardless of quality. However good projects are not always available and hence the firm has to provide incentives for the manager to wait for the good projects. Further, one of the advantages of failure in projects is that the agent may earn further rents from future projects, while a success reveals the business is profitable for the firm and might lead the firm to place a specialist in charge of the business. Thus, the manager might want to take up projects which fail in order to postpone the completion of the learning phase. The problem of the firm is to find the optimal amount of funding and reward structure in order to incentivize the manager to select the right projects.

To study these issues, we develop a model in which a principal contracts with an agent to complete a task. The agent’s ability to complete the task is unknown to both the principal
and the agent. Completing the task requires success in a project. The agent’s performance in a project depends both on his ability and the quality of the project at hand. In particular, only high ability agents have a chance of success in good quality projects, which arrive\(^2\) stochastically and may not be available at any given point. Bad quality projects, which fail regardless of the ability of the agent, are always available. The quality of the projects available is privately observed by the agent before deciding which project to implement in any particular period. The principal only gets to observe whether a project implemented resulted in a success or a failure and not the quality of the project - this is the source of asymmetric information in the model.

Since only good quality projects can succeed, the principal would want the agent to only implement these projects. However, the agent is biased towards implementing projects regardless of quality, since he gets a private benefit regardless of quality of the project and his ability. In order to incentivize the agent to wait for a good project to arrive, the principal offers reward for success in a project.

Failure in a project leads to a reduction in belief regarding the agent’s ability and hence reduces the belief regarding probability of success in a project. This suggests that the rewards for success, needed to incentivize the agent to wait, should increase with past failures. However, this in turn creates an incentive for the agent to deviate and earn a rent. Suppose the principal expects the agent to implement only good projects. If the agent deviates and implements a bad project, then the resulting failure leads to a reduction in the principal’s belief regarding the agent’s ability, while the agent’s belief about his ability remains unchanged\(^3\). Thus, the agent can ensure himself a strictly positive rent by this deviation.

The optimal contract has rewards for success decreasing with the number of past failures. Since success in a project completes the task and obviates the need for further project implementation, the agent will select a good project only if the rewards for succeeding in the

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\(^2\)The arrival rate of good projects is independent of the agent’s ability. Thus ability here refers to the agent’s capability of succeeding in good projects.

\(^3\)This is because the agent knows that performance in bad projects is not indicative of ability.
project compensates him for the potential loss of continuation rents that selecting a good project makes more likely. These continuation rents not only include the private benefit from implementing projects but also rents due to possible divergence in beliefs described above. These factors combine to produce rewards for success which decrease with the number of past failures.

Another feature of the optimal contract is that, increasing the number of trials results in higher rewards to be paid to the agent for success. This is because increasing the number of trials implies that the potential loss of continuation rents from selecting a good project is higher for the agent. The loss in continuation rents is higher due to the possibility of getting private benefits from implementing a larger number of projects as well as earning higher rents due to the possibility of greater divergence of beliefs.

The optimal number of trials is determined by considering the trade-off between higher rent paid to the agent and better information obtained through increasing number of trials. Increasing the number of trials provides more opportunities for a high ability agent to succeed and thus reduces the probability that the agent was high ability but failed due to a lack of sufficient opportunities. However as discussed above, increasing the number of trials leads to higher bonuses paid to the agents for success. We further find that the optimal number of trials is an increasing function of the prior belief regarding the agent’s ability and the payoff that the principal gets from success and is a decreasing function of the cost of implementing projects.

The model can also be used to analyze financial contracting between entrepreneurs and investors. An entrepreneur often has a better understanding of the products he can launch, but may receive private benefits, monetary or reputational, from launching products even when these are not profitable. Furthermore, it is initially unknown whether the entrepreneur has the necessary skills to make a good product succeed. Also, success by a entrepreneur often leads to his replacement (Wasserman 2008). Thus we can apply the model to highlight...
some of the agency problems present in the relationship between the entrepreneur and the investor and illustrate how they impact the financial arrangements between them.

Empirical evidence on venture capital financing is consistent with the results obtained in the model. For instance, Kaplan and Strömberg (2003) find evidence that founders’ cash flow rights decline over financing rounds and decrease as the firm performance worsens. This is consistent with the model’s prediction that the rewards for the agent are a decreasing function of past failures. Similarly the result that a higher prior about the agent’s ability leads to increased funding is consistent with the findings in the empirical literature on venture capital financing which suggest that entrepreneurs who have succeeded in the past are likely to get better deals. (Gompers, Kovner, Lerner and Scharfstein 2010).

**Related literature:** This paper is related to the literature on contracting for experimentation. The experimentation literature has mostly focused on how to incentivize effort. Bergemann and Hege (1998, 2005) and Hörner and Samuelson (2013) study dynamic moral hazard models in which the principal finances the agent to work on projects but the agent can choose to divert cash for private benefits or equivalently not exert effort. The experimentation literature has focused mainly on how to incentivize effort. However effort is only part of the overall incentive problem. In a managerial context, it is often likely the case that managers are industrious but the primary issue is determining how effective managers are in their tasks\(^5\). Our goal in this paper is to understand how the principal can optimally incentivize the agent to implement the right projects while learning about the agent’s ability.

We analyze a situation where the agent is better informed about the quality of projects but biased relative to the principal. The experimentation component arises because both the principal and the agent learn about the agent’s ability as the agent implements projects and they observe the projects’ outcomes. The relevant deviation is not lowering effort but rather

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5See for instance Kaplan (1984) who considers effort-based models as inadequate for capturing incentive issues in management. Further PwC (2017) suggests that problem solving, creativity and innovation are among some of the most important skills as rated by CEOs across countries.
selecting bad projects.

Halac, Kartik and Liu (2016) study long-term contracts for experimentation, with adverse selection about the agent’s ability and moral hazard about his effort choice. They find that the optimal bonus structure is either constant or back-loaded, that is the agent is rewarded more for later success. In contrast, we find that bonus structure should instead be front-loaded, that is the agent should be rewarded more for success after a fewer number of failures. The difference is driven by the fact that in our setting the agent gets a private benefit from implementing projects and hence must be compensated for the loss in continuation payoffs.

Manso (2011) derives an optimal contract where the agent chooses between shirking, exploiting a well-known approach, or exploring a new approach. He finds that the optimal contract which induces the agent to try the new approach exhibits tolerance for early failure and rewards for long-term success. In contrast, in our setting the agent faces a choice between implementing a bad project or waiting for a good project to arrive to implement it. Our model suggests that tolerating early failures and rewarding long-term success might lead to adverse incentives for an agent who derives benefits from continuing to work on projects. In particular, our model brings into focus the incentive cost of giving an agent a higher number of opportunities to succeed.

Hidir (2017) involves the agent exerting effort in order to acquire information about the unknown quality of a project where both effort choice and signals regarding quality are private information for the agent. Our model shares the feature that it is ex-ante unknown how long it may take in order to acquire information. However, in her model, the agent receives a rent at each point he is waiting for news while in our setup the agent receives a payoffs only when he implements projects.

This paper is also related to the literature on assessing managerial ability originating from Holmström (1999). The literature highlights that firms draw inferences about the manager’s ability based on public signals. This in turn provides an incentive for the manager to take actions to distort the public signals. However typically the managers take actions which try
and make them appear better than they are (or at least no worse than what they are).\textsuperscript{6} In contrast, in our model, managers benefit from the possibility of making the principal more pessimistic about his ability. In that respect, this is closer to the literature on belief manipulation\textsuperscript{7}. The literature on belief manipulation has mostly focused on situations in which agents have to apply (hidden) effort. In contrast, our paper suggests another source - selecting bad projects - through which the agent might create a divergence between public belief about his ability and his own private belief and earn a rent on the basis of that.

The paper is connected with the literature on delegation originating from Holmström (1977, 1984). An important focus in this literature has been on how to incentivize an biased agent with superior information to act in the principal’s interest. We highlight the fact that delegation also allows us to learn about the agent’s ability. Recently, there has been quite a few papers related to dynamic delegation - Hörner and Guo (2015), Lipnowski and Ramos (2015), Li, Matouschek & Powell (2017) - however these are in a repeated game setting and there is no learning component. The exception is Guo (2016). In her setting, the agent receives private information only once at the beginning of the game while in our setup the agent receives private information multiple times over the course of the game.

The rest of the paper is organized as follows. In section 2, we describe the model setup and solve a benchmark case with complete information. In section 3, we illustrate the basic insights and tradeoffs by considering the optimal contract which allows for one and two trials. In section 4, we derive the optimal contract for the general problem. In section 5, we present comparative statics results. Section 6 discusses some extensions and empirical implications and we conclude in section 7.

\textsuperscript{6}See for example Hermalin (1993), Holmström and Ricart i Costa (1986).
\textsuperscript{7}See for example Bergemann and Hege (2005), Bhaskar (2012), Wolf (2017).
1.2 The Model

In this section, I describe the model setup and solve a benchmark case with complete information.

1.2.1 Setup

There are two risk-neutral players: a (male) agent and a (female) principal. Both have a common discount factor \( \delta \in (0, 1) \). Time \( t = 0, 1, 2... \) is discrete with an infinite horizon.

**Ability**: The ability of the agent is persistent and is either high or low. Neither the principal nor the agent knows the true ability - the initial common prior is that the agent is high ability with probability \( \alpha_0 \in (0, 1) \). The agent’s ability can be assessed through performance in projects.

**Projects**: Each period there are up to two types of projects available - “bad” and “good”. A “bad” project fails regardless of the ability of the agent, whereas “good” project succeeds with probability \( \gamma \in (0, 1) \) if the agent is of high ability and fails otherwise. In each period, there is always a bad project available, whereas a good project is available with probability \( p \in (0, 1) \). The availability of projects is independent of the agent’s ability. The agent can implement up to one project each period. If a good project becomes available in a specific period and the agent chooses not to implement it that period, then the agent cannot imple-

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8There are a few justifications for the common prior assumption. First, the agent’s assessment of ability is based on past performance and hence is likely to be known to the principal. Second, the uncertainty about agent’s ability might be interpreted as uncertainty about the quality of the match, which is similarly unknown to both the agent and the principal. Further, we note that although the analysis begins with a common prior assumption, over the course of time, it is possible that beliefs about ability might diverge due to asymmetric information.

9Thus one can interpret ability of the agent as corresponding to his ability to capitalize on opportunities
ment that particular project in future periods either.

**Payoffs:** Following Zwiebel (1996), the agent gets a private benefit $b > 0$ per project implemented.\(^{10}\) It costs $c > 0$ to implement a project. Outside options per period for both the principal and the agent are normalized to 0 each. The principal values successful outcome at $R > c$.\(^{11}\)

**Information:** In each period, only the agent observes if a good project is available. Given the financing from the principal, the agent has a choice between implementing no project, implementing a bad project or implementing a good project (if available). The principal can observe if a project is chosen in a specific period and also what the outcome of the project is. In particular, success in a project is immediately observed by both the principal and the agent. The quality of the project chosen in case of failure of the project is not observed by the principal (even ex post).

**Learning:** Not implementing a project provides no information regarding the ability of the agent. Suppose the principal expects the agent to implement projects if and only if they are good. In that case, failure leads to a reduction of the principal’s belief regarding the ability of the agent. Let $\alpha_k$ denote the probability that the agent is of high ability given $k$ past failures and no success. Then (assuming again that the agent only implements good projects) Bayes’ law implies

$$\alpha_k = \frac{(1 - \gamma)^k \alpha_0}{(1 - \gamma)^k \alpha_0 + (1 - \alpha_0)}.$$  \(^{(1.1)}\)

Success in a project reveals that the agent is of high ability since only high ability agents can succeed.

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\(^{10}\)The private benefit includes benefits such as publicity as well as learning in case of the entrepreneurship example and also takes into account effort cost of implementing projects - thus one can interpret $b$ as the net benefit to the agent from implementing projects.

\(^{11}\)Since only high ability agent can achieve success, $R$ summarizes the future surplus the principal gets from interacting with a high ability agent.
We note that it is possible for the beliefs of the agent and the principal to diverge. In particular, if an agent selects to implement a bad project, then his belief will be unchanged following failure. However if the principal expected the agent to implement a project if and only if it was good and she sees the project fail, then she will reduce her belief regarding the agent’s ability.

**Contracts:** We consider contracting at period zero with full commitment on part of the principal. We restrict attention to contracts in which (i) the agent implements a project if and only if it is good and (ii) payments are conditional only on the number of past failures. Formally, a contract is given by \((k, X)\) where \(k \in \{0, 1, \ldots\}\) is the maximum number of trials the principal is willing to fund and \(X = (X_{0k}, X_{1k}, \ldots, X_{sk}, \ldots X_{k-1k})\) specifies the transfer \(^{12}\) to be made to the agent conditional on the agent succeeding after \(s\) failures and the contract allowing for a total of \(k\) failures. We assume limited liability: \(X_{sk}\) cannot be negative. This is not the most general set of contracts. The simplifying assumptions on the contract set are designed to bring out in the simplest possible way what the basic economic tension is in the delegation and learning problem. Once the basic tradeoff is clearly modeled, it is easier to explore the robustness of the optimal contract to generalizations of the contract set.

One possible interpretation of the contracts under study is as follows. The agent has no money of his own to fund projects. At the beginning of the game, the principal commits to a line of credit up to an amount \(kc\) to be used for undertaking projects where \(k\) is a non-negative integer and is a choice variable for the principal. This provides enough funds to try \(k\) projects since each project requires \(c\) to be implemented. If the agent exhausts the funding without obtaining a success, the game ends. The other contingency where the game ends is when the first success is achieved.

**Histories:** There are two relevant histories to keep track of. One is the public history

\(^{12}\)An alternative interpretation for \(X\) is given in section 6.
of past failures, specifically the number of failures up to period $t$.\textsuperscript{13} The other is the agent’s private history including the number of past failures up to $t$ and the quality of projects implemented up to $t$.\textsuperscript{14}

Let $\Pi_k$ denote the principal’s expected payoff at time 0 from a contract which allows for $k$ trials and has the agent implement a project if and only if it is good. The principal’s problem is to choose $k$ and $\{X_{sk}\}_{s=0}^{k-1}$ at time 0 to maximize her expected payoff $\Pi_k$. The agent’s strategy at a given point in time is to choose which project (if any) to implement that period as a function of his private history and the projects available at that period. Let $V_k(m, s)$ be the agent’s expected payoff after $s$ failures, $m$ of which were good projects, in a $k$-trial contract\textsuperscript{15}.

Figure 1 illustrates the game tree for the stage game when both good and bad projects are available and there have been $s$ failures in projects out of which $m \leq s$ were failures in good projects. If $s \geq k$, then the principal does not finance projects and hence the payoff to both the principal and the agent is given by 0 each. If $s < k$, then the principal finances the project. If the agent chooses not to implement a project, then both the principal and the agent get 0 each and the number of failures in projects remains unchanged. If the agent implements a bad project, then the agent gets $b$ and the principal gets $-c$. The number of failures which have failed is given by $s + 1$, while the number of failures in good projects is still given by $m$. If the agent implements a good project, then it can result in either success or failure. In case the project fails, the agent gets $b$ while the principal gets $-c$. The number of projects that have failed equals $s + 1$ while the number of good projects that have failed

\textsuperscript{13}Note that since the contract specifies payments only as function of number of past failures, it’s not required to track the order of sequence of failures and non-implementation. This is without loss of generality given the IID assumption regarding the availability of good projects.

\textsuperscript{14}The agent’s private history also includes availability of projects in past periods, however this does not affect payoff.

\textsuperscript{15}If the principal expects the agent to implement a project iff it is good, then $s$ failures corresponds to the principal’s belief about the agent’s ability to be $\alpha_s$, while $m$ failures in good projects corresponds to the agent’s belief about his ability to be $\alpha_m$. There is thus a one to one map between the number of failures $(m, s)$ and the beliefs $(\alpha_m, \alpha_s)$. 


is given by $m + 1$. Since the principal does not observe the quality of the project but only observes failure, she cannot identify if the project implemented was good or bad. If the good project succeeds, the principal pays the agent $X_{sk}$. Thus the agent’s payoff is given by $b + X_{sk}$ while the principal’s payoff is given by $R - X_{sk} - c$.

### 1.2.2 Complete Information Benchmark

In this subsection, we derive the optimal contract when the principal can observe the quality of the projects available each period and write a contract which can include the quality. In this case, the principal implements a project if and only if it is good and keeps experimenting until the point at which her belief falls below a cutoff level. We derive below this cutoff belief.

Let $\alpha_k$ denote the belief regarding the agent upon observing $k$ failures and zero successes. Suppose that there is a good project available. Then if the principal permits the good project
to be implemented and stops experimenting if the project fails, her payoff is given by

\[ \alpha_k \gamma R - c. \]

In the above expression, \( \alpha_k \gamma \) refers to the probability of success in a good project given \( k \) failures and zero successes in good projects and \( R \) is the payoff to the principal in the event of success. Thus expected surplus from implementing a good project is given by \( \alpha_k \gamma R \) and \( c \) is the cost of implementing a project.

The principal should thus experiment as long as the above payoff is non-negative, that is till the highest \( k \) such that

\[ \alpha_k \gamma R \geq c. \]

Assumption 1: Experimentation is initially profitable in the absence of an agency problem:

\[ \alpha_0 \gamma R \geq c. \]

This assumption means that without the agency problem, the principal would be willing to experiment at least once at the initial belief.

### 1.3 The Special Case with at Most One or Two Trials

This section illustrates some basic insights and tradeoffs in the special case where first there is only one trial and second where there may be up to two trials.

#### 1.3.1 One Trial Contract

In this case, the agent gets only one shot at implementing a project. For the contract that allows for one trial, we need to determine the optimal bonus \( X_{01} \) that incentivizes the agent
to implement the project if and only if the project is good. The incentive compatibility condition for not implementing a project over choosing a bad project is given by

$$\delta V_1(0,0) \geq b. \quad (1.2)$$

The equation says that the payoff to the agent from not implementing a project has to be greater than that of selecting the bad project. The payoff from not implementing a project is given by $\delta V_1(0,0)$. It refers to the observation that if the agent chooses to not implement a project, then he gets 0 this period and the next period utility for the agent is still given by $V_1(0,0)$ since the the number of failures are unchanged if the agent selects not to implement a project. If the agent selects the bad project, then he gets $b$ this period but the project is sure to fail and since the contract only allows for one trial, his continuation payoff is 0.

The incentive compatibility condition for choosing the good project if it is available is given by

$$b + \alpha_0 \gamma X_{01} \geq \max(\delta V_1(0,0),b). \quad (1.3)$$

Given equation (2), we can simplify as

$$b + \alpha_0 \gamma X_{01} \geq \delta V_1(0,0). \quad (1.4)$$

The left side stands for the expected payoff to the agent if he selects a good project. It consists of the current gain $b$ that the agent makes if he implements a project and the expected bonus in case of success. Since the project is good and the belief that the agent is of high ability is given by $\alpha_0$, the probability of success is given by $\alpha_0 \gamma$. In case of success, the agent is rewarded by the bonus $X_{01}$ as stated in the contract. The contract allows for only one trial; hence if the agent fails, the principal chooses to stop experimenting in which case the agent receives 0. The term on the right side refers to the payoff from not implementing a project which is same as before.
The agent’s ex-ante value in such an incentive compatible contract is given by

\[ V_1(0, 0) = p(b + \alpha_0 \gamma X_{01}) + (1 - p)\delta V_1(0, 0) \]

\[ = \frac{p}{1 - \delta(1 - p)}(b + \alpha_0 \gamma X_{01}). \]

\[ = \theta(b + \alpha_0 \gamma X_{01}) \quad (1.5) \]

where \( \theta \equiv \frac{p}{1 - \delta(1 - p)}. \) Since both \( p \) and \( \delta \) lie between 0 and 1, we get \( 0 < \theta < 1. \)

We observe that incentive compatibility for the good project is always satisfied since \( \delta < 1 \) and the expected payoff from implementing a project is non-negative\(^{16}\). Hence we only need to make sure that \( X_{01} \) is high enough so that incentive compatibility condition for the bad project is satisfied. Plugging in the value of \( V_1(0, 0) \) and solving for \( X_{01} \) we obtain,

\[ X_{01} \geq \frac{b(1 - \delta)}{\delta \alpha_0 \gamma p}. \quad (1.6) \]

The principal’s expected payoff from this contract is given by \( \Pi_1 \) which satisfies

\[ \Pi_1 = \theta[\alpha_0 \gamma (R - X_{01}) - c]. \]

The term \( R - X_{01} \) represents the payoff to the principal in case of success while \( c \) stands for the cost of implementing the project. Since the contract allows for only one failure, one failure ends the experimentation. As the bonus payments enter negatively in the principal’s profit, she won’t pay the agent more than required and hence inequality (4) is satisfied with an equality. Thus we get

\[ X_{01} = \frac{b(1 - \delta)}{\delta \alpha_0 \gamma p}. \quad (1.7) \]

We thus observe that \( X_{01} \) is an increasing function of \( b \) and a decreasing function of \( \delta, \alpha_0, \gamma, p \)

\(^{16}\)From equation (5), we obtain \( V_1(0, 0) = \theta(b + \alpha_0 \gamma X_{01}). \) Inserting this in equation (4), the right hand side equals \( \delta \theta(b + \alpha_0 \gamma X_{01}) \). Since \( 0 < \delta, \theta < 1 \), equation (4) is satisfied.
come along is high enough that he is willing to not implement the bad project. The cost of passing up on the bad project at hand is the private benefit $b$. Hence higher is the $b$, greater the incentive needs to be for the agent to pass up on that in the current period. Since the agent has to wait till at least the next period to see if a good project comes along, the more impatient an agent is, higher needs to be the bonus from succeeding in a good project. The bonus is only paid out in the event of success in the good project and hence it is decreasing in $\alpha_0\gamma$, the probability of success of the good project. Finally, the lower the value of $p$, the more the agent needs to wait for a good project to come along and hence the reward for waiting has to be higher.

The corresponding expected payoff to the agent from accepting the contract is given by

$$V_1(0,0) = \frac{b}{\delta}.$$  

The principal should prefer to offer this contract over not experimenting at all if and only if $\Pi_1 \geq 0$ which gives us:

$$\alpha_0\gamma R \geq c + \frac{b(1-\delta)}{\delta p}.$$  

**Assumption 2:**

$$\alpha_0\gamma R > c + \frac{b(1-\delta)}{\delta p}. \quad (1.8)$$

This inequality says that the principal will want to experiment at least once even in the second best.

1.3.2 Two Trial Contract

In this case, the agent gets at most two shots at implementing projects. We first consider what happens in case the first trial results in failure. If the first trial fails, there is only...
one more failure permitted in the contract. Hence the analysis is similar to the analysis for a one failure contract considered above. Since the contract requires the agent to implement a project if and only if it is good and on path the belief of the agent is $\alpha_1$ after the first failure, we obtain

$$X_{12} \geq \frac{b(1 - \delta)}{\delta \alpha_1 \gamma p}.$$  \hspace{1cm} (1.9)

We observe that the bonus offered to incentivize the agent in the last opportunity has to be higher in the contract with two trials than in the contract with one trial that is $X_{12} > X_{01}$. This is because the agent’s belief about his ability is lower and hence he needs a higher incentive to wait for the good project.

In order to determine $X_{02}$, we consider the incentive compatibility conditions prior to first failure. The incentive compatibility condition for selecting the good project given 0 failures is now given by

$$b + \alpha_0 \gamma X_{02} + (1 - \alpha_0 \gamma) \delta V_2(1, 1) \geq \delta V_2(0, 0).$$  \hspace{1cm} (1.10)

Since the principal does not stop experimenting immediately after a failure but allows the agent to continue to experimenting, the agent’s payoff upon failure is given by $\delta V_2(1, 1)$ and not 0 as before.

The incentive compatibility condition for rejecting the bad project gives us

$$\delta V_2(0, 0) \geq b + \delta V_2(0, 1).$$  \hspace{1cm} (1.11)

Unlike the one failure contract, failure in a project in this case does not stop experimentation. The agent does not update his beliefs about himself after the expected failure but the principal’s belief declines to $\alpha_1$ (as implementing the bad project is "off path"; that is, the principal was expecting the agent to implement only good projects). We note that even if the agent deviates from the principal’s prescribed strategy after 0 failures to implement a bad project, he will choose to implement a project iff good in the second trial. This follows from verifying that the two incentive compatibility conditions - (i) $b + \alpha_0 \gamma X_{12} \geq \delta V_2(0, 1)$
and (ii) \( \delta V_2(0, 1) \geq b \) are satisfied\(^{17}\). The agent’s value from the contract in such a case is given by

\[
V_2(0, 1) = \theta[b + \alpha_0 \gamma X_{12}]
\]

The agent’s ex-ante value (on path) is given by

\[
V_2(0, 0) = \theta[b + \alpha_0 \gamma X_{02} + (1 - \alpha_0 \gamma) \delta V_2(1, 1)].
\]

Once again the incentive compatibility for the good project is satisfied since \( \delta < 1 \) and the expected payoff from implementing the project is non-negative. Thus we only need to make sure that \( X_{02} \) is high enough so that incentive compatibility condition for the bad project is satisfied. Plugging in the value of \( V_2(0, 0) \) and solving for \( X_{02} \) we get,

\[
X_{02} \geq \frac{b}{\theta \alpha_0 \gamma} \left[ \frac{1}{\delta} - (1 - \alpha_0 \gamma) \delta \theta^2 \right] + X_{12}\left[1 - \delta \theta (1 - \gamma)\right] \quad (1.12)
\]

We thus observe that \( X_{02} \) is an increasing function of \( X_{12} \).

The principal’s expected payoff from offering a contract which allows for two trials is given by \( \Pi_2 \) which satisfies

\[
\Pi_2 = \theta[\alpha_0 \gamma (R - X_{02}) - c]
\]

\[
+ \delta \theta^2 (1 - \alpha_0 \gamma)[\alpha_1 \gamma (R - X_{12}) - c].
\]

Since both \( X_{02} \) and \( X_{12} \) enter negatively in the expression for expected payoff and \( X_{02} \) is increasing in \( X_{12} \), the principal will try to minimize these two as much as possible. Hence both equations (7) and (10) hold with equality and we obtain,

\[
X_{12} = \frac{b(1 - \delta)}{\delta \alpha_1 \gamma p}. \quad (1.13)
\]

\[
X_{02} = \frac{b(1 - \delta)}{\delta \alpha_0 \gamma p} + \frac{b(1 - \delta)}{\delta \alpha_1 \gamma p} + b. \quad (1.14)
\]

\(^{17}\)This is discussed in more detail in Section 4.
It’s useful to think about the individual terms in the above expression. The first term plays a similar role as the term in equation (4) - it provides incentives to forego on the bad project in favor of waiting for a good project to come along. However in equation (14), there are now two additional terms - these refer to the fact that in the contract with two failures there are additional benefits to selecting a bad project when there is another opportunity still remaining. If the agent selects a bad project, he knows for sure that the game will not end this period - since the project is sure to fail - and hence gives the agent an opportunity to earn further rent. There are two sources of this additional rent. First, the agent gets to implement another project which gives him a benefit of \( b > 0 \). Second, the agent has the opportunity to gain an additional rent because his belief is higher than the belief which the principal had in mind while designing the bonus for the next project - we can see this from

\[
V_2(0, 1) = \theta[b + \alpha_0 \gamma X_{12}] = \theta[b + \frac{\alpha_0}{\alpha_1} \frac{b(1 - \delta)}{\delta p}] > \theta[b + \frac{b(1 - \delta)}{\delta p}] = V_2(1, 1).
\]

We also see that \( X_{02} > X_{12} \) - that is the contract has to be front-loaded. While comparing \( X_{02} \) and \( X_{12} \) we see that the agent is more pessimistic about his ability upon implementing a good project and failing - hence he has to be possibly provided a greater incentive in order to make sure he waits for the good project. On the other hand, the agent has to be provided additional incentives in the first attempt to compensate him to forego the possible rents from taking up the second project as outlined in the previous paragraph. What \( X_{02} > X_{12} \) says is that the second effect dominates and hence the contract is front-loaded. We note that this contrasts with some of the existing results in the literature. For example, Halac, Kartik and Liu (2016) found instances where contracts have bonuses which are increasing as the agent gets more pessimistic. The main difference in our model is that the agent gets a benefit each time a project is undertaken and hence the contract has to compensate the agent for the loss in continuation value in order to incentivize him to implement only good projects.

It’s also useful to compare \( X_{02} \) with the bonus \( X_{02}^V \) that the principal would have to pay to the agent in the scenario the principal could verify the quality of the project implemented
before giving permission to go ahead with the second trial and could commit to firing the agent in case it was discovered that he had selected a bad project. In this case the the bonus\(^{18}\) can be obtained as

\[
X^V_{02} = \frac{b(1 - \delta)}{\delta \alpha_0 \gamma p}
\]

Thus if the principal could verify the project quality ex-post and commit to firing the agent for selecting the bad project, the contract becomes back-loaded that is \(X^V_{02} < X_{12}\).

We also note that \(X^V_{02} > X_{01}\), that is increasing the number of trials implies that earlier success have to be rewarded more in the contract which has higher number of trials. This is because the agent has to be compensated for greater losses in rents in the contract with higher number of trials.

If we compare \(\Pi_2\) with \(\Pi_1\), we see that the principal faces benefits and costs in moving from a contract with 1 trial to 2 trials. The change in the expected payoff can be decomposed as:

\[
\Pi_2 - \Pi_1 = \delta \theta^2 (1 - \alpha_0 \gamma) \left[ \alpha_1 \gamma (R - X_{12}) - c \right] + \theta \alpha_0 \gamma (X_{02} - X_{01})
\]

The additional benefit is captured by the term

\[
\delta \theta^2 (1 - \alpha_0 \gamma) \left[ \alpha_1 \gamma (R - X_{12}) - c \right].
\]

This reflects the case that the high ability agent might fail while attempting a good project on the first attempt which happens with probability \((1 - \alpha_0 \gamma)\) but allows for the possibility that the agent succeeds on the second attempt.

The cost on the other hand can be seen in the term

\[
\theta \alpha_0 \gamma (X_{02} - X_{01}).
\]

\(^{18}\)This is also the bonus that the principal would pay to an agent if he can costlessly replace the agent with another agent upon failure in a project. In this case though ability is not agent-specific but is more about the quality of the idea that is being assessed through projects.
If we compare it to the case with one failure we see that that the principal gets a lower payoff if the agent succeeds in the first attempt since $X_{02} > X_{01}$. Thus the main tradeoff to the principal is increasing the number of experiments funded leads to more accurate information about the ability of the agent but has to be paid for not only in terms of more cost of experimentation but also in higher rents to the agent in case of earlier success.

1.4 Optimal Contract

In this section, we examine the properties of the optimal contract that incentivizes the agent to implement the project if and only if it is a good project.

We can decompose the problem into a two step procedure: First, given a maximum number $k$ of trials that the principal is willing to fund, what should the optimal bonus scheme be in order for the agent to choose the project if and only if it is a good project? Having found the optimal bonus scheme, we determine the number of trials the principal is willing to fund.

1.4.1 Optimal Bonus

**Definition:** Given a maximum number of trials $k$ that the principal is willing to fund, we say that the bonus scheme $(X_{sk})_{s=0,1,...,k-1}$ is incentive compatible if under such a bonus scheme the agent chooses to implement projects if and only if they are good projects. We define an optimal contract as a contract that is incentive compatible and maximizes the principal’s expected payoff.

Let $(X_{sk})_{s=0,1,...,k-1}$ be a incentive compatible bonus scheme. Let $\Pi_{s,k}$ denote principal’s
expected payoff from such a contract when \( s < k \) failures and zero successes in good projects have taken place. Then \( \Pi_{s,k} \) satisfies the following the recurrence relation:

\[
\Pi_{s,k} = p[\alpha s \gamma (R - X_{s,k}) + (1 - \alpha s \gamma) \delta \Pi_{s+1,k} - c] + (1 - p) \delta \Pi_{s,k}
\]

With probability \( p \), a good project becomes available and is implemented. This leads to an expected profit of \( \alpha s \gamma (R - X_{s,k}) + (1 - \alpha s \gamma) \delta \Pi_{s+1,k} - c \). Given that the bonus scheme is incentive compatible, all the earlier failures were in good projects and hence the probability that the agent is high ability is given by \( \alpha s \) from equation (1). Thus the probability of success in the good project is given by \( \alpha s \gamma \). In case of a success, the principal gets \( R - X_{s,k} \) since the contracts specifies \( X_{s,k} \) as the bonus to be paid in such a situation. In case of a failure which happens with probability \( (1 - \alpha s \gamma) \), the future payoff is given by \( \delta \Pi_{s+1,k} \). Finally \( c \) stands for the cost of implementing the project. With probability \( 1 - p \), the good project is not available and thus a project is not implemented. Hence we move on to the next period and the profit for the principal is summarized by \( \delta \Pi_{s,k} \).

The above recurrence relation can be further simplified to yield

\[
\Pi_{s,k} = \theta(\alpha s \gamma (R - X_{s,k}) + (1 - \alpha s \gamma) \delta \Pi_{s+1,k} - c)
\]

where \( \theta = \frac{p}{1 - \delta (1 - p)} \). Thus the overall expected profit from offering a contract which tolerates \( k \) failures is given by \( \Pi_{0,k} \equiv \Pi_k \) where

\[
\Pi_k = \theta[\alpha_0 \gamma (R - X_{0,k}) + (1 - \alpha_0 \gamma) \delta \Pi_{1,k} - c]
\]

\[
= \theta[\alpha_0 \gamma (R - X_{0,k}) - c] + \theta(1 - \alpha_0 \gamma) \delta \Pi_{1,k}
\]

\[
= \theta[\alpha_0 \gamma (R - X_{0,k}) - c] + \theta^2(1 - \alpha_0 \gamma)(\alpha_1 \gamma (R - X_{1,k}) + (1 - \alpha_1 \gamma) \delta \Pi_{2,k} - c)
\]

\[
= \theta(\alpha_0 \gamma (R - X_{0,k}) - c) + \sum_{s=1}^{k-1} \theta^{s+1} \delta^s \left( \prod_{m=0}^{s-1} (1 - \alpha_m \gamma) \right) (\alpha_s \gamma (R - X_{s,k}) - c)
\]

Given \( k \), the principal’s profit maximization problem is to choose \((X_{s,k})_{s=0}^{k-1}\) and \((V_k(m, s))_{m=0}^{s}\) to maximize \( \Pi_k \) subject to the following constraints: subject to, for each \( s = 0, ..., k - 1 \),
\[ b + \alpha_m \gamma X_{sk} + (1 - \alpha_m \gamma) \delta V_k(m + 1, s + 1) \geq \delta V_k(m, s) \quad \text{(IC-G)} \]
\[ b + \delta V_k(m, s + 1) \leq \delta V_k(m, s) \quad \text{(IC-B)} \]
\[ X_{sk} \geq 0 \quad \text{(LL)} \]

where \( V_k(m, s) \) is defined by:

\[
V_k(m, s) = \max_{1_{Gms}, 1_{BGms}, 1_{Bms}, 1_{Gms+1_{BGms}} \leq 1} \{ p[1_{Gms}(b + \alpha_m \gamma X_{sk}) + (1 - \alpha_m \gamma) \delta V_k(m + 1, s + 1)) + 1_{BGms}(1 - 1_{Gms})(b + \delta V_k(m, s + 1)) + (1 - 1_{BGms})(1 - 1_{Gms})\delta V_k(m, s)] + (1 - p)[1_{Bms}(b + \delta V_k(m, s + 1)) + (1 - 1_{Bms})\delta V_k(m, s)]\}
\]

where \( 1_{Gms} \) is an indicator function which takes value = 1 if the agent selects the good project (after \( s \) public failures of projects, of which \( m \) were good) if it is available and 0 otherwise. Similarly \( 1_{BGms} \) stands for the indicator function for the agent’s choice regarding an implementation of bad project if a good project is available ((after \( s \) public failures of projects, of which \( m \) were good) while \( 1_{Bms} \) stands for the indicator function for the agent’s choice regarding implementation of a bad project (after \( s \) public failures of projects, of which \( m \) were good) if a good project is not available.

Our first result deals with the question of how should the principal set \( X_{sk} \) to maximize the expected profit from such a contract.

**Proposition 1:** Suppose the principal’s optimal contract funds up to \( k \) trials. Then
bonuses \((X_{sk})_{s=0,1,...,k-1}\) in this contract are given by

\[
X_{sk} = (k - 1 - s)b + \sum_{m=s}^{k-1} \frac{b(1 - \delta)}{\delta p^\gamma \alpha_m}.
\]

Proof: See the appendix

**Sketch of the proof**

The proof is divided into the following steps. Instead of the profit maximization problem, we focus on the equivalent cost minimization problem.

**Step One:** We first consider a relaxed problem by restricting agent’s off path strategies to have only one-period deviations - that is the agent can only deviate once (by either choosing not to implement a project when a good project is available or by implementing a bad project) but from then on will choose to implement projects if and only if they are good projects. Since the bonus schemes are such that they act as incentives against all deviations, it has to be true that they prevent the agent from these types of deviations. We can thus write the relaxed problem as

\[
\min_{(X_{sk})_{k=0}} \theta_0 \alpha \gamma X_{0,k} + \sum_{s=1}^{k-1} \theta^{s+1} \delta^s \left[ \prod_{m=0}^{s-1} (1 - \alpha_m \gamma) \right] [\alpha_s \gamma X_{s,k}]
\]

subject to for each \(s = 0, ..., k - 1,\)

\[
b + \alpha_s \gamma X_s + (1 - \alpha_s \gamma) \delta V_k^T (s + 1, s + 1) \geq \delta V_k (s, s) \quad \text{(IC-G-O-s)}
\]

\[
b + \delta V_k^T (s, s + 1) \leq \delta V_k (s, s) \quad \text{(IC-B-O-s)}
\]

\[
X_{sk} \geq 0 \quad \text{(LL)}
\]
where

$$V_k^T(s, s) = \theta(b + \alpha_s X_{sk}) + \sum_{m=s+1}^{k-1} \theta^{m+1-s} \delta^{m-s} \prod_{n=s}^{m-1} (1 - \alpha_n \gamma) \left[ b + \alpha_m \gamma X_{mk} \right]$$

and

$$V_k^T(s, s + 1) = \theta(b + \alpha_s \gamma X_{s+1k}) + \sum_{m=s+1}^{k-2} \theta^{m+1-s} \delta^{m-s} \prod_{n=s}^{m-1} (1 - \alpha_n \gamma) \left[ b + \alpha_m \gamma X_{m+1k} \right]$$

**Step Two:** We then show that IC-G-O-s are satisfied. To see this, we observe that $V_k^T(s, s)$ can be rewritten as

$$V_k^T(s, s) = \theta(b + \alpha_s \gamma X_s + (1 - \alpha_s \gamma) \delta V_k^T(s + 1, s + 1))$$

Thus we can rewrite the IC-G-O-s as

$$b + \alpha_s \gamma X_s + (1 - \alpha_s \gamma) \delta V_k^T(s + 1, s + 1) \geq \delta \theta(b + \alpha_s \gamma X_s + (1 - \alpha_s \gamma) \delta V_k^T(s + 1, s + 1))$$

which is always satisfied since $b + \alpha_s \gamma X_s + (1 - \alpha_s \gamma) \delta V_k^T(s + 1, s + 1) > 0$ and $0 < \delta, \theta < 1$.

**Step Three:** Next, if the only off path strategies available to the agent are these one-period deviations, then all the IC-B-O-s need to hold with equality, otherwise the principal can decrease bonuses without affecting incentives following $s$ failures and before to increase profit\(^{19}\).

**Step Four:** Based on the IC-B-O-s holding with equality, we obtain a difference equation linking $X_{sk}$ and $X_{s+1k}$:

$$X_{sk} = \frac{b(1 - \delta)}{\delta \gamma \alpha_{sk} p} + X_{s+1k} + b$$

along with the boundary condition:

$$X_{k-1k} = \frac{b(1 - \delta)}{\delta \gamma \alpha_{k-1k} p}$$

\(^{19}\)It is possible to decrease bonuses with violating limited liability conditions since one can show that $X_{sk} > 0$, which follows from IC-B-O-s and induction - the details are shown in the appendix.
This gives us a solution for $X_{sk}$ as stated in the proposition.

**Step Five:** We finally show that the $X_{sk}$ we found by restricting the agent’s off-path strategy are enough to deter the agent from more complex off-path strategies involving multiple deviations. Intuitively, the contract in the relaxed problem ensured that the agent has no incentives to deviate if never deviated. The agent’s private belief is either the same as the public belief (if he deviates by not implementing a project when a good project is available) or higher (if he deviates by selecting a bad project). Hence we can verify deviating is even less attractive to the agent if he has deviated before.

Proposition 1 lends itself to the following two corollaries:

**Corollary 1:** Bonuses are front-loaded i.e $X_{0k} > X_{1k} > \ldots > X_{k-1k}$.

The intuition is that earlier bonuses need to compensate the agent for giving up the rents that he could have got from future projects as well as rents due to the possibility of divergence between the private belief of the agent and the belief based on public history.

**Corollary 2:** Increasing the number of failures allowed increases the bonus needed to incentivize the agent at each stage: $X_{sk} > X_{sk'}$ for $k > k'$ for $s = 0, 1 \ldots k' - 1$.

The intuition follows from observing that an increase in the number of trials implies that the agent has an opportunity to get greater private benefits by implementing more projects as well as earn higher rents by causing a greater divergence between public and private beliefs. Thus the agent has to be compensated for a greater potential loss of continuation rents for selecting good projects when there is an increase in number of maximum failures allowed.
1.4.2 Optimal Number of Trials

Having found the optimal bonus scheme, we move on to examine the question of how should the principal decide on the optimal number of trials. To understand the determinants, it’s useful to decompose the impact on expected payoff of the principal as a result of a change in the number of trials. The change in payoff for the principal if he decides to increase the number of trials from \( k \) to \( k + 1 \) is given by

\[
\Delta \Pi_k = \theta^{k+1} k \left[ \prod_{m=0}^{k-1} (1 - \alpha_m \gamma) \right] [\alpha_k \gamma (R - X_{kk+1}) - c] \\
+ \sum_{s=1}^{k} \theta^s \delta^{s-1} \alpha_0 (1 - \gamma)^{s-1} \gamma (X_{s-1k} - X_{s-1k+1})
\]

\[
\equiv MB_{SB}^k - MC_{SB}^k
\]

We can decompose the total change in the expected payoff of the principal into two parts: the “marginal benefit” and the “marginal cost”. We define and expand on the terms below.

Increasing the number of trials from \( k \) to \( k + 1 \) has two consequences for the principal’s expected payoff - first, there is an additional opportunity to succeed in case the first \( k \) trials result in failure and second, the bonuses for success in the first \( k \) trials have to be altered as a consequence of corollary 2.

Since the number of trials has gone up from \( k \) to \( k + 1 \), there is now an additional opportunity to experiment. The “marginal benefit” refers to the impact on the expected payoff due to the principal having one additional chance of experimentation, holding fixed the bonus to be paid in case of success in the first \( k \) trials. We note that the additional trial is of use only if the first \( k \) trials have resulted in failure. For \( k \geq 1 \), the expected payoff from the additional opportunity is given by

\[
MB_{SB}^k \equiv \theta^{k+1} k \left[ \prod_{m=0}^{k-1} (1 - \alpha_m \gamma) \right] [\alpha_k \gamma (R - X_{kk+1}) - c]
\]
We can decompose this expression into two parts - $\prod_{m=0}^{k-1}(1-\alpha_m\gamma)$ refers to the probability of no success in the first $k$ trials while $\theta^{k+1}\delta^k[\alpha_k\gamma(R - X_{kk+1}) - c]$ refers to the expected payoff for success in the $k + 1^{th}$ trial. $MB^{SB}_0$ is given by $\theta[\alpha_0\gamma(R - X_{01}) - c]$.

**Lemma 1:** The “marginal benefit” of experimentation is decreasing in the maximum number of failures tolerated by the principal, that is $MB^{SB}_k$ is a decreasing function of $k$.

Proof: See the appendix

The intuition is that not only does the new opportunity present itself much later (which is reflected in the terms $\theta^{k+1}\delta^k$), but it is also less likely to present itself - the probability is given by $\prod_{m=0}^{k-1}(1-\alpha_m\gamma) = \{1 - \alpha_0 + \alpha_0(1-\gamma)^k\}$ - and also when it presents itself the expected payoff $(\alpha_k\gamma(R - X_{kk+1}) - c)$ is decreasing in $k$ as well since the probability of success $\alpha_k\gamma$ is lower and the principal also needs to pay a higher bonus $X_{kk+1}$ to incentivize the agent.

The “marginal cost” captures the fact that increasing the number of trials permitted results in increasing the bonus that has to be promised to the agent in case of success after $0, 1, ... k - 1$ failures. This observation follows from corollary 2. The “marginal cost”\(^{20}\) for $k \geq 1$ is given by

$$MC^{SB}_k \equiv \sum_{s=1}^{k} \theta^s\delta^{s-1}\alpha_0(1-\gamma)^{s-1}\gamma(X_{s-1k+1} - X_{s-1k})$$

In the above expression, $\alpha_0(1-\gamma)^{s-1}\gamma$ refers to the probability of success in the $s^{th}$ trial, while $\theta^s\delta^{s-1}(X_{s-1k+1} - X_{s-1k})$ refers to (discounted) value of increased bonus. We also define $MC^{SB}_0 \equiv 0$.

Using the result for the optimal bonuses from proposition 1, we can rewrite the “marginal

\(^{20}\)One could decompose the effect on expected profit due to an increase in the number of trials in different ways. However it is instructive for the analysis to have the cost of financing a project $c$ be subtracted from the “marginal benefit”, as opposed to including it as part of “marginal cost".
cost” for an incentive compatible contract as

\[ MC_k^{SB} = \sum_{s=1}^{k} \theta^s \delta^{s-1} \alpha_0 (1 - \gamma)^{s-1} \gamma (b + \frac{b(1 - \delta)}{\delta \alpha_k \gamma p}) \]

**Lemma 2:** The “marginal cost” of experimentation is increasing in the maximum number of failures tolerated by the principal, that is \( MC_k^{SB} \) is increasing function of \( k \).

**Proof:** See the appendix

The intuition is that a higher value of \( k \) implies a lower value of \( \alpha_k \) which results in a higher increase in bonus to be paid in the event of earlier success as \( X_{s-1k+1} - X_{s-1k} = b + \frac{b(1 - \delta)}{\delta \alpha_k \gamma p} \) as well as there being a higher probability of earlier success since \( \sum_{s=1}^{k} \theta^s \delta^{s-1} \alpha_0 (1 - \gamma)^{s-1} \gamma \) is increasing in \( k \) as well.

Once we have the decomposition of changes in expected payoff of the principal as a result of changing the number of trials allowed, we can characterize the optimal number of trials that the principal should be willing to tolerate. The change in expected payoff due to a change in the maximum number of trials can be viewed as the difference of the “marginal benefit” and the “marginal cost”. The “marginal benefit” is a decreasing function of the number of trials permitted and the “marginal cost” is an increasing function of the number of trials permitted. Hence the change in expected payoff is positive as long as the “marginal benefit” exceeds the “marginal cost” and thus the principal should choose the largest number of trial for which the “marginal benefit” exceeds the “marginal cost”. This is also illustrated in Figure 2 below.

**Proposition 2:** The optimal number of trials is unique and given by the highest \( k \) for which \( MB_k^{SB} \geq MC_k^{SB} \)
We can also compare the optimal number of trials in the complete information benchmark and the second best. In the complete information case, there is no bonus to be paid and hence the “marginal cost” as defined above equals 0 for any number of trials decided upon by the principal. We thus have $MC_{CI}^k = 0$ for any $k$. The “marginal benefit” of an additional trial in the complete information benchmark is given by

$$MB_{CI}^k \equiv \theta^{k+1} \delta^k \prod_{m=0}^{k-1} (1 - \alpha_m \gamma) [\alpha_k \gamma R - c]$$

The “marginal benefit” is higher in the complete information benchmark as compared to the second best. Hence the principal should experiment more in the complete information as compared to the situation in which the agent has to be incentivized through bonuses. This discussion is summarized in the following proposition.

**Proposition 3:** The second best allows for an inefficiently low number of trials compared to the complete information benchmark.

### 1.5 Comparative Statics

In this section, we provide comparative statics results on the number of trials and the principal’s expected payoff as a function of parameters.

**Proposition 4:** The principal’s second best expected payoff as well as the number of trials are increasing in $R$ and $\alpha_0$ and decreasing in $c$.

---

21Recall that the cost of financing a project $c$ is subtracted from the marginal benefit in the decomposition described above.
Figure 1.2: Optimal number of trials

**Comparative statics with respect to $\alpha_0$**

To understand how a change in $\alpha_0$ impacts the number of trials, we look at how it impacts the $MB_k^{SB}$ and $MC_k^{SB}$. We note that $MB_k^{SB}$ is an increasing function of $\alpha_0$ (all proofs are in the appendix) while it is possible for $MC_k^{SB}$ to be either an increasing or decreasing function of $\alpha_0$. The impact on the “marginal cost” is driven through two channels - holding fixed the number of trials - an increase in $\alpha_0$ leads to a reduction in bonus paid when success happens after a specific number of failures. However it is also more likely that the agent succeeds earlier, which combined with the front-loading of bonuses imply that the principal could end up paying more. Hence the impact on $MC_k^{SB}$ is ambiguous. Thus it might seem possible that as a result of increase in $\alpha_0$, the increase in “marginal cost” is so high that the principal might end up reducing the number of experiments he wants to perform. However as shown in the Appendix, an increase in the prior is always going to lead to an increase in the number of trials.

The effect on expected payoff is unambiguous as well - holding fixed the number of trials,
it can be shown that expected payoff of the principal increases as $\alpha_0$ increases. Since the principal is free to vary the number of trials (which includes the option of not changing the number of trials), her expected payoff is going to be higher in situations when there is an increase in $\alpha_0$.

**Comparative statics with respect to $c$:**

An increase in $c$ leads to a reduction in the “marginal benefit” but has no effect on “marginal cost”. Hence the number of trials permitted is going to be weakly lower. Holding fixed the number of trials, expected payoff is decreasing in $c$ and hence an increase in $c$ leads to a reduction in expected payoff.

**Comparative statics with respect to $R$:**

An increase in $R$ leads to a increase in the “marginal benefit” but has no effect on “marginal cost”. Hence the number of trials permitted is going to be weakly higher. Expected payoff is going to increase following an argument similar to that for the $\alpha_0$ case.

### 1.6 Discussion

#### 1.6.1 Connecting Predictions with Empirics

The model developed can be applied to venture capital industry. We can view $X_{sk}$ as a measure of cash-flow rights\(^{22}\) for the entrepreneur upon success. Corollary 1 suggests that

\(^{22}\)Cash-flow rights for entrepreneurs are defined as the fraction of a portfolio company’s equity value that entrepreneurs have a claim to.
the cash-flow rights for the entrepreneurs are a decreasing function of the number of past failures. Kaplan and Strömberg (2003) find evidence that founders’ cash flow rights decline over financing rounds and increase with firm performance. They suggest that the increase in VC cash flow rights over financing rounds is consistent with the VC demanding more equity as compensation for providing additional funding. Our model provides an alternative explanation based on incentive theory for reasons why founders’ cash-flow rights decline over financing rounds as well as when firm’s performance becomes worse.

Our model also has some implications for the structure of anti-dilution provisions which protect previous investors during “down rounds”. Anti-dilution provisions are quite common (see for e.g., Kaplan and Strömberg 2003; Gompers, Gornall, Kaplan, and Strebulaev 2016) and are meant to protect the investors against future financing rounds at a lower valuation than the valuation of the current (protected) round. Typically these come at the cost of reduced equity shares for the founders during down rounds and are often associated with loss of motivation on part of the founders. One can interpret the optimal bonuses identified in proposition 1 as a measure of the maximum amount of equity dilution for the entrepreneurs per each round that is consistent with still keeping entrepreneurs incentivized to act in the investor’s interest.

The result that an increase in the prior about the entrepreneur’s ability is associated with greater financing is consistent with the findings in the empirical literature on venture capital financing which suggests that entrepreneurs who have succeeded in the past are likely to get better deals (Gompers, Kovner, Lerner and Scharfstein 2010). The empirical evidence regarding the effect of $c$ on financing of experimentation is mixed. Recent research (Kerr, Nanda and Rhodes-Kropf 2014; Ewens, Nanda, and Rhodes-Kropf forthcoming) suggests that the main impact of a reduction in $c$ has been in increasing the number of entrepreneurs financed. However investors have reduced the amount of funding to individual entrepreneurs at the initial stage and now wait for more information about future prospects of the invest-
1.6.2 Non-Monetary Rewards

Our model has so far interpreted $X$ as monetary payments made from the principal to the agent. However in a lot of settings, especially within organizations, ability to exchange money is often limited\footnote{The restriction on the use of monetary rewards is a common feature in the delegation literature.}. Similarly, founders are often rewarded for success not via monetary bonuses or cash flow rights but via greater control rights. To capture this in our model, we can also interpret $X$ in our model as promised continuation utilities instead of monetary bonuses. Let $f(X)$ denote the cost to the principal of providing continuation utility $X$ to the agent. Thus now success after $s$ failures results in the agent receiving $X_{sk}$ as before but the principal’s payoff is given by $R - f(X_{sk})$. If we assume that $f(X)$ is an increasing convex function of $X$, then the expression obtained for $X_{sk}$ in proposition 1 remains unchanged. Further the results for the optimal trials as well as the comparative statics results too remain qualitatively similar. Thus our model can be widely applied to settings even where monetary rewards are not available.

1.6.3 Private Observability and Disclosure

In our model, success in a project was immediately observed by the principal. Suppose instead that the outcome in a project is privately observed by the agent but can be verifiably disclosed. However if success is not immediately disclosed, then they are lost. Further, assume that the principal’s payoff from project success obtains here only when the agent discloses it. Then one question that might be of interest is under the optimal contract found above, does the agent have enough incentive to disclose the success? The answer is yes, and
one can see it in the context of the two trial example. Suppose the agent implements the first trial in period $t$ and obtains a success. In case he reveals the success, he gets a payoff of $b + X_{02}$. However, if he chooses to hide the success, then he moves on to the second trial. Having received success, the agent knows that he is a high ability type for sure while the belief about his ability based on public history is given by $\alpha_1$. Hence following the logic for the two trial case, he will indeed choose to wait for the good project to come before choosing to implement a project. His payoff in this case is given by $b + \theta(b + \gamma X_{12})$. Since $X_{02} > X_{12} + b$, we obtain

\[
b + X_{02} > b + b + X_{12} > b + \theta(b + \gamma X_{12})
\]

and hence the agent will choose to disclose success as soon as he obtains one.

### 1.7 Conclusion

This paper studied a dynamic principal-agent model for experimentation in which the agent is financed to work on projects and we learn about the agent’s ability through observing his performances in the projects. Performance also depends on the quality of the projects implemented; this quality is private information for the agent who is biased towards implementation. We identified the sources of rents received by the agent in this setting and showed that the optimal bonus structure has payments for success decreasing in the number of past failures. The optimal amount of funding to be made available for the agent for implementing projects is determined by comparing the information received by the principal as a result of higher number of observations and the higher rents to be paid to the agent as a consequence of increasing the number of observations.

There are some questions related to the issues analyzed in the paper that may be of
interest for future research. One possibility is to analyze more general reward structure for instance by allowing the principal to contract on a richer set of variables, for example time or periods in which no project is implemented. Another interesting question to study is what happens in the absence of commitment power on behalf of the principal. Finally, it could also be interesting to study the dynamics of the relationship in a multi-stage interaction between the principal and the agent - where performance in a stage has implications for the incentive structure in later stages. These remain for future research.

1.8 Bibliography


1.9 Appendix: Proofs

1.9.1 Proof of Proposition 1:

Fix $k$, the maximum number of failures permitted. We are interested in characterizing the bonus scheme $(X_{sk})_{s=0,1,...,k-1}$ that maximizes the principal’s profit and also ensures that the agent chooses to implement the project if and only if it is a good project.

The proof is divided into the following steps. We first study a relaxed problem by restricting the agent’s off path strategies to have only one deviation - that is the agent can only deviate once but from then on will choose to implement projects if and only if they are good projects. Since the bonus contracts are such that they act as incentives to all deviations, it has to be true that they prevent the agent from such deviations. We then show that if the only off path strategies available to the agent are these deviations, then the incentive compatibility condition for the bad projects have to hold with equality, otherwise the principal can change bonuses to increase profit. Based on that, we obtain a difference equation linking $X_{sk}$ and $X_{s+1k}$ as well as a boundary solution for $X_{k-1k}$. This gives us a solution for $X_{sk}$ as stated in the proposition. We finally show that the $X_{sk}$ we found by restricting the agent’s off-path strategy to one deviations are enough to deter the agent from more complex off-path strategies involving multiple deviations.

*Principal’s problem*

The principal’s expected profit under an incentive compatible contract that has the agent implementing project if and only if it is a good project is given by

$$
\Pi_k = \theta[\alpha_0 \gamma(R - X_{0k}) - c] + \sum_{s=1}^{k-1} \theta^{s+1} \delta^s \left\{ \prod_{m=0}^{s-1} (1 - \alpha_m \gamma) \{\alpha_s \gamma(R - X_{sk}) - c) \right\}
$$

We see in the above expression that the each of the $X_{sk}$ enter negatively in the principal’s profit - hence if the principal can reduce any $X_{sk}$ without violating the limited liability or
any of the incentive compatibility constraints she would do so.

The principal’s problem is to chose \((X_{sk})_{s=0,1...k=1}\) and \((V_k(m, s))_{m=0,1...s=0,1...k=1}\) to maximize profit subject to the incentive compatibility conditions and the limited liability. This is equivalent to the following cost minimization problem:

\[
\min_{(X_{sk})_{s=0,1...k=1},(V_k(m, s))_{m=0,1...s=0,1...k=1}} \theta \alpha_0 \gamma X_{0,k} + \sum_{s=1}^{k-1} \theta^{s+1} \delta^s (\prod_{m=0}^{s-1} (1 - \alpha_m \gamma) (\alpha_s \gamma X_{sk})
\]

subject to incentive compatibility for good projects (IC-G)

\[
b + \alpha_m \gamma V_k(m, s) + (1 - \alpha_m \gamma) \delta V_k(m + 1, s + 1) \geq \delta V_k(m, s)
\]

incentive compatibility for bad projects (IC-B)

\[
\delta V_k(m, s) \geq b + \delta V_k(m, s + 1)
\]

and limited liability (LL)

\[
X_{sk} \geq 0
\]

and \(V_k(m, s)\) is defined by:

\[
V_k(m, s) = \max_{1_Gms, 1_BGms, 1_Bms, 1_Gms+1_BGms \leq 1} \{ p[1_Gms(b + \alpha_m \gamma X_{sk}) \\
+ (1 - \alpha_m \gamma) \delta V_k(m + 1, s + 1)) \\
+ 1_BGms(1 - 1_Gms)(b + \delta V_k(m, s + 1)) \\
+ (1 - 1_BGms)(1 - 1_Gms) \delta V_k(m, s)] \\
+ (1 - p)[1_Bms(b + \delta V_k(m, s + 1)) \\
+ (1 - 1_Bms) \delta V_k(m, s)] \}
\]

where \(1_Gms\) is an indicator function which takes value = 1 if the agent selects the good project if it is available and 0 otherwise. Similarly \(1_BGms\) stands for the indicator function for the agent’s choice regarding bad projects if a good project is available while \(1_Bms\) stands
for the indicator function for the agent’s choice regarding bad projects if a good project is not available.

Suppose the number of public failures is \( s \) out of which \( m \) failures were in good projects. We define \( V_k^T(m, s) \) as the expected profit of the agent if he implements the project if and only if it is a good project from then on.

Then \( V_k^T(m, m) \) satisfies the following recurrence relation:

\[
V_k^T(m, m) = p(b + \alpha_m \gamma X_{mk} + (1 - \alpha_m \gamma)\delta V_k^T(m + 1, m + 1)) + (1 - p)\delta V_k^T(m, m)
\]

\[
= \theta(b + \alpha_m \gamma X_{mk} + (1 - \alpha_m \gamma)\delta V_k^T(m + 1, m + 1))
\]

\[
= \theta(b + \alpha_m \gamma X_{mk}) + \sum_{y=m+1}^{k-1} \theta^{y+1-m} \delta^{y-m} \prod_{n=m}^{y-1} (1 - \alpha_n \gamma)[b + \alpha_y \gamma X_{yk}]
\]

We can similarly get an expression for \( V^T(m, m + 1) \) which is given by

\[
V_k^T(m, m + 1) = p(b + \alpha_m \gamma X_{m+1k} + (1 - \alpha_m \gamma)\delta V_k^T(m + 1, m + 2)) + (1 - p)\delta V_k^T(m, m + 1)
\]

\[
= \theta(b + \alpha_m \gamma X_{m+1k} + (1 - \alpha_m \gamma)\delta V_k^T(m + 1, m + 2))
\]

\[
= \theta(b + \alpha_m \gamma X_{m+1k}) + \sum_{y=m+1}^{k-2} \theta^{y+1-m} \delta^{y-m} \prod_{n=m}^{y-1} (1 - \alpha_n \gamma)[b + \alpha_y \gamma X_{y+1k}]
\]

*Restriction to one-period deviations:

We start out by restricting the agent to one-period deviations. That is only once will he deviate from the principal’s prescribed strategy and from then on he will select the to implement the project if and only if it is a good project. Since the agent is restricted to one-period deviations, the incentive compatibility constraints are that for each of \( s = 0, 1, \ldots, k - 1 \) the following inequalities need to hold true.

40
\[ b + \alpha_s \gamma X_{sk} + (1 - \alpha_s \gamma) \delta V^T_k(s + 1, s + 1) \geq \delta V^T_k(s, s) \quad \text{(IC-G-O-s)} \]

\[ b + \delta V^T_k(s, s + 1) \leq \delta V^T_k(s, s) \quad \text{(IC-B-O-s)} \]

The top inequality (IC-G-O-s) says that the agent prefers to implement a good project if a good project is available. The bottom inequality (henceforth referred to IC-B-O-s) says the payoff from not implementing a project is greater than implementing a bad project.

**IC-G-O-s is always satisfied**

We first note that the incentive compatibility condition for the good project is always satisfied. To see this, we observe that

\[ \delta V^T_k(s, s) = \delta \theta (b + \alpha_s \gamma X_{sk} + (1 - \alpha_s \gamma) \delta V^T_k(s + 1, s + 1)) \]

\[ < (b + \alpha_s \gamma X_{sk} + (1 - \alpha_s \gamma) \delta V^T_k(s + 1, s + 1)) \]

since \(0 < \delta, \theta < 1\).

\[ *X_{sk} > 0 \text{ for all } s \]

We next observe that \(X_{sk} > 0\) for all \(s\). To show this we use a induction argument. That is, we start by showing that this is true for \(X_{k-1k} > 0\) and \(X_{k-2k} > 0\) and then show that if \(X_{m+1k} > 0\), then \(X_{mk} > 0\).

The incentive compatibility condition for the bad project when beliefs are \(\alpha_{k-1}\) is given by

\[ \delta V^T_k(k - 1, k - 1) \geq b \]
However we note that
\[ V^T_k(k - 1, k - 1) = \theta(b + \alpha_{k-1}\gamma X_{k-1k}) \]

Hence we get
\[ X_{k-1k} \geq \frac{b(1 - \delta)}{\delta\alpha_{k-1}\gamma} > 0. \]

Consider \( s = k - 2 \). The incentive compatibility condition for the bad project when beliefs are \( \alpha_{k-1} \) is given by
\[ \delta V^T_k(k - 2, k - 2) \geq b + \delta V^T_k(k - 2, k - 1) \]
\[ \Rightarrow V^T_k(k - 2, k - 2) - V^T_k(k - 2, k - 1) \geq \frac{b}{\delta} \]

Using the expressions for \( V^T(m, m) \) and \( V^T(m, m + 1) \), the LHS can be simplified to give
\[ V^T_k(k - 2, k - 2) - V^T_k(k - 2, k - 1) = \theta\{\alpha_{k-2}\gamma(X_{k-2k} - X_{k-1k})\} + \theta^2\delta(1 - \alpha_{k-2}\gamma)\{b + \alpha_{k-1}\gamma X_{k-1k}\} \]

This allows us to obtain
\[ \theta\alpha_{k-2}\gamma X_{k-2k} \geq \left[ \frac{b}{\delta} - \theta^2\delta(1 - \alpha_{k-2}\gamma)b \right] + \theta\alpha_{k-2}\gamma X_{k-1k} - \theta^2\delta(1 - \alpha_{k-2}\gamma)\alpha_{k-1}\gamma X_{k-1k} \]
\[ = b\left[ \frac{1}{\delta} - \theta^2\delta(1 - \alpha_{k-2}\gamma) \right] + \theta\alpha_{k-2}\gamma X_{k-1k}[1 - \theta\delta(1 - \gamma)] \]
\[ > 0 \]

where the second line follows from using Bayes’ rule on \( \alpha_{k-2} \). The third line follows from observing that each of \( b > 0, \frac{1}{\delta} - \theta^2\delta(1 - \alpha_{k-2}\gamma) > 0 \) and \( \theta\alpha_{k-2}\gamma X_{k-1k}[1 - \theta\delta(1 - \gamma)] > 0 \).

General induction step: Assume that each of \( X_{k-1k}, X_{k-2k}...X_{m+k} > 0 \). We now show that this implies \( X_{mk} > 0 \). The incentive compatibility condition for bad projects when beliefs are \( \alpha_s \) is given by
\[ \delta V^T_k(s, s) \geq b + \delta V^T_k(s, s + 1) \]
We can follow similar steps as above and show that

\[ V_k^T(s, s) - V_k^T(s, s+1) = \theta \alpha_s \gamma X_{sk} + X_{s+1k}[\theta^2 \delta(1 - \alpha_s \gamma)\alpha_{s+1} \gamma - \theta \alpha_s \gamma] + \]

\[ + \sum_{m=s+2}^{k-1} A_m X_{mk} + \theta^{k-s} \delta^{k-s-1}(1 - \alpha_s \gamma)(1 - \alpha_{s+1} \gamma)\ldots(1 - \alpha_{k-2} \gamma)\alpha_{k-1} \gamma b \]

Here \( A_m \) is the coefficient for \( X_m \) and is given by

\[ A_m = \theta^{m-s+1} \delta^{m-s} \{(1 - \alpha_s \gamma)(1 - \alpha_{s+1} \gamma)\ldots(1 - \alpha_{m-1} \gamma)\alpha_m \gamma \]

\[ - \theta^{m-s} \delta^{m-s-1} \{(1 - \alpha_s \gamma)(1 - \alpha_{s+1} \gamma)\ldots(1 - \alpha_{m-2} \gamma)\alpha_{m-1} \gamma \}
\]

\[ = \theta^{m-s+1} \delta^{m-s} \{(1 - \alpha_s \gamma)(1 - \alpha_{s+1} \gamma)\ldots(1 - \alpha_{m-2} \gamma)\alpha_{m-1}(1 - \gamma) \gamma \}
\]

\[ - \theta^{m-s} \delta^{m-s-1} \{(1 - \alpha_s \gamma)(1 - \alpha_{s+1} \gamma)\ldots(1 - \alpha_{m-2} \gamma)\alpha_{m-1} \gamma \}
\]

\[ = \theta^{m-s} \delta^{m-s-1} \{(1 - \alpha_s \gamma)(1 - \alpha_{s+1} \gamma)\ldots(1 - \alpha_{m-2} \gamma)\alpha_{m-1} \gamma(\theta \delta(1 - \gamma) - 1) \}
\]

\[ < 0 \]

Thus we get that

\[ \theta \alpha_s \gamma X_{sk} \geq b \left[ \frac{1}{\delta} - \theta^{k-s} \delta^{k-s-1}(1 - \alpha_s \gamma)(1 - \alpha_{s+1} \gamma)\ldots(1 - \alpha_{k-2} \gamma)\alpha_{k-1} \gamma b \right] + X_{s+1k} \theta \alpha_s \gamma \left[ 1 - \theta \delta(1 - \gamma) \right] + \sum_{m=s+2}^{k-1} (-A_m) X_{mk} > 0 \]

where the last equality follows from the observation that \( b > 0, X_{m+1k}, \ldots X_{k-1k} > 0 \) (from the induction step) as well as the coefficients on \( b, X_{s+1k} \ldots X_{k-1k} \) are all positive. Hence we get that \( X_{sk} > 0 \).

* All IC-B-O-s hold with equality

We now argue that all IC-B-OS need to hold with equality.
The argument is by contradiction. Let \( s \) be the first instance whereby the inequality is strict that is,
\[
\delta V_k^T(s, s) > b + \delta V_k^T(s, s + 1)
\]
and
\[
\delta V_k^T(m, m) = b + \delta V_k^T(m, m + 1)
\]
for all \( 0 \leq m < s \).

Rewrite using the definition of \( V_k^T(m, m) \) and \( V_k^T(m, m + 1) \)
\[
\delta V_k^T(s, s) > b + \delta V_k^T(s, s + 1)
\]
as
\[
\theta(b + \alpha_s \gamma X_{sk} + (1 - \alpha_s \gamma)\delta V_k^T(s + 1, s + 1)) > b + \delta V_k^T(s, s + 1)
\]
We observe that neither \( V_k^T(s + 1, s + 1) \) nor \( V_k^T(s, s + 1) \) depend on \( X_{sk} \). Hence it is possible to reduce \( X_{sk} \) by a small amount and still have the inequality holding. Since the principal’s profit is decreasing in \( X_{sk} \), such an adjustment increases the principal’s profit and hence it contradicts \( X_{sk} \) being a part of the optimal bonus structure.

It remains to argue that none of the other constraints are violated as a result of this change in \( X_{sk} \). We observe that the expressions for \( V_k^T(m, m) \) as well as \( V_k^T(m, m + 1) \) are not dependent on \( X_{sk} \) where \( m > s \). Hence changing \( X_{sk} \) has no impact on any of the inequalities for \( s + 1, s + 2...k - 1 \).

What about the incentive constraints for \( m < s \)? We know that for all such \( m \) the following relation holds.
\[
\delta V_k^T(m, m) = b + \delta V_k^T(m, m + 1)
\]
Reducing \( X_s \) by \( \epsilon \) decreases \( \delta V_k^T(m, m) \) by \( \epsilon \{\theta^{s-m} \delta^{s-m-1}(1 - \alpha_m \gamma)...(1 - \alpha_{s-1} \gamma)\alpha_s \gamma \} \) while decreases \( \delta V_k^T(m, m + 1) \) by \( \epsilon \{\theta^{s-m-1} \delta^{s-m-2}(1 - \alpha_m \gamma)...(1 - \alpha_{s-2} \gamma)\alpha_{s-1} \gamma \} \). Observe that
\[
(1 - \alpha_{s-1} \gamma)\alpha_s = (1 - \gamma)\alpha_{s-1}
\]
and hence

$$(1 - \alpha_m \gamma) \ldots (1 - \alpha_{s-1} \gamma) \alpha_s \gamma = (1 - \alpha_m \gamma) \ldots (1 - \alpha_{s-2} \gamma) \alpha_{s-1} (1 - \gamma).$$

Thus the fall in $\delta V_k^T(m, m)$ is smaller than the $\delta V_k^T(m, m + 1)$ and hence the incentive compatibility constraint for bad project continues to hold.

*Recurrence relation:*

We have shown that all the IC-B–O-s need to hold with equality. We now prove the following recurrence relation:

$$X_{sk} = \frac{b(1 - \delta)}{\delta \gamma \alpha_s p} + X_{s+1k} + b$$

along with the boundary condition:

$$X_{k-1k} = \frac{b(1 - \delta)}{\delta \gamma \alpha_{k-1} p}$$

The IC-B-O-$k - 1$ gives us

$$\delta V_k^T(k - 1, k - 1) = b$$

$$\Rightarrow \theta \delta(b + \alpha_{k-1} \gamma X_{k-1,k}) = b$$

$$\Rightarrow p \delta(b + \alpha_{k-1} \gamma X_{k-1,k}) = b(1 - \delta(1 - p))$$

Simplifying we get,

$$X_{k-1k} = \frac{b(1 - \delta)}{\delta \gamma \alpha_{k-1} p}.$$

To prove the recurrence relation we use induction on $s$.

For $s = k - 2$, the IC-B-OS gives us

$$\delta V_k^T(k - 2, k - 2) = b + \delta V_k^T(k - 2, k - 1)$$
This can be rewritten as

\[ \delta p(b + \alpha_{k-2}\gamma X_{k-2} + (1 - \alpha_{k-2}\gamma)\delta V^T_k(k - 1, k - 1)) = b(1 - \delta + \delta p) + \delta V^T_k(k - 2, k - 1)(1 - \delta + \delta p) \]

To simplify the above expression, we observe

\[ V^T_k(k - 2, k - 1)(1 - \delta + \delta p) = p(b + \alpha_{k-2}\gamma X_{k-1k}) \]

and the IC-B-O-\(k - 1\) gives us

\[ \delta V^T_k(k - 1, k - 1) = b \]

Thus we get,

\[ \delta pb + \delta p\alpha_{k-2}\gamma X_{k-2k} = b(1 - \delta + \delta p) + \delta p(b + \alpha_{k-1}\gamma X_{k-1k}) \]

\[ - \delta p(1 - \alpha_{k-2}\gamma)b \]

which gives us

\[ X_{k-2k} = \frac{b(1 - \delta)}{\delta p\gamma\alpha_{k-2}} + X_{k-1k} + b \]

which verifies the recurrence equation above for \(s = k - 2\).

We now assume that the recurrence relation holds for \(s + 1, s + 2\ldots, k - 2, k - 1\) and show that it holds for \(X_{sk}\) as well.

The IC-B-O-s gives us

\[ \delta V^T_k(s, s) = b + \delta V^T_k(s, s + 1) \]

We observe that

\[ V^T_k(s, s) = \theta(b + \alpha_s\gamma X_{sk} + (1 - \alpha_s\gamma)\delta V^T_k(s + 1, s + 1)) \]

Hence

\[ \delta \theta(b + \alpha_s\gamma X_{sk} + (1 - \alpha_s\gamma)\delta V^T_k(s + 1, s + 1)) = b + \delta V^T_k(s, s + 1) \]

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Multiplying throughout by $1 - \delta + \delta p$ and simplifying we get,

$$\delta p\alpha_s \gamma X_{sk} = b(1 - \delta) + (1 - \delta + \delta p)\delta V^T_k(s, s + 1)$$

$$-\delta^2 p(1 - \alpha_s \gamma)V^T_k(s + 1, s + 1)$$

We see that

$$(1 - \delta + \delta p)V^T_k(s, s + 1) = p[b + \alpha_s \gamma X_{s+1k} +$$

$$+ p(1 - \alpha_s \gamma)\delta V^T_k(s + 1, s + 2)]$$

Inserting this in the above equation we get,

$$\delta p\alpha_s \gamma X_{sk} = b(1 - \delta) + \delta[pb + p\alpha_s \gamma X_{s+1k} +$$

$$+ p(1 - \alpha_s \gamma)(\delta V^T_k(s + 1, s + 2) - \delta V^T_k(s + 1, s + 1))]$$

We know that

$$\delta V^T_k(s + 1, s + 1) = b + \delta V^T_k(s + 1, s + 2)$$

This gives us

$$\delta p\alpha_s \gamma X_{sk} = b(1 - \delta) + \delta[pb + p\alpha_s \gamma X_{s+1k}$$

$$- p(1 - \alpha_s \gamma)b]$$

$$= b(1 - \delta) + \delta p\alpha_s \gamma[X_{s+1k} + b]$$

which gives us

$$X_{sk} = \frac{b(1 - \delta)}{\delta p\alpha_s \gamma} + X_{s+1k} + b$$

which proves the recurrence relation.
*Deriving the formula stated in the proposition

We thus see that

\[ X_{sk} = \frac{b(1 - \delta)}{\delta p \alpha_s \gamma} + X_{s+1k} + b \]

\[ = \frac{b(1 - \delta)}{\delta p \alpha_s \gamma} + \frac{b(1 - \delta)}{\delta p \alpha_{s+1} \gamma} + X_{s+2k} + b + b \]

\[ = (k - 1 - s)b + \sum_{m=s}^{k-1} \frac{b(1 - \delta)}{\delta p \gamma \alpha_m}. \]

* Showing this is sufficient to deter more complex off path strategies for the agent

We now verify that \((X_{sk})_{s=0,1..k-1}\) we found above is sufficient to guarantee that the agent won’t want to deviate from the prescribed strategy even if he had access to more complex strategies than one deviations.

The idea is to use induction to show that \((X_{sk})_{s=0,1..k-1}\) is enough to prevent the agent from taking up bad projects regardless of the beliefs of the agent and the principal - that is we show that

\[ \delta V_k(m, s) \geq b + \delta V_k(m, s + 1). \]

where \(m = 0, 1...s\) and \(s = 0, 1...k - 1\).

Note that it suffices to make sure that the incentive compatibility condition for the bad project holds since in that case, there is no gain to choosing not to implement a project when the project available is good as in the next period the agent’s payoff is going to be the same as the previous period but now discounted.

Fix \(s = k - 1\). We want to show that for \(m = 0, 1...k - 1\)

\[ \delta V_k(m, k - 1) \geq b. \]

One possible strategy for the agent is that he selects not to implement a project if the project available is bad and implement the good project if it is available. Since \(V_k(m, k - 1)\)
is the maximum payoff possible, it has to be true that $V_k(m, k-1)$ gives a weakly higher payoff than following the above strategy that is

$$
\delta V_k(m, k-1) \geq \delta \theta (b + \alpha_m \gamma X_{k-1})
$$

Since $m \leq k-1$, we get that $\alpha_m \geq \alpha_{k-1}$ and hence

$$
\delta V_k(m, k-1) \geq \delta \theta (b + \alpha_{k-1} \gamma X_{k-1})
$$

$$
= \delta \theta (b + \alpha_{k-1} \gamma \frac{b(1 - \delta)}{\delta \alpha_{k-1} \gamma p})
$$

$$
= \delta \theta (b(1 + \frac{1 - \delta}{\delta p}))
$$

$$
= \delta \theta (1 - \delta + \delta p)
$$

$$
= b
$$

where the last line follows from noting $\theta \equiv \frac{p}{1 - \delta(1 - p)}$.

Fix $s = k-2$. We want to show that for $m = 0, 1...k-2$

$$
\delta V_k(m, k-2) \geq b + \delta V_k(m, k-1).
$$

To reduce notation, we are going to refer to $V_k(m, k-2) \equiv V_{m,k-2}$ and so on for the remaining part of this proof. One possible strategy for the agent is that he selects the safe project if the risky project is bad and the risky project if it is a good project. Since $V_{m,k-2}$ is the maximum payoff possible, it has to be true that $V_{m,k-2}$ gives a weakly higher payoff than following the above strategy that is

$$
V_{m,k-2} \geq \theta (b + \alpha_m \gamma X_{k-2} + (1 - \alpha_m \gamma) \delta V_{m+1,k-1}).
$$

Hence it is enough to show that

$$
\delta (b + \alpha_m \gamma X_{k-2} + (1 - \alpha_m \gamma) \delta V_{m+1,k-1}) \geq \frac{1}{\theta} (b + \delta V_{m,k-1})
$$

Simplifying the expression we get,

$$
\delta \alpha_m \gamma X_{k-2} + (1 - \alpha_m \gamma) \delta^2 V_{m+1,k-1} \geq \frac{b}{\theta} - \delta b + \frac{\delta}{\theta} V_{m,k-1}
$$
We know that
\[ X_{k-2} = \frac{b(1 - \delta)}{p} + X_{k-1} + b \]
and
\[ V_{m,k-1} = \theta(b + \alpha_m X_{k-1}) \]

Using the above two equalities to simplify the previous inequality
\[ \delta \alpha_m \gamma X_{k-2} + (1 - \alpha_m \gamma) \delta^2 V_{m+1,k-1} \geq \frac{b}{\theta} - \delta b + \frac{\delta}{\theta} V_{m,k-1} \]
which is the same as
\[ \frac{\alpha_m}{\alpha_{k-2}} \frac{b(1 - \delta)}{p} + \delta \alpha_m \gamma b + (1 - \alpha_m \gamma) \delta^2 V_{m+1,k-1} \geq \frac{b}{\theta} \]
which can be further simplified to yield
\[ \frac{b(1 - \delta)}{p} \left[ \frac{\alpha_m}{\alpha_{k-2}} - 1 \right] - \delta b(1 - \alpha_m \gamma) + (1 - \alpha_m \gamma) \delta^2 V_{m+1,k-1} \geq 0 \]
which gives us
\[ \frac{b(1 - \delta)}{p} \left[ \frac{\alpha_m}{\alpha_{k-2}} - 1 \right] + \delta (1 - \alpha_m \gamma)(\delta V_{m+1,k-1} - b) \geq 0 \]
But \( m \leq k - 2 \) which gives us \( \alpha_m \geq \alpha_{k-2} \) and we also get from the previous step that \( \delta V_{m+1,k-1} - b \geq 0 \) which verifies that
\[ \frac{b(1 - \delta)}{p} \left[ \frac{\alpha_m}{\alpha_{k-2}} - 1 \right] + \delta (1 - \alpha_m \gamma)(\delta V_{m+1,k-1} - b) \geq 0 \]
and hence
\[ \delta V(m, k - 2) \geq b + \delta V(m, k - 1). \]

We now want to show that if for all \( m = 0, 1...r \) and \( r = s + 1, s + 2...k - 1 \)
\[ \delta V(m, r) \geq b + \delta V(m, r + 1). \]
then the following relation holds for all $m = 0, 1, \ldots$:

$$
\delta V(m, s) \geq b + \delta V(m, s + 1).
$$

We proceed similarly as before. We know that

$$
V_{m,s} \geq \theta(b + \alpha_m \gamma X_s + (1 - \alpha_m \gamma)\delta V_{m+1,s+1}).
$$

Hence it is enough to show that

$$
\delta(b + \alpha_m \gamma X_s + (1 - \alpha_m \gamma)\delta V_{m+1,s+1}) \geq \frac{1}{\theta}(b + \delta V_{m,k-1})
$$

which is the same as showing

$$
\delta \alpha_m \gamma X_{sk} + (1 - \alpha_m \gamma)\delta^2 V_{m+1,s+2} \geq \frac{b}{\theta} - \delta b + \frac{\delta}{\theta} V_{m,s+1}
$$

We can use the induction assumption to get

$$
V_{m,s+1} = \theta(b + \alpha_m \gamma X_{sk} + (1 - \alpha_m \gamma)V_{m+1,s+2})
$$

and also

$$
X_{sk} = X_{s+1k} + \frac{b(1 - \delta)}{\delta \alpha_s \gamma p} + b
$$

to simplify the above inequality as

$$
\frac{b(1 - \delta)}{p} \left[ \frac{\alpha_m}{\alpha_s} - 1 \right] + \delta (1 - \alpha_m \gamma) [\delta V_{m+1,s+1} - b - \delta V_{m+1,s+2}] \geq 0
$$

We get $\frac{\alpha_m}{\alpha_s} - 1 \geq 0$ since $m \leq s$ and also $\delta V_{m+1,s+1} - b - \delta V_{m+1,s+2} > 0$ from the induction assumption. Hence we have verified that indeed

$$
\frac{b(1 - \delta)}{p} \left[ \frac{\alpha_m}{\alpha_s} - 1 \right] + \delta (1 - \alpha_m \gamma) [\delta V_{m+1,s+1} - b - \delta V_{m+1,s+2}] \geq 0
$$

and this concludes the induction argument.
1.9.2 Proof of Lemma 1

The expression for $MB_{SB}^k$ is given by

$$MB_{SB}^k = \theta^{k+1}\delta^k\left[\prod_{m=0}^{k-1}(1 - \alpha_m\gamma)[\alpha_k\gamma(R - X_{kk+1}) - c]\right]$$

The lemma follows from observing that each of the terms above are decreasing in $k$. We note that $\delta$ as well as $\theta$ lie between 0 and 1. Hence $\theta^{k+1}$ and $\delta^k$ are both decreasing in $k$.

Second, since $(1 - \alpha_i\gamma)$ lies between 0 and 1, the product

$$\prod_{m=0}^{k-1}(1 - \alpha_m\gamma)$$

also lies in between 0 and 1 and hence increasing $k$ multiplies this with a term which is between 0 and 1 and thus reduces it further.

From Bayes’ rule we get,

$$\alpha_k = \frac{(1 - \gamma)^k\alpha_0}{(1 - \gamma)^k\alpha_0 + (1 - \alpha_0)}$$

and thus $\alpha_k$ is a decreasing function of $k$.

Finally

$$-X_{kk+1} = -\frac{b(1 - \delta)}{\delta\gamma\alpha_k\rho}$$

is also decreasing in $k$ since $\alpha_k$ is decreasing in $k$.

1.9.3 Proof of Lemma 2

The expression for “marginal cost” is given as

$$MC_{SB}^k = \sum_{s=1}^{k}\theta^s\delta^{s-1}[\alpha_0(1 - \gamma)^{s-1}\gamma(b + \frac{b(1 - \delta)}{\delta\alpha_k\gamma\rho})]$$

We observe that

$$\theta^s\delta^{s-1}[\alpha_0(1 - \gamma)^{s-1}\gamma(b + \frac{b(1 - \delta)}{\delta\alpha_k\gamma\rho})]$$
is positive and is also increasing in $k$ since $\alpha_k$ is decreasing in $k$. Hence increasing $k$ leads to an increase in the marginal cost - first, each of the terms above increase due to $\alpha_k$ being a decreasing function of $k$ and second, a positive term gets added since we are summing from 1 to $k$.

### 1.9.4 Proof of Proposition 2

We see that

$$
\Delta \Pi_k = \theta^{k+1} \delta^k \left[ \prod_{m=0}^{k-1} (1 - \alpha_m \gamma) \right] \left[ \alpha_k \gamma (R - X_{k,k+1}) - c \right] \\
+ \sum_{s=1}^{k} \theta^s \delta^{s-1} \alpha_0 (1 - \gamma)^{s-1} \gamma (X_{s-1,k} - X_{s-1,k+1})
$$

Using the definitions of marginal benefit and marginal cost as defined in the text, we can see that this can be written as

$$
\Delta \Pi_k \equiv MB^{SB}_k - MC^{SB}_k
$$

Lemma 1 says that $MB^{SB}_k$ is decreasing in $k$ while lemma 2 says that $MC^{SB}_k$ is increasing in $k$. Thus we get that $\triangle \Pi_k$ is decreasing in $k$.

As we increase $k$, $\alpha_k \gamma (R - X_{kk+1}) - c$ becomes negative for some finite $k$ which implies that the “marginal benefit” becomes negative for some finite $k$. The “marginal cost” on the other hand is always positive and is strictly increasing. Assumption 2 guaranteed that $MB^{SB}_0 > 0 = MC^{SB}_0$ which suggested that some experimentation is optimal in the second best. As we increase $k$, there exists a value of $k$, say $k^*$ for which $MB^{SB}_{k^*} \geq MC^{SB}_{k^*}$ and $MB^{SB}_{k^*+1} < MC^{SB}_{k^*+1}$. The optimal number of trials is given by $k^*$. To see this, note that if $k > k^*$, the principal can increase expected payoff by reducing $k$ since at such a $k$, $MB^{SB}_k < MC^{SB}_k$. However if $k < k^*$, then $MB^{SB}_k > MC^{SB}_k$ and hence the principal can increase expected payoff by increasing $k$. 

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1.9.5 Proof of Proposition 3

In the complete information benchmark, there are no bonuses paid. Hence $MC_{CI}^k = 0$ for all $k$ while the marginal benefit is given by

$$MB_{CI}^k = \theta^{k+1}\delta^k \prod_{m=0}^{k-1} (1 - \alpha_m \gamma)[\alpha_k \gamma R - c]$$

Since $X_{kk+1} > 0$ we see that $MB_{CI}^k > MB_{SB}^k$. Thus in the complete information benchmark, both “marginal benefit” is higher and the “marginal cost” is lower compared to the second best. Hence the optimal of trials will be higher as well. Note that even if $MB_{CI}^k > MB_{SB}^k$ it is still true that $MB_{CI}^k$ is decreasing in $k$ - the argument is similar to that presented in the proof of Lemma 2 - and hence experimentation is terminated after a finite number of failures even in the complete information benchmark.

1.9.6 Proof for the Comparative Statics

Comparative statics with respect to $\alpha_0$

**Lemma A.5.1:** $MB_{SB}^k$ is increasing in $\alpha_0$ for all $k$ for which $MB_{SB}^k > 0$.

Proof: We see that

$$MB_{SB}^k \equiv \theta^{k+1}\delta^k \prod_{m=0}^{k-1} (1 - \alpha_m \gamma)[\alpha_k \gamma (R - X_{kk+1}) - c]$$

We examine separately the terms which are a function of $\alpha_0$:

$$\prod_{m=0}^{k-1} (1 - \alpha_m \gamma)[\alpha_k \gamma (R - X_{kk+1}) - c]$$

This can be simplified as

$$\prod_{m=0}^{k-1} (1 - \alpha_m \gamma)[\alpha_k \gamma (R - X_{kk+1}) - c]$$

We note that

$$\prod_{m=0}^{k-1} (1 - \alpha_m \gamma) \alpha_k \gamma = \alpha_0 (1 - \gamma)^k \gamma$$
and hence is increasing in $\alpha_0$.

From equation (1), we see that $\alpha_k$ is also increasing in $\alpha_0$.

Finally

$$-X_{kk+1} = -\frac{b(1 - \delta)}{\delta \gamma \alpha_k p}$$

is increasing in $\alpha_0$ since $\alpha_k$ is increasing in $\alpha_0$. Thus $[\prod_{m=0}^{k-1}(1 - \alpha_m \gamma)][\alpha_k \gamma (R - X_{kk+1})]$ is increasing in $\alpha_0$.

Next we observe that

$$\prod_{m=0}^{k-1}(1 - \alpha_m \gamma) = 1 - \alpha_0 + \alpha_0(1 - \gamma)^k$$

Taking derivative of this expression with respect to $\alpha_0$, we get $-1 + (1 - \gamma)^k < 0$ - hence $\prod_{m=0}^{k-1}(1 - \alpha_m \gamma)$ is decreasing in $\alpha_0$ which implies that $-\prod_{m=0}^{k-1}(1 - \alpha_m \gamma)c$ is increasing in $\alpha_0$.

Thus both of the components in the expression for $MB_k^{SB}$ is increasing in $\alpha_0$ which gives us the result.

**Lemma A.5.2:** Fix $k \geq 1$. An increase in $\alpha_0$ can lead to a increase in $MC_k^{SB}$.

Proof: We start by noting

$$MC_k^{SB} = \sum_{s=1}^{k} \theta^s \delta^{s-1} \alpha_0 (1 - \gamma)^{s-1} \gamma (b + \frac{b(1 - \delta)}{\delta \alpha_k \gamma p})$$

$$= \alpha_0 (1 + \frac{(1 - \delta)}{\delta \alpha_k \gamma p}) [\sum_{s=1}^{k} \theta^s \delta^{s-1} b (1 - \gamma)^{s-1} \gamma]$$

The portion that is dependent on $\alpha_0$ is given by $\alpha_0 (1 + \frac{(1 - \delta)}{\delta \alpha_k \gamma p})$. The derivative of this expression with respect to $\alpha_0$ is given by

$$1 + \left\{ \frac{1 - \delta}{\delta}, \frac{1}{\gamma p} \right\} \{1 - \frac{1}{(1 - \gamma)^{k-1}}\}$$

which can be positive - hence an increase in $\alpha_0$ can lead to a increase in $MC_k^{SB}$.

Alternatively observe that for $\delta = 1$, $MC_k^{SB}$ simplifies to $\sum_{s=1}^{k} \alpha_0 (1 - \gamma)^{s-1} \gamma b$ which is an increasing function of $\alpha_0$. 

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Lemma A.5.3 : An increase in $\alpha_0$ leads to an increase in the expected payoff for the principal.

The principal’s expected profit for $k$ trials is given by

$$
\Pi_k = \theta[\alpha_0\gamma(R - X_{0k}) - c] + \sum_{s=1}^{k-1} \theta^{s+1}\delta^s\{\prod_{m=0}^{s-1}(1 - \alpha_m\gamma)\}\{\alpha_s\gamma(R - X_{sk}) - c\}
$$

Fix $k$. Then an increase in $\alpha_0$ leads to an increase in the $\Pi_k$. The proof is similar to showing that the “marginal benefit” is an increasing function of $\alpha_0$ (Lemma A.5.2). The only difference is we have $X_{sk}$ where $s = 0, 1...k - 1$ in place of $X_{kk+1}$. However if we hold fixed $k$, then $X_{sk}$ is a decreasing function of $\alpha_0$ just as $X_{kk+1}$ is decreasing function of $\alpha_0$ and hence analogous arguments hold.

Lemma A.5.4 : An increase in $\alpha_0$ leads to an increase in the number of trials in the second best.

Define $k^*(\alpha_0)+1$ as the optimal number of trials in the second best when initial prior about the agent being of high ability is given by $\alpha_0$.

We have $\Pi_{k^*(\alpha_0)+1} - \Pi_{k^*(\alpha_0)} = \Delta\Pi_{k^*(\alpha_0)} \geq 0$, since $k^*(\alpha_0) + 1$ is the optimal number of trials when prior is given by $\alpha_0$. Using the expressions for $MB_{k^*(\alpha_0)}$ and $MC_{k^*(\alpha_0)}$, we can rewrite this condition as

$$
\theta^{k^*(\alpha_0)+1}\delta^{k^*(\alpha_0)}(1 - \alpha_0\gamma)\cdot(1 - \alpha_{k^*(\alpha_0)}\gamma)[\alpha_{k^*(\alpha_0)}\gamma(R - X_{k^*(\alpha_0)+1} - X_{k^*(\alpha_0)+1}) - c]
$$

$$
+ \sum_{s=1}^{k^*(\alpha_0)} \theta^{s}\delta^{s-1}\alpha_0(1 - \gamma)^{s-1}\gamma\{X_{s-1k^*(\alpha_0)} - X_{s-1k^*(\alpha_0)+1}\} \geq 0
$$

Since $X_{kk+1} = \frac{b(1-\delta)}{\delta\alpha_k\gamma\beta}$ and $X_{s-1k} - X_{s-1k+1} = -b - \frac{b(1-\delta)}{\delta\alpha_k\gamma\beta}$, the above expression can be rewritten as

$$
\theta^{k^*(\alpha_0)+1}\delta^{k^*(\alpha_0)}\alpha_0(1 - \gamma)^{k^*(\alpha_0)}\gamma R - (1 - \alpha_0 + \alpha_0(1 - \gamma)^k)(\frac{b(1-\delta)}{\delta p} + c)
$$

$$
- \sum_{s=1}^{k^*(\alpha_0)} \theta^{s}\delta^{s-1}\alpha_0(1 - \gamma)^{s-1}\gamma(b + \frac{b(1-\delta)}{\delta\alpha_{k^*(\alpha_0)}\gamma\beta}) \geq 0
$$

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from which we obtain
\[ \theta^{k^*(\alpha_0)} + \delta^{k^*(\alpha_0)} (1 - \gamma)^{k^*(\alpha_0)} R - \sum_{s=1}^{k^*(\alpha_0)} \theta^s \delta^{s-1} (1 - \gamma)^{s-1}b > 0. \]

We can rewrite \( \Delta \Pi^{k^*(\alpha_0)} \) as
\[
\Delta \Pi^{k^*(\alpha_0)} = \theta^{k^*(\alpha_0)} + \delta^{k^*(\alpha_0)} \alpha_0 (1 - \gamma)^{k^*(\alpha_0)} R
- (1 - \alpha_0 + \alpha_0 (1 - \gamma)^{k^*(\alpha_0)}) \left( \frac{b(1 - \delta)}{\delta p} + c \right)
- \sum_{s=1}^{k^*(\alpha_0)} \theta^s \delta^{s-1} \alpha_0 (1 - \gamma)^{s-1}b
- \sum_{s=1}^{k^*(\alpha_0)} \theta^s \delta^{s-1} (1 - \gamma)^{s-1} \frac{(-1 + (1 - \gamma)^{k^*(\alpha_0)}) b(1 - \delta)}{(1 - \gamma)^{k^*(\alpha_0)}} \delta p
\]

Using the envelope theorem, we obtain
\[
\frac{\partial \Delta \Pi^{k^*(\alpha_0)}}{\partial \alpha_0} = \theta^{k^*(\alpha_0)} + \delta^{k^*(\alpha_0)} (1 - \gamma)^{k^*(\alpha_0)} R
- (-1 + (1 - \gamma)^{k^*(\alpha_0)}) \left( \frac{b(1 - \delta)}{\delta p} + c \right)
- \sum_{s=1}^{k^*(\alpha_0)} \theta^s \delta^{s-1} (1 - \gamma)^{s-1}b
- \sum_{s=1}^{k^*(\alpha_0)} \theta^s \delta^{s-1} (1 - \gamma)^{s-1} \frac{(-1 + (1 - \gamma)^{k^*(\alpha_0)}) b(1 - \delta)}{(1 - \gamma)^{k^*(\alpha_0)}} \delta p
\]

Since \(-1 + (1 - \gamma)^{k^*(\alpha_0)} < 0 \) and
\[
\theta^{k^*(\alpha_0)} + \delta^{k^*(\alpha_0)} (1 - \gamma)^{k^*(\alpha_0)} R - \sum_{s=1}^{k^*(\alpha_0)} \theta^s \delta^{s-1} (1 - \gamma)^{s-1}b > 0.
\]

we obtain that
\[
\frac{\partial \Delta \Pi^{k^*(\alpha_0)}}{\partial \alpha_0} > 0
\]

Hence an increase in \( \alpha_0 \) increases \( \Delta \Pi^{k^*(\alpha_0)} \). Since \( \Delta \Pi^{k^*(\alpha_0)} \geq 0 \), this implies that an increase in prior leads to an increase in the number of trials (from proposition 2).
Comparative statics with respect to $c$

Lemma A.5.5: $MB^S_B$ is decreasing in $c$ and $MC^S_B$ is independent of $c$. Hence an increase in $c$ leads to a decrease in the number of trials.

The first part of the lemma follows from observing that

$$MC^S_B = \sum_{s=1}^{k} \theta^{s} \delta^{s-1} \alpha_0(1 - \gamma)^{s-1} \gamma(b + \frac{b(1 - \delta)}{\delta \alpha_k \gamma p})$$

is independent of $c$ while

$$MB^S_B = \theta^{k+1} \delta^k [\prod_{m=0}^{k-1} (1 - \alpha_m \gamma)](\alpha_k \gamma (R - X_{kk+1}) - c)$$

is clearly a decreasing function of $c$ for a given value of $k$.

The second part of the lemma is a consequence of proposition 2.

Lemma A.5.6: An increase in $c$ leads to a decrease in the expected payoff of the principal.

Let $c^H > c^L$ and let $k^*(c)$ denote the optimal number of trials when cost of implementing a project is given by $c$. Let $\Pi_k(c)$ denote the principal’s expected payoff from a $k$-trial contract when the cost of implementing project is $c$. We observe that

$$\Pi_k(c) = \theta[\alpha_0 \gamma (R - X_{0k}) - c] + \sum_{s=1}^{k-1} \theta^{s+1} \delta^s [\prod_{m=0}^{s-1} (1 - \alpha_m \gamma)] \{\alpha_s \gamma (R - X_{sk}) - c\}$$

Holding fixed $k$, we observe that $\Pi_k(c)$ is a decreasing function of $c$.

From Lemma A.5.6, $k^*(c^L) \geq k^*(c^H)$.

Next observe that $\Pi_{k^*(c^L)}(c^L) \geq \Pi_{k^*(c^H)}(c^L)$, since $k^*(c^L)$ denote the optimal number of trials when cost of implementing a project is given by $c^L$.

Thus we get $\Pi_{k^*(c^L)}(c^L) \geq \Pi_{k^*(c^H)}(c^L) \geq \Pi_{k^*(c^H)}(c^H)$ which concludes the proof.
Chapter 2

Informal Risk Sharing and Index Insurance: Theory with Experimental Evidence

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1We appreciate guidance and support from Patrick Bolton, Emily Breza, Christian Gollier, Wojciech Kopczuk, Dan Osgood, Bernard Salanić and seminar participants in the Applied Micro Theory and Financial Economics colloquiums at Columbia University. All remaining errors are ours.
“...and when basis risk is large, having an informal network can help by providing insurance against basis risk. Thus the presence of informal risk sharing actually increases demand for index-based insurance in the presence of basis risk...” -- World Development Report (2014)

2.1 Introduction

The business of agriculture is inherently risky, particularly for the poor, due to a myriad of unpredictable weather and climate events. Recently, innovative index-based weather insurance has emerged as a way to help society insure against weather related events.\(^2\) A standard index-based contract pays out when some constructed-index falls below or above a given non-manipulable threshold.\(^3\)

The justification for index insurance is that it overcomes several market frictions e.g., moral hazard, that plague traditional indemnity-based insurance and financial instruments. Index-based insurance differs in the sense that the contractual terms (premiums and payouts) are based on publicly observable and non-manipulable index (local weather). However, this innovation comes with a cost: “basis risk”. In particular, there is a potential mismatch between the payouts triggered by the local weather and the actual losses associated with weather realizations of the insurance policy holder. This mismatch or “basis risk” arises because weather realized on an individual farm unit may not perfectly correlate with the local weather index—whose construction is typically based on observations recorded at weather

\(^2\)The design and coverage for index-based weather insurance can be wide ranging. Hazell et al. (2010) cites at least 36 pilot index insurance projects that were underway in 21 developing countries. Examples include: India–rainfall insurance (Mobarak and Rosenzweig 2012; Cole et al. 2013); Ethiopia–rainfall (Hazell et al. 2010; McIntosh et al. 2013; Duru 2016); China–drought and extreme temperature (Hazzel et al. 2010); Mexico–drought and excess moisture (Hazell et al. 2010); Ghana–rainfall (Karlan et al. 2014); Kenya and Ethiopia–“livestock” weather-insurance (Jensen et al. 2014).

\(^3\)See Carter et al. (2017) for a recent survey about index insurance in developing countries.
stations that surround the policy holder.\footnote{Satellite measurements are used in some cases (e.g., Carter et al. 2017; IRI 2013). Even so, the individual weather realizations is not perfectly correlated with the satellite index.}

Empirical studies about weather index-based insurance are growing (e.g., Cai et al. 2009; Giné and Yang 2009; Cole et al. 2013; Karlan et al. 2014), which in turn have noted two fundamental puzzles. The first is that, demand for index products has been lower than expected. The second is that, the demand seems to be especially low from the most risk averse consumers. Despite its promise, scaling up index insurance will require our understanding about the various constraints to its take-up. Several candidate reasons for the low demand have been offered including: financial illiteracy, lack of trust, poor marketing, credit constraints, present bias, complexity of index contracts, “basis risk” and price effects.

Another suggested explanation for the thin index insurance market in poor populations is pre-existing informal risk-sharing arrangements. Indeed, the extent to which informal risk-sharing networks affect the demand for index-based insurance remains an open question, both empirically and theoretically. In this paper, we focus on microfounded reasons underlying the relation between informal risk schemes and formal index insurance. Specifically, we ask: \textit{When does an informal risk sharing scheme impede or support the take-up of formal index insurance?} We analyze this question in an environment where an individual endogenously chooses to join an informal group and make purchase decisions about index insurance. Our analysis show that the presence of an individual in a risk sharing arrangement reduces his risk aversion — a phenomenon we term “Effective Risk Aversion”. The paper documents that “Effective Risk Aversion” is a paramount statistic that underlies individual’s purchase decisions about index-based insurance.

Appealing to “Effective Risk Aversion”, it is shown that informal schemes may either reduce or increase the take-up of index insurance. The main intuition follows from the simple observation that in the presence of a risk-sharing arrangement, an individual’s risk tolerance is higher.\footnote{This intuition is comparable to Itoh (1993), who studies optimal incentive contracts in a group. He shows that side contracts can serve as mutual insurance for members in a group and can induce effort at} This has two implications for the take-up of index insurance. First,
the individual being more risk-tolerant makes him less willing to buy insurance. Second, the individual becomes more tolerant to the basis risk, and so is more likely to take-up. These two forces have opposite effects on the decision to purchase index insurance. Consider the case of a highly risk averse individual who will not buy index insurance if acting alone because of his sensitivity to basis risk. Being in a group reduces his risk aversion “effectively” making him more tolerant towards basis risk and thus more likely to purchase index insurance. Now consider the case of an individual with intermediate risk aversion who would buy index insurance if acting alone. The presence of informal insurance may crowd out his take-up for index insurance due to his lower willingness to pay. Our analysis thus has implications for informal schemes acting as a substitute or complement to index insurance.

Several testable hypotheses emerge from our theoretical analysis, which are useful for the design of index insurance contracts and understanding the development or commercial success of such innovative financial products. We develop a tractable empirical framework to investigate these hypotheses using data from a panel of field experimental trials in rural India. First, we provide empirical evidence that the overall effect of informal risk-sharing on the take-up of index insurance is ambiguous. There is evidence that informal risk sharing schemes may support take-up, finding that when downside basis risk is high, risk-sharing increases the index demand by approximately 13 to 40 percentage points. In addition, we provide evidence that the existence of risk-sharing arrangement makes individuals more sensitive to price changes, with an estimated increased elasticity of about 0.34.

Finally, we show that an increase in the size of risk-sharing groups decreases take-up. This effect is stronger once we have conditioned on basis risk – a counter force. Strikingly, this result stand in contrast to standard information diffusion models, in which an increase in exposed group size should facilitate uptake of index insurance (e.g., Jackson and Yariv 2010; Banerjee et al. 2013). For example, Banerjee et al. (2013) show that information passage or diffusion within a social network increases the likelihood of participation in a cheaper cost when members of the group can monitor each other’s effort by coordinating their choice of effort. While Itoh (1993) looks at effort decisions, we analyze insurance decisions.
microfinance program across 43 villages in South India. Similarly, Cole, Tobacman and Stein (2014) attributed the observed increase in take-up of index insurance to information generated by village-wide insurance payouts. Our analysis documents that the effective reduction in risk aversion following individuals’ exposure to risk-sharing group treatments explains the findings.

Our paper is related to the broader literatures on risk sharing (e.g., Itoh 1993; Townsend 1994; Munshi 2011; Munshi and Rosenzweig 2009 and many subsequent others), take-up of index insurance (e.g., Giné, Townsend and Vickery 2008; Mobarak and Rosenzweig 2012; Cole et al. 2013; Cole, Stein and Tobacman 2014; Karlan et al. 2014; Clarke 2016; Casaburi and Willis 2017) and the linkages between informal institutions and formal markets (e.g., Arnott and Stiglitz 1991; Kranton 1996; Duru 2016). Clarke (2016) studies the relation between individual risk aversion and the take-up of index insurance. He finds that demand is hump-shaped with demand for the index being higher in the intermediate risk averse region. Unlike Clarke (2016), we incorporate pre-existing risk-sharing arrangements to study their effect on the take-up.

Perhaps, most related is Mobarak and Rosenzweig (2012), who show that the existence of informal risk-sharing networks increases demand for index insurance, consistent with their empirical analysis. Our paper is distinct in several ways. Our model is microfounded, allowing for heterogeneity among individuals and endogenous decisions to join risk sharing groups. Results are based on the notion of “Effective Risk Aversion”—a consequence of efficient risk sharing. This allows us to identify new channels underlying the effect of informal schemes on demand for formal index insurance, and provides novel explanations for the two empirical puzzles based on their interactions. As mentioned previously, one of our channels relates to the increase in tolerance to basis risk, implying an increase in take-up - this reaffirms previous results found in Mobarak and Rosenzweig suggesting that informal risk sharing schemes support take-up of formal index insurance. The additional channel is connected to the increase in tolerance to aggregate gambles, implying a reduced demand for index insurance.
Finally, we analyze the take-up of index insurance at the extensive margin, unlike Mobarak and Rosenzweig (2012) and Clarke (2016) who looked at the intensive margin.

The rest of the paper is organized as follows. Section 2 presents the model. Results from several analysis are contained in Sections 3 and 4. Section 5 presents testable hypotheses from our model and investigates them empirically using field experimental data for a specific index contract “rainfall insurance”. Section 6 concludes. All formal proofs, tables and figures are relegated to the Appendix.

2.2 The Model

To investigate the coexistence and interactions between pre-existing (informal) institutional risk sharing and (formal) index-based insurance, it is crucial to specify preferences, shocks and informal arrangements in the economy.

Setup

We consider an individual $i$ with absolute risk aversion parameter $\gamma_i > 0$ and receive utility $u_i(z) = -e^{-\gamma_i z}$ from consuming income $z$. The individual faces uncertain income realization according to

$$z_i = w_i + h_i$$

where $w_i$ and $h_i$ denotes the deterministic and the stochastic component of the individual’s income. The stochastic component consists of two parts, $h_i = \varepsilon_i + v$: where $\varepsilon_i$ is the individual’s idiosyncratic risk (e.g., disease shocks), and $v$ is the aggregate shock (e.g., drought, rainfall). As we describe below, $\varepsilon_i$ corresponds to the part of the stochastic component which can be insured via informal risk-sharing while $v$ corresponds to the portion that can be insured via formal index insurance. We assume the following
\[ \varepsilon_i \sim N(0, \sigma_i^2) \]
\[ v = \begin{cases} 
0 & \text{with probability } 1 - p \\
-L & \text{with probability } p 
\end{cases} \]

**Informal risk sharing:** There exists a group \( g \) that individual \( i \) has the option to join. We think of the group as a representative agent with a CARA utility function and absolute risk aversion denoted by \( \gamma_g \). We denote the income realization of that group as

\[ z_g(\epsilon) = w_g + h_g \]

where \( w_g \) and \( h_g \sim N(0, \sigma_g^2) \) denotes the deterministic and the stochastic component of the group’s income. In this case, the stochastic component can only be insured through risk-sharing arrangements. Following Udry (1990), we assume perfect information: group-idiiosyncratic variances are public information and the realizations of shocks are also perfectly observed by all individuals when they occur in the society. This provides enforcement for the informal relationships.

Individual \( i \) has the choice of entering into a risk-sharing arrangement with the group. An unmatched individual receives his random income. If the individual joins the group, he can enter into a binding agreement prior to the realization of their incomes, specifying how their pooled income is going to be shared. ⁶

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⁶The model thus reflects several practical contexts including the case where cooperatives buy index insurance for their members. To illustrate: an index contract package was designed for groundnut farmers in Malawi for a 1 acre of production. Eligibility requires a farmer to be within 20 km of one of the meteorological stations in the program. This package consists of a loan (of about 4500 Malawi Kwacha or US$35) that covers the cost of groundnut seed (of about US$25, International Crops Research Institute for the Semi-Arid Tropics [ICRISAT] bred), the index insurance premium (about US$2), and tax (about US$0.50). After signing the paperwork, the farmer receives a bag of groundnut seed which is deemed sufficient for 1 acre of production and an insurance certificate for a payout policy that maxes at the loan size plus interest.
**Index Insurance:** There are no financial markets allowing any individual to insure himself against his idiosyncratic risks. However, with the introduction of index-weather based insurance it is possible to insure against $v$. Aggregate shocks can be insured by *formal* index-based insurance which is subject to basis risk (e.g., Cole et al. 2013). We model basis risk as in Clarke (2016):

(~US$7). Prices vary by the weather station and crop. In this program, farmers are organized into joint liability “groups” of about 10-20 members. Farmers plant the groundnut seed, and then at the end of the production season provide their yields to the farm association or cooperative, which markets the yields. The proceeds and insurance payouts are then used to pay for the loan, and any remaining profits are returned to the farmer—net of any loan deductions. Similar contract developments involving groups decisions are ongoing in Kenya and Tanzania, among others (see e.g., Osgood et al. 2007).
<table>
<thead>
<tr>
<th>Index = 0</th>
<th>Index = 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>$v = 0$</td>
<td>$v = -L$</td>
</tr>
<tr>
<td>$1 - q - r$</td>
<td>$p$</td>
</tr>
<tr>
<td>$1 - p$</td>
<td>$p - r$</td>
</tr>
<tr>
<td>$1 - q$</td>
<td>$q$</td>
</tr>
</tbody>
</table>

Table 2.1: Two Sided Basis Risk: Joint Probability Structure
Where in Table 1: individual $i$ suffers aggregate risk which can take the value 0 with probability $1 - p$ or $-L$ with probability $p$. There is also an index which can take the value 1 (i.e., payout) with probability $q$ or 0 (i.e., no payout) with probability $1 - q$. As usual, the index may not be perfectly correlated with the aggregate risk and so there are four possible joint realizations of the aggregate risk and index. In this case, $r$ denotes the probability that a negative aggregate shock is realized but the index suggests no payouts. This corresponds to the downside basis risk faced by the consumer if he purchases index insurance. Similarly, $q + r - p$ corresponds to an upside basis risk where an insured agent does not suffer an aggregate shock and yet payouts are triggered. Note that both downside and upside basis risks are increasing in $r$. We also assume that the index is informative about the aggregate loss that is $\text{Prob}(v = 0, I = 0) \times \text{Prob}(v = 1, I = 1) > \text{Prob}(v = 0, I = 1) \times \text{Prob}(v = 1, I = 0)$ which implies that $r < p(1 - q)$.

2.3 Demand for Index Insurance: no informal access

Suppose that individual $i$ is faced with the choice of either buying index insurance, denoted by 1 or not, denoted by 0. We first consider the case where the individual does not have access to an informal risk-sharing arrangement. In order to determine demand for index insurance, we compare the certainty equivalents for buying versus not buying the index. Formally, consider individual $i$ whose income process is given by

$$z_i^0(\epsilon) = w_i + \varepsilon_i + v$$
where the independent shocks are

\[ \varepsilon_i \sim N(0, \sigma_i^2) \]

\[ v = \begin{cases} 
0 & \text{with probability } 1 - p \\
-L & \text{with probability } p 
\end{cases} \]

If individual does **not buy** the index: the expected utility of individual \( i \) is

\[
E(-e^{-\gamma_i z_i^0}) = E(-e^{-\gamma_i(w_i + \varepsilon_i + v)}) \\
= -E(e^{-\gamma_i w_i})E(e^{-\gamma_i \varepsilon_i})E(e^{-\gamma_i v}) \\
= -e^{-\gamma_i w_i} e^{\frac{\gamma_i^2 \sigma_i^2}{2}} (1-p) + pe^{\gamma_i L} 
\]

For individual \( i \) with CARA utility function with income \( z_i \), we derive the certainty equivalent \( (CE_i) \) according to:

\[-e^{-\gamma_i CE_i} = E(-e^{-\gamma_i z_i}) \]

Thus, the certainty equivalent for individual with no index insurance is given by

\[
CE_i^0 = -\frac{1}{\gamma_i} \log E(e^{-\gamma_i z_i^0}) \\
= -\frac{1}{\gamma_i} (-\gamma_i w_i + \frac{\gamma_i^2 \sigma_i^2}{2}) + \log([1 - p] + pe^{\gamma_i L}) \\
= w_i - \frac{\gamma_i \sigma_i^2}{2} - \frac{1}{\gamma_i} \log([1 - p] + pe^{\gamma_i L}) 
\]

If the individual buys insurance he pays a fixed premium \( \pi \) and receives a stochastic payout \( \eta \) which depends on the level of coverage and on the value of the index. If the individual buys index insurance and the Index=1, the insurance company pays the individual \( \beta L \). For Index=0, there is no transfer from the insurance company to the individual. Thus, the actuarially fair premium is \( q \beta L \). Due to loading, administrative costs and lack of competition, the premium is typically not actuarially fair. This is captured as \( \pi = mq \beta L \) for \( m > 1 \).

If the individual buys insurance, his income process is now given by:

\[ z_i^1(\varepsilon) = w' + \varepsilon_i + v' \]
where \( w' \equiv w_i - \pi \) and \( v' \equiv v + \eta \). Thus \( v' \) and \( \varepsilon_i \) are independent and the distribution of \( v' \) is given by

\[
v' = \begin{cases} 
0 & \text{with probability } 1 - q - r \\
-L & \text{with probability } r \\
\beta L & \text{with probability } q + r - p \\
-L + \beta L & \text{with probability } p - r 
\end{cases}
\]

So, if the individual **buys** the index: the expected utility is

\[
E(-e^{-\gamma_i z_1^i}) = E(-e^{-\gamma_i (w'+\varepsilon_i+v')}) \\
= -E(e^{-\gamma_i w'})E(e^{-\gamma_i \varepsilon_i})E(e^{-\gamma_i v'}) \\
= -e^{-\gamma_i w'} e^{\frac{\gamma_i^2 \sigma_i^2}{2}} ([1 - q - r] + re^{\gamma_i L} + [q + r - p]e^{-\gamma_i \beta L} + [p - r]e^{-\gamma_i (-L + \beta L)})
\]

Thus, the certainty equivalent for individual with index insurance is given by

\[
CE_i^1 = -\frac{1}{\gamma_i} \log E(e^{-\gamma_i z_1^i}) \\
= -\frac{1}{\gamma_i}(-\gamma_i w' + \frac{\gamma_i^2 \sigma_i^2}{2} + \log([1 - q - r] + re^{\gamma_i L} + [q + r - p]e^{-\gamma_i \beta L} + [p - r]e^{-\gamma_i (-L + \beta L)})) \\
= w' - \frac{\gamma_i \sigma_i^2}{2} - \frac{1}{\gamma_i} \log([1 - q - r] + re^{\gamma_i L} + [q + r - p]e^{-\gamma_i \beta L} + [p - r]e^{-\gamma_i (-L + \beta L)})
\]

Thus, the individual buys insurance if \( CE_i^1 \geq CE_i^0 \). Using the expressions for CEs from above this condition can be rewritten as

\[
w' - \frac{\gamma_i \sigma_i^2}{2} - \frac{1}{\gamma_i} \log([1 - q - r] + re^{\gamma_i L} + [q + r - p]e^{-\gamma_i \beta L} + [p - r]e^{-\gamma_i (-L + \beta L)}) \geq w_i - \frac{\gamma_i \sigma_i^2}{2} - \frac{1}{\gamma_i} \log([1 - \pi] + pe^{\gamma_i L}) \\
-mq\beta L - \frac{1}{\gamma_i} \log([1 - q - r] + re^{\gamma_i L} + [q + r - p]e^{-\gamma_i \beta L} + [p - r]e^{-\gamma_i (-L + \beta L)}) \geq -\frac{1}{\gamma_i} \log([1 - \pi] + pe^{\gamma_i L}) \\
-\frac{1}{\gamma_i} \log([1 - q - r] + re^{\gamma_i L} + [q + r - p]e^{-\gamma_i \beta L} + [p - r]e^{-\gamma_i (-L + \beta L)}) + \frac{1}{\gamma_i} \log([1 - \pi] + pe^{\gamma_i L}) \geq mq\beta L
\]

where the second inequality uses \( w' \equiv w_i - \pi \). Observe that

\[
-\frac{1}{\gamma_i} \log([1 - q - r] + re^{\gamma_i L} + [q + r - p]e^{-\gamma_i \beta L} + [p - r]e^{-\gamma_i (-L + \beta L)} = CE_i(v') \text{ i.e., the CE for individual faced with } v' \text{ gamble. Equivalently: } -\frac{1}{\gamma_i} \log([1 - \pi] + pe^{\gamma_i L}) = CE_i(v). \text{ Thus the individual buys index insurance if}
\]

\[
CE_i(v') - CE_i(v) \geq mq\beta L
\]
We obtain the individual’s decision to buy the index in two ways: small losses (analytically) versus large losses (numerically).

2.3.1 Small Losses:

Let’s suppose losses are small. Then, we can approximate the CEs as follows

\[ CE_i(v) \approx -pL - \frac{1}{2}\gamma_i\sigma_v^2 \]

and

\[ CE_i(v') \approx -pL + \beta Lq - \frac{1}{2}\gamma_i\sigma_v^2 \]

where the variances of \( v \) and \( v' \) are \( \sigma_v^2 \) and \( \sigma_v^2 \), respectively. This means the individual buys the index if the following condition is satisfied

\[ \frac{1}{2}\gamma_i(\sigma_v^2 - \sigma_v^2) \geq (m - 1)q\beta L \]

Since \( m > 1 \), the RHS is always positive. For \( \sigma_{v'}^2 \geq \sigma_v^2 \) the LHS is non-positive and hence the individual will not buy index insurance. \( \sigma_{v'}^2 \) captures two parts: reduction in variance from buying insurance and an increase in variance due to the presence of basis risk. It is therefore possible for \( \sigma_{v'}^2 \geq \sigma_v^2 \) depending on these effects. However even for \( \sigma_{v'}^2 < \sigma_v^2 \) the individual may not buy index insurance for low values of \( \gamma_i \). Thus, there exist a threshold \( \gamma^* = \max(0, \frac{2(m-1)q\beta L}{\sigma_v^2 - \sigma_{v'}^2}) \) such that the individual with risk aversion parameter \( \gamma_i < \gamma^* \) will not buy the index insurance. Since the index insurance is actuarially unfair \( m > 1 \) the individual suffers a reduction in expected income. However, there is a change in variance from buying index insurance. The individual compares these two forces. If the variance does not decrease then nobody buys the index. But if the variance decreases, then individuals with high risk aversion will assign more weight to this reduction in variance; hence will buy
the index. Whereas for individuals with low risk aversion, this reduction in variance may not be enough to compensate for the loss in expected income; hence will not buy the index. The above discussion is summarized in Proposition 1 below.

**PROPOSITION 1:** Consider an individual with CARA utility function and risk aversion parameter \( \gamma_i > 0 \). Under small losses and actuarially unfair index insurance \( m > 1 \), the following two results hold.

1. The individual will purchase an index cover \( \beta \) iff \( \frac{1}{2} \gamma_i (\sigma^2_\nu - \sigma^2_{\nu'}) \geq (m - 1)q\beta L \)

2. In particular, if \( \sigma^2_{\nu'} < \sigma^2_\nu \) the individual will purchase the index iff \( \gamma_i > \gamma^* = \max(0, \frac{2(m-1)q\beta L}{\sigma^2_\nu - \sigma^2_{\nu'}}) \)

### 2.3.2 Large Losses

So far we have been analyzing the implications of informal arrangements on the decisions to buy index insurance assuming small losses. In this subsection, we extend the analysis to the case of large losses. It is still the case that an individual with risk aversion \( \gamma_i \) if acting individually chooses to buy the index insurance if

\[
CE_i(v') - CE_i(v) \geq mq\beta L
\]

which is equivalent to

\[
-\frac{1}{\gamma_i} \log([1 - q - r] + re^{\gamma L} + [q + r - p]e^{-\gamma \beta L} + [p - r]e^{-\gamma L + \beta L}) + \frac{1}{\gamma_i} \log([1 - p] + pe^{\gamma L}) \geq mq\beta L
\]

We illustrate the condition numerically in Figure 1. The red curve represents the left side of the inequality that is the difference in the CEs while the green line represents the right side of the inequality: \( mq\beta L \). The x-axis represents different values for risk aversion, indicating that individuals with risk-aversion levels in between the two vertical black lines purchase index insurance. Unlike the case of small loses, the decision to buy index insurance is bounded between two \( \gamma \)— thresholds. Within this interval, the above inequality is satisfied and individuals purchase the index cover. Next, observe that individuals with sufficiently
high or low risk-aversion will choose not to buy index insurance. The simple intuition is that high risk-averse individuals do not buy because of the basis risk while low risk-averse individuals choose not to buy because of loading of premium ($m > 1$). This is similar to the findings of Clarke (2016) who examines purchases of index insurance at the intensive margin.

2.4 Demand for Index Insurance: informal group access

2.4.1 Informal Risk Sharing

This subsection discusses the informal risk sharing arrangements before the introduction of index insurance. Since our set up has a non-transferable utility (NTU) representation, we first show that the model has a transferable utility (TU) representation under certainty equivalents (CE). The set-up is NTU because of the heterogeneity in risk-aversion where one unit of income yields utility $u_i(1) = -exp(-\gamma_i)$ for an individual $i$ with risk aversion $\gamma_i$, but utility $u_g(1) = -exp(-\gamma_g) \neq u_i(1)$ for a representative agent acting for the group $g$ with risk aversion $\gamma_g$. We work with certainty equivalent units, which allows for TU representations. This is stated in the following Lemma.

**LEMMA 1:** The NTU model has a TU representation, where CEs are transferable across individuals $(i, g)$.

Next, since CE is transferable, we also have the following lemma.

**LEMMA 2:** Suppose individual $i$ decides to join the group $g$ and risk is shared efficiently between them. Then under transferable CEs we can think of the pair $(i, g)$ as a representative agent with risk aversion parameter $\gamma_{i^*}$, where $\frac{1}{\gamma_{i^*}} = \frac{1}{\gamma_i} + \frac{1}{\gamma_g}$. This implies that $\gamma_{i^*} < \min(\gamma_i, \gamma_g)$.

Lemma 2 allows us to conveniently analyze the decision of individual $i$ to take index in-
surance in the presence of risk sharing arrangements. It also shows that the risk aversion of the individual $i$ will be effectively lower if he is in a group, as compared to if he was acting as an individual. The latter is summarized in Definition 1 below.

**DEFINITION 1:** $\gamma_{i*}$ as “Effective Risk Aversion”: This refers to the risk aversion parameter for a representative agent $i^*$ representing group consisting of $(i, g)$ that shares risk efficiently.

**REMARK:** We can now examine whether it is optimal for individual $i$ to join the group $g$. To do this we compare the CE of the group if they were sharing risk efficiently to the sum of CEs for the individual $i$ and group $g$ if they were acting separately. Indeed, joining the group provide welfare gains to the individual (and the group). The argument is similar to Wilson (1968). For contradiction: suppose that $i$ and $g$ are un-matched, then $i$ and $g$ can form a pair where each consumes his income. In this case, each is at least as well-off in the pair, as compared to remaining unmatched. However, by the mutuality principle, both can be better-off when in the group. This requires their income shares to rise and fall together with the independent random part of their incomes. The following lemma formally shows that if is efficient for $i$ and $g$ to form a pair.

**LEMMA 3:** Suppose risk is shared efficiently within a group. Then it is efficient for individual $i$ to join group $g$.

### 2.4.2 Extensive Margin 0-1: with informal group access

Consider now the demand for index insurance for the individual who has access to informal risk-sharing arrangement. From LEMMA 2, this is the same as the demand for index insurance of a representative agent with risk aversion parameter $\gamma_{i^*}$ where $\frac{1}{\gamma_{i^*}} = \frac{1}{\gamma_i} + \frac{1}{\gamma_g}$.
Thus, we can apply the preceding analysis to evaluate the decision of an individual in a group to purchase index insurance.

The representative agent’s income process in the absence of index insurance is given by

\[ z_i^0 = w_i + w_g + h_g + \varepsilon_i + v \]

If individual does not buy the index: the expected utility of representative agent is

\[ E(-e^{-\gamma_i^* z_i^0}) = -e^{-\gamma_i^*(w_i + w_g)} e^{\frac{\gamma_i^2 (\sigma_i^2 + \sigma_g^2)}{2}} ([1 - p] + pe^{\gamma_i^* L}) \]

and the certainty equivalent with no index insurance is given by

\[ CE_i^0 = w_i + w_g - \frac{\gamma_i^*(\sigma_i^2 + \sigma_g^2)}{2} - \frac{1}{\gamma_i^*} \log([1 - p] + pe^{\gamma_i^* L}) \]

Next, if individual buys index insurance, the group’s income process is now given by:

\[ z_i^1 = w' + h_g + \varepsilon_i + v' \]

where \( w_i' \equiv w_i + w_g - \pi \) and \( v' \equiv v + \eta \).

If the individual buys the index: the expected utility of the representative agent is

\[ E(-e^{-\gamma_i^* z_i^1}) = -e^{-\gamma_i^* w_i'} e^{\frac{\gamma_i^2 (\sigma_i^2 + \sigma_g^2)}{2}} ([1 - q - r] + re^{\gamma_i^* L} + [q + r - p]e^{-\gamma_i^* \beta L} + [p - r]e^{-\gamma_i^* (-L + \beta L)}) \]

The certainty equivalent for the representative agent with index insurance is given by

\[ CE_i^1 = w_i' - \frac{\gamma_i^*(\sigma_i^2 + \sigma_g^2)}{2} - \frac{1}{\gamma_i^*} \log([1 - q - r] + re^{\gamma_i^* L} + [q + r - p]e^{-\gamma_i^* \beta L} + [p - r]e^{-\gamma_i^* (-L + \beta L)}) \]

Thus, the individual buys insurance if \( CE_i^1 \geq CE_i^0 \), which we can rewrite as

\[ CE_i^1(v') - CE_i^1(v) \geq mq\beta L \]

where \( -\frac{1}{\gamma_i^*} \log([1 - q - r] + re^{\gamma_i^* L} + [q + r - p]e^{-\gamma_i^* \beta L} + [p - r]e^{-\gamma_i^* (-L + \beta L)}) = CE_i^1(v') \)

and \( -\frac{1}{\gamma_i^*} \log([1 - p] + pe^{\gamma_i^* L}) = CE_i^1(v) \).

Using the approximation for small losses, the index insurance purchase rule is

\[ \frac{1}{2} \gamma_i^*(\sigma_i^2 - \sigma_g^2) \geq (m - 1)q\beta L \]
The next result evaluates the impact of informal risk sharing arrangement on the take-up of index insurance.

**PROPOSITION 2:** Consider an individual with risk aversion parameter \( \gamma_i \) who joins a group with parameter \( \gamma_g \). Then, under small losses and actuarially unfair index insurance \( m > 1 \), the following results hold.

1. Independent of his presence in the group, the individual \( i \) will not purchase index insurance if \( \gamma_i < \gamma^* \).
2. Independent of his risk aversion parameter \( \gamma_i \), the individual \( i \) will not purchase index insurance if \( \gamma_g \leq \gamma^* \).
3. However, the individual may buy index insurance if \( \gamma_i \geq \gamma^* \) and \( \gamma_g \geq \gamma^* \) are satisfied. Particularly, he buys the index cover in the presence of the group if \( \sigma_i^2 < \sigma_g^2 \) and \( \gamma_i^* = \frac{\gamma_i \gamma_g}{\gamma_i + \gamma_g} > \gamma^* = \max(0, \frac{2(m-1)g\beta L}{\sigma_i^2 - \sigma_g^2}) \).

Proposition 2 shows that informal risk-sharing arrangements can impede the discrete (0-1) take-up of index insurance. The intuition is based on the fact that the "effective" risk aversion of individuals forming a group are lower than the risk aversion of the individuals if they were acting individually. Essentially the group lowers the individual’s aversion to risk (Lemma 2) which in turn might move the individual from a purchase zone to the non-purchase zone based on \( \gamma^* \).

### 2.4.3 The Case of Large Losses

The results from Proposition 2 can be modified to fit the case of large losses. When losses are small, an individual’s decision to not buy index insurance remain unchanged in the presence of informal arrangements. However if losses are large, our theory suggests that informal insurance might facilitate in taking up of index insurance. This happens for instance if an individual is initially too risk averse to buy index insurance on his own, however in
the presence of informal arrangements his effective risk aversion might be such that he ends up purchasing the index cover. To illustrate, consider Figure 1. An individual with risk aversion parameter 6 would not have purchased the index insurance if he was acting individually. However if he pairs with a group that brings his effective risk aversion to the range \((0.8, 4.7)\), then he chooses to purchase the index cover. We also see that it is possible that informal insurance acts as a barrier to take up. For example, consider an individual with risk aversion parameter 3. Acting individually, he will buy the index insurance, however if the presence of a risk-sharing arrangement reduces his effective risk aversion to below 0.8, then he will choose not to buy the index insurance. The analysis provides explanations and predictions for several empirical findings which are discussed in the next section.

2.5 Model-Implications and Experimental Evidence

Our theoretical evaluation of the interaction between informal risk sharing schemes and demand for index insurance provide several testable hypotheses with implications for the design of index insurance contracts. This section discusses the emerging hypothesis and explores them empirically combining field experimental data from multiple sources for a specific index contract “rainfall insurance”. We begin with a discussion of the testable hypotheses, and then follow this with a description of the data and experimental design. For each hypothesis, we present the testing procedure and the resulting empirical results.

2.5.1 Discussions, and testable implications

First, why might more risk averse individuals not take up index insurance? Our framework suggests a plausible answer. Absent risk-sharing arrangements, low take-up among high risk averse individuals may be due to aversion to basis risk (Clarke 2016). However, another plausible reason may be due to the presence of informal risk sharing groups (i.e., based on
our theory, Section 4). The presence of risk sharing groups leads to effective reduction in an individual’s risk aversion, making him more tolerant towards aggregate risk and more sensitive to the price of index insurance. For this reason, more risk averse people may end up not buying index insurance, as compared to an individual with the same risk aversion parameter who might take it up if the individual was unmatched.

Second, why is the take-up for index insurance unexpectedly low? Possible answers lie in the role of existing informal arrangements. In particular, (1) When does informal arrangement support the index take up? Our analysis suggests that high risk averse individuals in risk sharing arrangements containing intermediate risk averse members are more likely to purchase index insurance. Acting alone, basis risk will act as a disincentive to the take-up of index insurance; however, the presence of the group makes the individual more tolerant to basis risk; (2) When does informal pairing not-support index take up? From our analysis, low to intermediate risk averse individuals that enter any risk sharing group are less likely to purchase index insurance. Their effective risk aversion is lower, and thus has lower willingness to pay for index insurance. The above discussions lead to the following sets of predictions.

**Prediction #1:** The link between informal risk-sharing and the take of index insurance is ambiguous. This is because of the existence of the two identifiable forces: sensitivity to either basis risk or price of the index contract. Ultimately, the overall impact of informal risk-sharing schemes on the demand for index insurance depends on which of these two forces dominate.

**Prediction #2:** Informal risk-sharing is more likely to complement the take-up of index insurance in regions with high aggregate (especially, if un-insurable by group) and basis risk. This follows because the presence of an informal risk sharing group helps to make the individual more tolerant to the basis risk, holding other forces constant. In addition, in the presence of risk-sharing arrangements, the sensitivity of index demand to price changes is
higher, as individuals become effectively less risk averse.

**Prediction #3:** The take-up for index insurance may be higher if the size of the group is smaller. This is because smaller groups are likely more risk averse, all else equal. For instance, under small losses (e.g., relative to \( w \) and \( \varepsilon \)), villages where there are more informal transfers, which can be proxied by the number of pairs in our model, are likely to see lower take-ups once price and basis risk are controlled for. With controls for price effects and basis risk, individual’s risk aversion from joining the larger group may be effectively lower leading to less demand for insurance. This prediction contradicts those that connect information diffusion and group size.

### 2.5.2 Data and sources

Ideally, we require data about the demand for index insurance contracts, informal risk sharing, a measure of basis risk, insurance premiums, and risk aversion. For this purpose, we draw on available data sets from a panel of experimental trials that were conducted across randomly selected rural farming households and villages in Gujarat, India.\(^7\) Data on risk aversion come from Cole et al. (2013), which is based on field experiments across 100 villages in 2006/2007. The measure of risk aversion follows Binswanger (1980), whereby respondents are asked to choose among cash lotteries varying in risk and expected return. The lotteries were played for real money, with payouts between zero and Rs. 110. The lottery choices are then mapped into an index between 0 and 1, where high values indicate greater risk aversion.\(^8\)

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\(^7\)All villages are located within 30 km of a rainfall station. Design of rainfall insurance contracts uses information from these rainfall stations.

\(^8\)A value 1 is assigned to individuals that choose the safe lottery. For those who choose riskier lotteries, the \([0, 1)\) mapping indicates the maximum rate at which they are revealed to accept additional risk (standard
From Cole, Tobacman and Stein (2014), we obtain data about the take-up of index insurance, premiums, and premium discounts available between 2006-2013 for 60 villages cumulatively. Most of these villages and households overlap with the 100 villages in Cole et al. (2013). This allows us to match households and villages between the two data sets. Our final data are merged from these two sources. We summarize the timeline of the rainfall-index insurance experiments and the available data in Figure 2 (of the Appendix).

2.5.2.1 Rainfall-index contracts and experimental setting

The specific index insurance contract that we examine is “rainfall insurance” whose payouts are based on a publicly observable rainfall index. This contract provides coverage against adverse rainfall events (i.e., covering drought and flood) for the summer (“Kharif”) monsoon growing season. Design of this contract is based on daily rainfall readings at local rainfall stations, specifying payouts as a function of cumulative rainfall during fixed time periods over the entire June 1-August 31 Kharif season. Typically, the maximum possible payout for a unit-policy is about Rs. 1500. Households have the option to purchase any number of policies to achieve their desired level of insurance coverage. The contracts are offered and paid-out year-to-year, whereby a marketing team visits households in the selected sample each year in April-May to offer the insurance policies. Households are required to opt-in to re-purchase each year to sustain their coverage.

“Group Identity” as risk-sharing proxy: The marketing teams for rainfall insurance used multiple strategies to sell the policies. Their strategies include the use of flyers, videos, and discount coupons, and involved randomization of these three marketing methods at the household level. More importantly, flyers were randomized along two dimensions with the aim of testing how formal insurance interacts with informal risk-sharing arrangements (cf: deviation) in return for higher expected return (\( \frac{\Delta \mu}{\Delta \sigma} \)). Additional details are available in Cole et al. (2013).
Cole et al. 2013). The flyers emphasized and provided cues on “group identity”, which has been found to be key for informal risk-sharing (Karlan et al., 2009). The treatments for group identity included:\(^9\)

**Religion** (Hindu, Muslim, or Neutral): A photograph on the flyer depicted a farmer in front of a Hindu temple (Hindu Treatment), a Mosque (Muslim Treatment), or a neutral building. The farmer has a matching first name, which is characteristically Hindu, characteristically Muslim, or neutral.

**Individual or Group** (Individual or Group): In the Individual treatment, the flyer emphasized the potential benefits of the insurance product for the individual buying the policy. The Group flyer emphasized the value of the policy for the purchaser’s family.

Note that the use of cues on group identity as a proxy for risk-sharing has been used in previous literature (e.g., Cole et al. 2013), which we follow here. While such approach may have the downside of not capturing actual risk-sharing since people generally choose who to group and share risk with (possibly, over and beyond religious and family lines), it has an empirical appeal: it allows for randomization of risk-sharing which is extremely useful for identification purposes, at least, as compared to cases where groups form endogenously and share risk.

### 2.5.2.2 Measuring basis risk

Each season, households were asked if they had experienced crop loss due to weather in the household panel experiments. We combine this with unique market information about whether the household \(i\) located in village \(v\) in a contract year \(t\) received an insurance payout.

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\(^9\)More details of the data and group treatments are available in our two primary sources of data: Cole et al. (2013); Cole, Tobacman and Stein (2014).
to define a measure of basis risk

\begin{align*}
\text{briskDOWNSIDE}_{ivt} &= 1(\text{loss}_{ivt} > \text{payout}_{ivt}) \\
\text{briskUPSIDE}_{ivt} &= 1(\text{loss}_{ivt} < \text{payout}_{ivt})
\end{align*}

which are indicators that capture the potential mismatch or discrepancy between insurance payouts and the actual crop loss or income loss suffered by the policy holder prior to the payout decisions. For instance, this may be due to the fact that the measured rainfall index is imperfectly correlated with rainfall at any individual farm plot. As illustrated, our measure of basis risk allows for the distinction between upside and downside risks, and follows directly from previous discussions in Section 2.\textsuperscript{10}

### 2.5.2.3 Summaries

The summary statistics of all relevant variables in our sample are reported in Table 2. The first two moments and order statistics of each variable are displayed. As shown, the data is made up of information about the demand for rainfall-index insurance, premium and randomized discounts, crop and revenue loss experience of households, treatments for risk-sharing as proxied by cues on “group identity”, and basis risks, respectively. The overall data spans 2006-2013, covering 645 households across a pool of 60 villages. Considerable variations exist among the variables which we shall exploit for identifying variation. Our main outcome of interest is binary, denoted “Bought”. Bought is defined based on whether

\textsuperscript{10}Since crop losses (but not payouts) are self-reported, there is a potential tendency for households to misreport, e.g., overstate losses, and thus might impact our measurement of basis risk up/down. To assess such potential misreporting, we regress households reported-crop loss experience on a vector of seventeen (17) household characteristics: spanning socio-demographics, educational level, asset holdings, access to formal insurance, per capita monthly expenditure, risk aversion, and indicators for whether a respondent has a muslim name and irrigates the farm. Results are reported in Table 15. None of these 17 variables is statistically significant at conventional levels, an evidence inconsistent with misreporting. The evidence is more consistent with a reporting behavior whereby crop losses occur due to weather shocks and then households report them as such. This finding hold across the wide range of model specifications, which differ based on the included controls.
households purchased index insurance in given market year. In our sample, about 39% of households bought rainfall-index insurance over the entire panel period.

The average risk aversion is 0.53 with a standard deviation of about 0.32. The overall share of households that received cues on Group, Hindu and Muslim treatments are about 4.0%, 2.8% and 2.9%, respectively. Our measure of basis risk that relies on the mismatch between pre-insurance crop losses and index payouts suggest higher relative frequency for downside basis risk (25.5%), as compared to upside basis risk (8.2%). For our basis risk measure that relies on the mismatch between pre-insurance revenue losses and index payouts, the relative frequency of downside and upside basis risks are quite close. A visual illustration for both downside and upside basis risks are shown in Figure 3. Empirical tests for the various predictions combine these variables with exogenous variations induced by the random assignment of price discounts and risk-sharing marketing treatments.\textsuperscript{12}

\subsection*{2.5.3 Empirical tests and results}

The testing procedure and empirical results are presented in this section. Additional robustness checks on our main results are discussed.

\textsuperscript{11}Revenue is measured for market years in which households reported a crop loss, and captures the “amount” of crop loss: calculated as the difference between that market year’s agricultural output and the mean value of output in all previous years where crop loss was not reported.

\textsuperscript{12}Ensuring balance across risk-sharing treatment groups e.g., assignment of group, Hindu and muslim cues is crucial for the experimental results. We ascertain balance using observable characteristics of the households. In Table 16 of the Appendix, we test whether the various household characteristics significantly differ across the risk sharing treatments. The results provide strong evidence in favor of balance (except for about two variables which are barely significant at 10\% level).
2.5.3.1 Empirical strategy and results: predictions #1 and #2

To test predictions #1 and #2, we estimate a model that links changes in take-up for index insurance

$$D_{ivt} = \mathbb{1}(bought = Yes)_{ivt}$$

and their unrestricted interaction with basis risk $brisk_{ivt}$ and exogenous variation in the price for insurance $Discount_{ivt}$

$$D_{ivt} = \theta RShare_{ivt} \times brisk_{ivt} + \beta_d Discount_{ivt} + \mu_i + \delta_t + \epsilon_{ivt}$$

$$D_{ivt} = \theta RShare_{ivt} \times Discount_{ivt} + \beta_b brisk_{ivt} + \mu_i + \delta_t + \epsilon_{ivt}$$

where $i$, $v$ and $t$ index the household, village and market year respectively. This specification includes a set of unrestricted household dummies, denoted by $\mu_i$, which capture unobserved differences that are fixed across households such as access to other forms of insurance. The market-year fixed effects, $\delta_t$ control for aggregate changes that are common across households, e.g. prices, and national policies. Our key parameter of interest $\theta$ is identified by household-level exogenous variation in the various treatments for risk-sharing and their interactions with the two forces: basis risk and insurance premium. Errors are clustered at the village level to allow for arbitrary correlations.

The results are reported separately for the two measures of basis risk: crop-loss mismatch with index payouts versus revenue-loss mismatch with index payouts. For the first Equation, which interacts risk sharing with basis risk, Tables 3 and 4 contain the estimates for crop-mismatch while Tables 5 and 6 contains the estimates for revenue-mismatch. Columns differ based on the included risk-sharing treatments and interactions with basis risk, and controls for premium discount and upside basis risk. In Tables 3 and 5, columns (2)-(4) include the various interaction terms, while column (1) omits the interactions. However, in Tables 4 and 6, column (1) includes the various interaction terms with basis risk, column (2) adds a control for premium discount, while column (3) adds controls for both premium discounts and upside basis risk.
Downside basis risk is negative and significant at conventional levels, upside basis risk is significantly positive, and premium discount is significantly positive across all specifications. The estimated price discount effects range between 0.0032 - 0.0035; with an average estimate of about 0.0034. An average estimate of 0.0034 implies that a 10 percent decline in the price of index insurance increases the probability of purchase by 0.034 percentage points, or 0.113 percent of the conditional mean take-up rate (≈0.30). The implied elasticity is 0.0113. While households negative demand-response to downside basis risk is substantial, this is less than their positive response to upward basis risk. Turning to our key coefficients of interest, there is evidence that informal risk-sharing significantly supports the take-up of index insurance, and that when downside basis risk is high risk-sharing increases the index demand by 13.0% points (column 4; Table 3) to 40.1% points (column 4; Table 6).

Next, for the second Equation, which interacts risk sharing with exogenous changes in premium, the results for crop-mismatch are contained in Tables 7 and 8, and those for revenue-mismatch are in Tables 9 and 10. Again, across all model specifications, downside basis risk is significantly negative, upside basis risk is positive and large, and premium discount is positive. For our main coefficients of interest, there is evidence that the existence of risk-sharing arrangement makes individuals more sensitive to price changes since both the direct and interaction terms on discount are positive. For example, when group cues are combined with discounts (Table 7; column 4), the sensitivity increases by about 10.1 percentage points which implies an increased elasticity of 0.337.

In addition, there is evidence that informal risk-sharing significantly either support or not-support the take-up of rainfall-index insurance. For instance, while Group cues has negative effect on index take-up (column 4; Table 7), Group cues treatment combined with Muslim cues has a significant positive effect on take-up (column 3; Table 8). However, when the various risk-sharing cues are combined with premium discount, most of the terms have significant positive effect on the take-up of insurance.

Taken together, these results (i.e., Tables 3-10) provide evidence that informal risk-
sharing has ambiguous effects on index take-up, empirically. With high downside basis risk, informal networks increase take-up, but under price effects, informal networks may have negative effect on take-up; making the overall impact of risk-sharing on the take-up of index insurance ambiguous. As shown in Proposition 2, risk aversion plays a central role in explaining these effects. Thus, we turn to the role of risk aversion in the subsequent analysis.\footnote{Since our theoretical analysis relies on CARA (with a simplifying property of no wealth effects), we examine how sensitive or robust our main results are to potential wealth effects. To do this, we re-estimate our empirical model with an additional control for households wealth. We used Factor analysis to estimate the wealth of households based on eight (8) asset holdings or ownership: 1(Electricity=Yes), 1(Mobile Phone=Yes), 1(Sew Machine=Yes), 1(Tractor=Yes), 1(Thresher=Yes), 1(Bull cart=Yes), 1(Bicycle=Yes), and 1(Motorcycle=Yes); where 1(\ldots) is a logical indicator that equals 1 whenever the argument in the bracket is true, and 0 otherwise. Figure 5 shows the estimated distribution of wealth. The implied results are also shown in Tables 17 and 18. The estimate on wealth is positive but not significant. However, the estimates for our key parameter of interest $\gamma$ are similar to the main results (i.e., very close and well within the confidence intervals of the main estimates).}

### 2.5.3.2 Empirical strategy and results: prediction #2

We modify previous specifications to investigate how risk aversion (effective) interacts with the two forces: sensitivities to either basis risk or insurance premium

\[
D_{\text{int}} = \theta \text{riskAversion}_{\text{int}} \times \text{brisk}_{\text{int}} + \beta_d \text{Discount}_{\text{int}} + \mu_i + \delta_t + \epsilon_{\text{int}}
\]

\[
D_{\text{int}} = \theta \text{riskAversion}_{\text{int}} \times \text{Discount}_{\text{int}} + \beta_b \text{risk}_{\text{int}} + \mu_i + \delta_t + \epsilon_{\text{int}}
\]

where all the terms are defined similarly as in previous sections, and errors are clustered at the village level. The results are reported in Table 11. Columns differ based on the included interactions with risk aversion. Column (1) uses market year dummies to control for potential sensitivity to changes in premium, and includes an interaction between basis risk and risk aversion. This interaction allows us to focus on the response of basis risk to changes in risk aversion I.e., we ask whether increase in risk aversion alter the demand-
response to basis risk. In columns (2)-(3), we directly control for potential sensitivity to basis risk, and include interactions between premium discounts and risk aversion to evaluate how households sensitivity to prices respond to changes in risk aversion.\textsuperscript{14}

Note that the direct coefficient on risk aversion is not estimable (but its interaction with other variables are) since we included household-level dummies which soaks-up any fixed household-level terms. From column (1), downside basis risk has significant negative effect on take-up (-12.0% points); its interaction with risk aversion is also negative (but not significant at conventional levels). This seems to suggest that, after controlling for price effects, an increase in individual’s risk aversion increases the negative sensitivity of index take-up to increases in basis risk. The result that basis risk when combined with risk-sharing cues positively affect take-up (Table 3 and 6; Muslim cues) can be explained by this negative effect of risk aversion on basis risk. Recall that joining a group effectively reduces individual’s risk aversion (LEMMA 2).

The results in columns (2)-(3) show that premium discounts have significantly positive impact on take-up, increasing index take-up by 0.369 to 0.396 percentage points (similar to previous estimates). The interaction with risk aversion is negative. The negative sign implies that increasing risk aversion has negative effect on the positive impact of premium discounts on insurance demand (although not statistically significant) and vice versa. This likely explains the positive effect of premium discount when combined with the various risk-sharing cues on index take-up (Tables 7-10), when combined with the result in LEMMA 2.

\textsuperscript{14}There is an empirical appeal to use the observed risk aversion values here (rather than the theory-derived risk aversion values). The sample is at the individual household level with larger size for the observed values. We do not have to calculate risk aversion values at the village level–which is an approach we will have take to obtain the theory-based values. Figure 4 illustrates the distribution of observed vs theory-derived risk aversion values.
2.5.3.3 Empirical strategy and results: prediction #3

We evaluate prediction #3 by linking observed changes in take-up for index insurance to a measure of group-size while controlling for the effect of basis risk and variations in insurance premium at the village level,

\[ D_{vt} = \theta GSize_{vt} + \beta_{b} brisk_{vt} + \beta_{d} Discount_{vt} + \mu_{v} + \delta_{t} + \epsilon_{vt} \]

where group size, \( GSize_{vt} \), is defined as the number of households that received cues on “group identity” per village. \( \mu_{v} \) are village-level fixed effects, capturing time-invariant potential unobserved heterogeneity. The results for alternative model specifications are reported in Tables 12-14. Our preferred specification is column (4), which examines the effect of group size on the demand for index insurance along with full controls for downside basis risk, upside basis risk and premium discounts. These additional controls are meant to soak-up household sensitivities to both basis risk and insurance premium within the framework of our theoretical model.

Consistent with prediction #3, the estimate on group size is negative, statistically significant across all specifications, and hold across alternative measures of group size which are based on the various risk-sharing treatments. Estimates from our preferred specification suggest that providing cues on “group identity” for an additional household in a village will result in about 2.8% points decrease in index take-up, all else equal (column 4; Table 12)\(^{15}\).

This represents 5.9% reduction in insurance insurance take-up, relative to the conditional mean defined over the entire sample period. The negative effects of group size on take-up are much larger in the model specification that controls for only downside basis risk (column 1). This is expected and can be understood based on our theory: the countervailing force to reduced index demand is “upside basis risk” when individuals become effectively less risk averse following more group exposure. Thus, controlling to eliminate this force should

\(^{15}\)We examine the sensitivity of our main results to potential wealth effects by including wealth as a control. Results are displayed in Tables 19 and 20. The estimate on wealth is positive but hardly significant. However, the estimates on group size are negative, significant and very close to our baseline results.
yield larger negative effects of increasing group size. Next, as expected, the results indicate that downside basis risk significantly reduces the demand for index insurance (about 10% points), upside basis risk increases index take-up (about 62% points), while offering premium discounts significantly increase the take-up (approximately 0.33%).

These results are inconsistent with theoretical and empirical findings in studies of information diffusion which will predict increased uptake of index insurance with an increase in exposed group size (e.g., Jackson and Yariv 2010; Banerjee et al. 2013).

2.6 Conclusion

Our evaluation of the effect of informal risk sharing schemes on the take-up for index insurance, documents that the effects are ambiguous and driven by two forces: sensitivities to basis risk and insurance premium, which operate through risk aversion. In our model, we consider the case of an individual who endogenously chooses to join a group and make decisions about index insurance. The presence of an individual in a risk sharing arrangement reduces his risk aversion, termed “Effective Risk Aversion”. We appeal to this phenomenon of “Effective Risk Aversion” to establish that such reduction in risk aversion can lead to either reduced or increased take up of index insurance, and emphasize how these results provide alternative explanations for two empirical puzzles: unexpectedly low take-up for index insurance and demand being particularly low for the most risk averse. Our model provide several testable hypotheses with implications for the design of index insurance contracts. Drawing on data from a panel of field experimental trials in India, we provide evidence for several predictions that emerge from our analyses.

Our study is an initial step towards the broader understanding of the linkages between informal risk-sharing and the market for formal index insurance. In ongoing research, we test the predictions from the model both in the laboratory and the field. Further, we aim to draw on the literature on network analysis and multi-dimensional matching to analyze
the interactions between index insurance and informal arrangements to inform the design of policy and index contracts. This line of work has broader implications for the design and introduction of insurance and financial contracts that aim at mitigating environmental risks among low-income societies.

**Figure 2.1: Index Take-up under Large Losses**

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Notes: Assumptions underlying Figure 1 are as follows: $p = q = \frac{1}{3}$, $L = 1$, $r = \frac{1}{9}$, $\beta = 0.5$, $m = 1.15$. The vertical black lines correspond to $\gamma = 0.8$ and $\gamma = 4.7$. 
Figure 2.2: Timelines of Data and Experimental Treatments

Notes: Figure shows the timeline of the data sets and experimental treatments that we combined for our empirical analysis. The two primary sources of our data are Cole et al. (2013) and Cole, Tobacman and Stein (2014). Major parts of our data come from the latter source.
Notes: Figures display the distribution of basis risk measured as the mismatch between households experience of pre-insurance loss in crops or revenue and receiving an index payout, respectively. This shown for both downside and upside basis risks. Revenue is measured for market years in which a crop loss is reported, and captures the “amount” of crop loss: calculated as the difference between that market year’s agricultural output and the mean value of output in all previous years where crop loss was not reported.
Table 2.2: Summary Statistics

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<th>VARIABLE</th>
<th>Obs.</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Index-Demand</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1(Bought=Yes)</td>
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<td>0.390</td>
<td>0.488</td>
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<td>1</td>
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<tr>
<td><strong>Price and Discounts</strong></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Premium</td>
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<td>159.4</td>
<td>56.08</td>
<td>44</td>
<td>257</td>
</tr>
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<td>90</td>
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<tr>
<td>1(Crop loss=Yes)</td>
<td>4,948</td>
<td>0.292</td>
<td>0.455</td>
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<td>1(Revenue loss=Yes)</td>
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<td>0.0940</td>
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<td>1</td>
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<td><strong>Risk-Share Treatments</strong></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>1(Group cues)</td>
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<td>0.0396</td>
<td>0.195</td>
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<td>1</td>
</tr>
<tr>
<td>1(Hindu cues)</td>
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<tr>
<td>1(Muslim cues)</td>
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<td>0.274</td>
<td>0</td>
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<tr>
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<th>2013</th>
</tr>
</thead>
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<td>Number of Households</td>
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<td>645</td>
</tr>
<tr>
<td>Number of Villages</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>Number of Districts</td>
<td>3</td>
<td>3</td>
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</tbody>
</table>

Notes: Table reports the summary statistics of the panel data used for our empirical analysis. This include information about take-up of rainfall-index insurance, premium and randomized discounts, crop and revenue loss experience of households, multiple treatments for risk-sharing, proxied by cues on “group identity”, and basis risks respectively. $1(.)$ is a logical indicator that takes the value 1 whenever the argument in the bracket is true, and zero otherwise. The merged data spans 2006-2013, covering 645 households across a pool of 60 villages. These are located in three districts in the state of Gujarat, namely: Ahmedabad, Anand and Patan.
Table 2.3: Crop Mismatch t1: Index Demand-Group Identity link vs Basis Risk

<table>
<thead>
<tr>
<th>VARIABLES</th>
<th>(1) bought</th>
<th>(2) bought</th>
<th>(3) bought</th>
<th>(4) bought</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Risk-share Treatments</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group cues</td>
<td>-0.0557</td>
<td>-0.0621</td>
<td>-0.0581</td>
<td>-0.0496</td>
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<tr>
<td></td>
<td>(0.0567)</td>
<td>(0.0612)</td>
<td>(0.0603)</td>
<td>(0.0580)</td>
</tr>
<tr>
<td>brisk DOWNSIDE</td>
<td>-0.161***</td>
<td>-0.160***</td>
<td>-0.104***</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.0239)</td>
<td>(0.0236)</td>
<td>(0.0227)</td>
<td></td>
</tr>
<tr>
<td>Group cues X brisk DOWNSIDE</td>
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</tr>
<tr>
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<td>(0.105)</td>
<td>(0.101)</td>
<td>(0.0991)</td>
<td></td>
</tr>
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<td>Hindu cues</td>
<td>-0.0320</td>
<td>-0.0518</td>
<td>-0.0424</td>
<td>-0.0234</td>
</tr>
<tr>
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<td>(0.0580)</td>
<td>(0.0598)</td>
<td>(0.0582)</td>
<td>(0.0588)</td>
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</tr>
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<td></td>
<td>(0.0952)</td>
<td>(0.0930)</td>
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<tr>
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<td>(0.0593)</td>
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<td>(0.0675)</td>
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</tr>
<tr>
<td>Muslim cues X brisk DOWNSIDE</td>
<td>0.158*</td>
<td>0.160*</td>
<td>0.130*</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.0827)</td>
<td>(0.0818)</td>
<td>(0.0776)</td>
<td></td>
</tr>
<tr>
<td>Discount</td>
<td></td>
<td></td>
<td>0.00348***</td>
<td>0.00327***</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(0.00589)</td>
<td>(0.00565)</td>
</tr>
<tr>
<td>brisk UPSIDE</td>
<td></td>
<td></td>
<td></td>
<td>0.523***</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(0.0247)</td>
</tr>
<tr>
<td>Constant</td>
<td>0.226***</td>
<td>0.350***</td>
<td>0.349***</td>
<td>0.300***</td>
</tr>
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<td></td>
<td>(0.0373)</td>
<td>(0.0411)</td>
<td>(0.0409)</td>
<td>(0.0397)</td>
</tr>
<tr>
<td>Observations</td>
<td>6,490</td>
<td>6,490</td>
<td>6,490</td>
<td>6,490</td>
</tr>
<tr>
<td>R-squared</td>
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<td>0.127</td>
<td>0.133</td>
<td>0.221</td>
</tr>
<tr>
<td>Number of Households</td>
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<td>989</td>
<td>989</td>
<td>989</td>
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<tr>
<td>Mkt Year FEs</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Household FEs</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Notes: Table reports the results from regressions of take-up for rainfall-index insurance on a vector of treatments for risk-sharing proxied by cues on “group identity” and their interactions with basis risk and discount assignments–exogenous variation in insurance premium at the household level. Columns (1)-(4) differ based on the included risk-sharing treatments and interactions with basis risk, and controls for premium discount and upside basis risk. Columns (2) - (4) include the various interaction terms, while column (1) omits the interactions. Errors are clustered at the village level. Stars indicate significance: ***, **, and * stand for significance at the 1%, 5%, and 10% level, respectively.
### Table 2.4: Crop Mismatch t2: Index Demand-Group Identity link vs Basis Risk

<table>
<thead>
<tr>
<th>VARIABLES</th>
<th>(1) bought</th>
<th>(2) bought</th>
<th>(3) bought</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Risk-share Treatments</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hindu cues</td>
<td>-0.0774</td>
<td>-0.0628</td>
<td>-0.0424</td>
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<tr>
<td></td>
<td>(0.0802)</td>
<td>(0.0781)</td>
<td>(0.0783)</td>
</tr>
<tr>
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<td>-0.103</td>
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<td>-0.0713</td>
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<td>(0.0992)</td>
<td>(0.0971)</td>
<td>(0.0918)</td>
</tr>
<tr>
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<td>0.0939</td>
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<td>0.0651</td>
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<td>(0.131)</td>
<td>(0.128)</td>
<td>(0.128)</td>
</tr>
<tr>
<td>brisk DOWNSIDE</td>
<td>-0.162***</td>
<td>-0.161***</td>
<td>-0.105***</td>
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<tr>
<td></td>
<td>(0.0241)</td>
<td>(0.0239)</td>
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<tr>
<td>Hindu cues X brisk DOWNSIDE</td>
<td>0.124</td>
<td>0.117</td>
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<tr>
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<td>(0.127)</td>
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<td>(0.122)</td>
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<td>0.154</td>
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<tr>
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<td>(0.167)</td>
<td>(0.162)</td>
<td>(0.157)</td>
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<td>Hindu cu. X Group cu. X brisk DOW.</td>
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<td>-0.302</td>
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<tr>
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<td>(0.277)</td>
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<td>(0.266)</td>
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<td>(0.0876)</td>
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<tr>
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<td>(0.138)</td>
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<td>Muslim cues X brisk DOWNSIDE</td>
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<td>0.197*</td>
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</tr>
<tr>
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<td>(0.112)</td>
<td>(0.112)</td>
<td>(0.105)</td>
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<td>-0.211</td>
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<td>0.00327***</td>
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<tr>
<td></td>
<td>(0.000587)</td>
<td>(0.000562)</td>
<td></td>
</tr>
<tr>
<td>brisk UPSIDE</td>
<td>0.523***</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>(0.0248)</td>
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<td>0.350***</td>
<td>0.301***</td>
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<tr>
<td></td>
<td>(0.0413)</td>
<td>(0.0411)</td>
<td>(0.0399)</td>
</tr>
</tbody>
</table>

**Notes:** Table shows the results from regressions of take-up for rainfall-index insurance on a vector of treatments for risk-sharing proxied by cues on “group identity” and their interactions with basis risk and discount assignments–exogenous variation in insurance premium at the household level. Columns (1)-(3) differ based on the included risk-sharing treatments and interactions with basis risk and premium discount. Columns (1) includes the various interaction terms with basis risk, column (2) adds a control for premium discount, while column (3) adds controls for both premium discounts and upside basis risk. Errors are clustered at the village level. Stars indicate significance: ***, **, and * stand for significance at the 1%, 5%, and 10% level, respectively.
Table 2.5: Revenue Mismatch t1: Index Demand-Group Identity link vs Basis Risk

<table>
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<tr>
<th>VARIABLES</th>
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<th>(2) bought</th>
<th>(3) bought</th>
<th>(4) bought</th>
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<td><strong>Risk-share Treatments</strong></td>
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<tr>
<td>Group cues</td>
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<td>-0.123***</td>
<td>-0.0430*</td>
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<tr>
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<td>(0.0568)</td>
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<tr>
<td></td>
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<td>(0.222)</td>
<td>(0.214)</td>
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</tr>
<tr>
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<tr>
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<td>(0.271)</td>
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<td>0.249***</td>
<td>0.229***</td>
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<td>(0.0378)</td>
<td>(0.0377)</td>
<td>(0.0363)</td>
</tr>
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<td>6,490</td>
<td>6,490</td>
<td>6,490</td>
</tr>
<tr>
<td>R-squared</td>
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<td>0.123</td>
<td>0.263</td>
</tr>
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<td>Number of Households</td>
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<td>989</td>
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<td>989</td>
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<tr>
<td>Mkt Year FEs</td>
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<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Household FEs</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Notes: Table reports the results from regressions of take-up for rainfall-index insurance on a vector of treatments for risk-sharing proxied by cues on “group identity” and their interactions with basis risk and discount assignments—exogenous variation in insurance premium at the household level. Columns (1)-(4) differ based on the included risk-sharing treatments and interactions with basis risk, and controls for premium discount and upside basis risk. Columns (2) - (4) include the various interaction terms, while column (1) omits the interactions. Errors are clustered at the village level. Stars indicate significance: ***, **, and * stand for significance at the 1%, 5%, and 10% level, respectively.
Table 2.6: Revenue Mismatch \( t_2 \): Index Demand-Group Identity link vs Basis Risk

<table>
<thead>
<tr>
<th>VARIABLES</th>
<th>(1) bought</th>
<th>(2) bought</th>
<th>(3) bought</th>
</tr>
</thead>
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<tr>
<td>Risk-sharing Treatments</td>
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<td></td>
</tr>
<tr>
<td>Hindu cues</td>
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<td>-0.0145</td>
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<td>0.00863</td>
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<td>-0.123***</td>
<td>-0.0429*</td>
</tr>
<tr>
<td>Hindu cues X brisk DOWNSIDE</td>
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<td>0.0499</td>
<td>-0.0379</td>
</tr>
<tr>
<td>Group cues X brisk DOWNSIDE</td>
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<td>-0.596**</td>
<td>-0.0843</td>
</tr>
<tr>
<td>Muslim cues</td>
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<td>-0.0461</td>
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<tr>
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<td>0.526***</td>
<td>0.401***</td>
</tr>
<tr>
<td>Muslim cue X Group cue X brisk DOW.</td>
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<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Discount</td>
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<td>0.00320***</td>
<td>0.00599***</td>
</tr>
<tr>
<td>brisk UPSIDE</td>
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<td>(0.000559)</td>
<td>(0.00223)</td>
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<tr>
<td>Hindu cue X Group cue X brisk DOW.</td>
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<td>0.529</td>
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</tr>
<tr>
<td>Muslim cue X Group cue X brisk DOW.</td>
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<td>--</td>
<td>--</td>
</tr>
<tr>
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<td>0.249***</td>
<td>0.229***</td>
</tr>
<tr>
<td>(0.0377)</td>
<td>(0.0376)</td>
<td>(0.0362)</td>
<td></td>
</tr>
</tbody>
</table>

Notes: Table shows the results from regressions of take-up for rainfall-index insurance on a vector of treatments for risk-sharing proxied by cues on “group identity” and their interactions with basis risk and discount assignments—exogenous variation in insurance premium at the household level. Columns (1)–(3) differ based on the included risk-sharing treatments and interactions with basis risk and premium discount. Column (1) includes the various interaction terms with basis risk, column (2) adds a control for premium discount, while column (3) adds controls for both premium discounts and upside basis risk. Errors are clustered at the village level. Stars indicate significance: ***, **, and * stand for significance at the 1%, 5%, and 10% level, respectively.
Figure 2.4: Observed versus Theory-derived Effective Risk Aversion

Notes: Figure shows the distribution of risk aversion elicited (i.e., observed) in the 2006/2007 baseline household surveys. For each village group level $v$, we apply our theoretical rule that says that the effective risk aversion $\gamma_{i=v^*}$ is less than the minimum of all members risk aversion in that village to derived the distribution of effective risk aversion. This is jointly displayed with observed values of risk aversion.
Table 2.7: Crop Mismatch t1: Index Demand-Group Identity link vs Price Effects

<table>
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<tr>
<th>VARIABLES</th>
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<th>(2) bought</th>
<th>(3) bought</th>
<th>(4) bought</th>
</tr>
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<tr>
<td><strong>Risk-share Treatments</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group cues</td>
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<td>-0.208***</td>
<td>-0.210***</td>
<td>-0.207***</td>
</tr>
<tr>
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<td>(0.0567)</td>
<td>(0.0331)</td>
<td>(0.0333)</td>
<td>(0.0313)</td>
</tr>
<tr>
<td>Discount</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td>0.00311***</td>
<td>0.00308***</td>
<td>0.00287***</td>
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<td>(0.000616)</td>
<td>(0.000606)</td>
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<td>Group cues X Discount</td>
<td></td>
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<td></td>
<td>0.104***</td>
<td>0.102***</td>
<td>0.101***</td>
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<tr>
<td></td>
<td>(0.0100)</td>
<td>(0.0104)</td>
<td>(0.0101)</td>
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<td>-0.275***</td>
<td>-0.276***</td>
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<tr>
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<td>(0.0380)</td>
<td>(0.0390)</td>
<td>(0.0365)</td>
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<td>0.131***</td>
<td>0.129***</td>
<td>0.135***</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.00978)</td>
<td>(0.00979)</td>
<td>(0.00894)</td>
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<td>-0.266***</td>
<td>-0.264***</td>
</tr>
<tr>
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<td>(0.0451)</td>
<td>(0.0482)</td>
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<tr>
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<td>0.130***</td>
<td>0.132***</td>
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<td>(0.0122)</td>
<td>(0.0113)</td>
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<td>brisk DOWNSIDE</td>
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<td></td>
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<tr>
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<td>-0.147***</td>
<td>-0.0938***</td>
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<tr>
<td></td>
<td>(0.0225)</td>
<td>(0.0218)</td>
<td></td>
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<tr>
<td>brisk UPSIDE</td>
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<td></td>
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<td></td>
<td></td>
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<td>0.262</td>
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<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
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<td>Household FEs</td>
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<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
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</table>

Notes: Table reports the results from regressions of take-up for rainfall-index insurance on a vector of treatments for risk-sharing proxied by cues on "group identity" and their interactions with basis risk and discount assignments—exogenous variation in insurance premium at the household level. Columns (1)-(4) differ based on the included risk-sharing treatments and interactions with premium discount, and controls for both downside and upside basis risks. Columns (2) - (4) include the various interaction terms, while column (1) omits the interactions. Errors are clustered at the village level. Stars indicate significance: ***, **, and * stand for significance at the 1%, 5%, and 10% level, respectively.
Table 2.8: Crop Mismatch t2: Index Demand-Group Identity link vs Price Effects

<table>
<thead>
<tr>
<th>VARIABLES</th>
<th>(1) bought</th>
<th>(2) bought</th>
<th>(3) bought</th>
</tr>
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<tbody>
<tr>
<td><strong>Risk-share Treatments</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hindu cues</td>
<td>-0.364***</td>
<td>-0.376***</td>
<td>-0.374***</td>
</tr>
<tr>
<td></td>
<td>(0.0485)</td>
<td>(0.0484)</td>
<td>(0.0458)</td>
</tr>
<tr>
<td>Hindu cues X Group cues</td>
<td>-0.445***</td>
<td>-0.458***</td>
<td>-0.438***</td>
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<tr>
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<td>(0.0575)</td>
<td>(0.0534)</td>
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<td>(0.0672)</td>
<td>(0.0615)</td>
</tr>
<tr>
<td>Hindu cues X Discount</td>
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<td>0.00299***</td>
<td>0.00278***</td>
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<tr>
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<td>(0.000608)</td>
<td>(0.000587)</td>
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<td>0.173***</td>
<td>0.177***</td>
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<tr>
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<td>(0.0113)</td>
<td>(0.00932)</td>
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<tr>
<td>Hindu cu. X Group cu. X Discount</td>
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<td>0.196***</td>
<td>0.190***</td>
</tr>
<tr>
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<td>(0.0132)</td>
<td>(0.0139)</td>
<td>(0.0131)</td>
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<tr>
<td>Muslim cues</td>
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<td>-0.201***</td>
<td>-0.192***</td>
</tr>
<tr>
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<td>(0.0242)</td>
<td>(0.0252)</td>
<td>(0.0214)</td>
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<td>Group cues</td>
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<td>-0.394***</td>
<td>-0.379***</td>
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<td>(0.0610)</td>
<td>(0.0551)</td>
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<td>0.461***</td>
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<td>(0.0757)</td>
<td>(0.0668)</td>
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<td>0.168***</td>
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<td>(0.0154)</td>
<td>(0.0150)</td>
<td>(0.0137)</td>
</tr>
<tr>
<td>Muslim cu. X Group cu. X Discount</td>
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<td>-0.174***</td>
<td>-0.163***</td>
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<td>(0.0217)</td>
<td>(0.0213)</td>
<td>(0.0189)</td>
</tr>
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<td>-0.149***</td>
<td>-0.0951***</td>
<td>-0.071***</td>
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<tr>
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<td>(0.0224)</td>
<td>(0.0217)</td>
<td>(0.0241)</td>
</tr>
<tr>
<td>brisk UPSIDE</td>
<td>0.526***</td>
<td>0.526***</td>
<td>0.526***</td>
</tr>
<tr>
<td>Constant</td>
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<td>0.341***</td>
<td>0.294***</td>
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<tr>
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<td>(0.0368)</td>
<td>(0.0398)</td>
<td>(0.0385)</td>
</tr>
</tbody>
</table>

| Observations | 6,490 | 6,490 | 6,490 |
| R-squared | 0.165 | 0.178 | 0.267 |
| Number of Households | 989 | 989 | 989 |
| Mkt Year FE|s | Yes | Yes | Yes |
| Household FE|s | Yes | Yes | Yes |

Notes: Table shows the results from regressions of take-up for rainfall-index insurance on a vector of treatments for risk-sharing proxied by cues on “group identity” and their interactions with basis risk and discount assignments–exogenous variation in insurance premium at the household level. Columns (1)-(3) differ based on the included risk-sharing treatments and interactions with premium discount and basis risk. Column (1) includes the various interaction terms with premium discount, column (2) adds a control for [downside] basis risk, while column (3) adds controls for both downside and upside basis risks. Errors are clustered at the village level. Stars indicate significance: *** , **, and * stand for significance at the 1%, 5%, and 10% level, respectively.
Table 2.9: Revenue Mismatch t1: Index Demand-Group Identity link vs Price Effects

<table>
<thead>
<tr>
<th>VARIABLES</th>
<th>(1) bought</th>
<th>(2) bought</th>
<th>(3) bought</th>
<th>(4) bought</th>
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</thead>
<tbody>
<tr>
<td><strong>Risk-share Treatments</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group cues</td>
<td>-0.0557</td>
<td>-0.208***</td>
<td>-0.207***</td>
<td>-0.205***</td>
</tr>
<tr>
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<td>(0.0331)</td>
<td>(0.0338)</td>
<td>(0.0309)</td>
<td></td>
</tr>
<tr>
<td>Discount</td>
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<td>0.00311***</td>
<td>0.00278***</td>
<td></td>
</tr>
<tr>
<td>(0.000616)</td>
<td>(0.000616)</td>
<td>(0.000583)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group cues X Discount</td>
<td>0.104***</td>
<td>0.102***</td>
<td>0.103***</td>
<td></td>
</tr>
<tr>
<td>(0.0100)</td>
<td>(0.0103)</td>
<td>(0.00916)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hindu cues</td>
<td>-0.0320</td>
<td>-0.268***</td>
<td>-0.265***</td>
<td>-0.276***</td>
</tr>
<tr>
<td>(0.0580)</td>
<td>(0.0380)</td>
<td>(0.0387)</td>
<td>(0.0363)</td>
<td></td>
</tr>
<tr>
<td>Hindu cues X Discount</td>
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<td>0.131***</td>
<td>0.140***</td>
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</tr>
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<td>(0.00978)</td>
<td>(0.00991)</td>
<td>(0.00836)</td>
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<tr>
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<td>-0.263***</td>
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<td>(0.0403)</td>
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<tr>
<td>Muslim cues X Discount</td>
<td>0.131***</td>
<td>0.130***</td>
<td>0.132***</td>
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</tr>
<tr>
<td>(0.0126)</td>
<td>(0.0125)</td>
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<tr>
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<td>(0.0244)</td>
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<td>(0.0227)</td>
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</tr>
<tr>
<td>Constant</td>
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<td>0.227***</td>
<td>0.248***</td>
<td>0.228***</td>
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<tr>
<td>(0.0373)</td>
<td>(0.0368)</td>
<td>(0.0371)</td>
<td>(0.0356)</td>
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</table>

Notes: Table reports the results from regressions of take-up for rainfall-index insurance on a vector of treatments for risk-sharing proxied by cues on “group identity” and their interactions with basis risk and discount assignments—exogenous variation in insurance premium at the household level. Columns (1)-(4) differ based on the included risk-sharing treatments and interactions with premium discount, and controls for both downside and upside basis risks. Columns (2) - (4) include the various interaction terms, while column (1) omits the interactions. Errors are clustered at the village level. Stars indicate significance: ***, **, and * stand for significance at the 1%, 5%, and 10% level, respectively.
Table 2.10: Revenue Mismatch \textit{t2}: Index Demand-Group Identity link vs Price Effects

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<tr>
<th>VARIABLES</th>
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<th>(3) bought</th>
</tr>
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<tr>
<td><strong>Risk Share Treatments</strong></td>
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</tr>
<tr>
<td>Hindu cues</td>
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<td>-0.368***</td>
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<td>(0.0485)</td>
<td>(0.0488)</td>
<td>(0.0454)</td>
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<td>0.00302***</td>
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<td>(0.000618)</td>
<td>(0.000585)</td>
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<td>0.174***</td>
<td>0.181***</td>
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<td>(0.00812)</td>
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<td>Group cues X Discount</td>
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<td>0.195***</td>
<td>0.192***</td>
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<td>(0.0138)</td>
<td>(0.0120)</td>
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<td>-0.196***</td>
<td>-0.189***</td>
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<td>-0.392***</td>
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<td>-0.426***</td>
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<td>0.408***</td>
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<td>(0.0638)</td>
</tr>
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<td>0.170***</td>
<td>0.169***</td>
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<td>(0.0154)</td>
<td>(0.0153)</td>
<td>(0.0137)</td>
</tr>
<tr>
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<td>-0.174***</td>
<td>-0.166***</td>
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<tr>
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<td>(0.0217)</td>
<td>(0.0219)</td>
<td>(0.0186)</td>
</tr>
<tr>
<td>brisk DOWNSIDE</td>
<td>-0.114***</td>
<td>-0.0351</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.0243)</td>
<td></td>
<td>(0.0226)</td>
</tr>
<tr>
<td>brisk UPSIDE</td>
<td>0.602***</td>
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<tr>
<td></td>
<td></td>
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<td>(0.0213)</td>
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<tr>
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<td>0.248***</td>
<td>0.228***</td>
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<tr>
<td></td>
<td>(0.0368)</td>
<td>(0.0371)</td>
<td>(0.0355)</td>
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</table>

Notes: Table shows the results from regressions of take-up for rainfall-index insurance on a vector of treatments for risk-sharing proxied by cues on “group identity” and their interactions with basis risk and discount assignments—exogenous variation in insurance premium at the household level. Columns (1)-(3) differ based on the included risk-sharing treatments and interactions with premium discount and basis risk. Columns (1) includes the various interaction terms with premium discount, column (2) adds a control for [downside] basis risk, while column (3) adds controls for both downside and upside basis risks. Errors are clustered at the village level. Stars indicate significance: ***, **, and * stand for significance at the 1%, 5%, and 10% level, respectively.
Table 2.11: Examining Two Forces: Basis Risk vs Price Sensitivities

<table>
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<th>(3) bought</th>
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<td>N/A</td>
<td>N/A</td>
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<td>-0.0817***</td>
</tr>
<tr>
<td>brisk DOWNSIDE X Risk aversion</td>
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<td>(0.0236)</td>
<td>(0.0227)</td>
</tr>
<tr>
<td>brisk UPSIDE</td>
<td></td>
<td></td>
<td>0.532***</td>
</tr>
<tr>
<td>Constant</td>
<td>0.288***</td>
<td>0.331***</td>
<td>0.287***</td>
</tr>
<tr>
<td>Observations</td>
<td>4,919</td>
<td>4,842</td>
<td>4,842</td>
</tr>
<tr>
<td>R-squared</td>
<td>0.134</td>
<td>0.135</td>
<td>0.223</td>
</tr>
<tr>
<td>No. of Households</td>
<td>645</td>
<td>645</td>
<td>645</td>
</tr>
<tr>
<td>Mkt Year FEs</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Household FEs</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Notes: Table shows the results from regressions of take-up for rainfall-index insurance on basis risk and discount assignments—exogenous variation in insurance premium and their interactions with risk aversion at the household level. Columns (1)-(3) differ based on the included interactions with risk aversion. Columns (1) use market year dummies to control for sensitivity to changes in premium, and includes an interaction between [downside] basis risk and risk aversion, while column (2)-(3) directly controls for sensitivity to basis risk, and include interactions between premium discounts and risk aversion. Errors are clustered at the village level. Stars indicate significance: ***, **, and * stand for significance at the 1%, 5%, and 10% level, respectively.
Table 2.12: Group cues: Does Larger Group size lead to Lower Index Demand?

<table>
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<tr>
<th>VARIABLES</th>
<th>(1) bought</th>
<th>(2) bought</th>
<th>(3) bought</th>
<th>(4) bought</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group size</td>
<td>-0.0267***</td>
<td>-0.0291***</td>
<td>-0.0261***</td>
<td>-0.0278***</td>
</tr>
<tr>
<td></td>
<td>(0.00138)</td>
<td>(0.00136)</td>
<td>(0.00129)</td>
<td>(0.00135)</td>
</tr>
<tr>
<td>brisk DOWNSIDE</td>
<td>-0.162***</td>
<td>-0.102***</td>
<td>-0.101***</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.0210)</td>
<td>(0.0210)</td>
<td>(0.0211)</td>
<td></td>
</tr>
<tr>
<td>brisk UPSIDE</td>
<td></td>
<td></td>
<td>0.632***</td>
<td>0.623***</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(0.0235)</td>
<td>(0.0239)</td>
</tr>
<tr>
<td>discount</td>
<td></td>
<td></td>
<td></td>
<td>0.00328***</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(0.00544)</td>
</tr>
<tr>
<td>Constant</td>
<td>0.278***</td>
<td>0.453***</td>
<td>0.429***</td>
<td>0.470***</td>
</tr>
<tr>
<td></td>
<td>(0.0386)</td>
<td>(0.0425)</td>
<td>(0.0412)</td>
<td>(0.0416)</td>
</tr>
<tr>
<td>Observations</td>
<td>4,299</td>
<td>4,299</td>
<td>4,299</td>
<td>4,222</td>
</tr>
<tr>
<td>No. of Villages</td>
<td>53</td>
<td>53</td>
<td>53</td>
<td>53</td>
</tr>
<tr>
<td>R-squared</td>
<td>0.146</td>
<td>0.162</td>
<td>0.288</td>
<td>0.292</td>
</tr>
<tr>
<td>Mkt Year FE$s$</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Village FE$s$</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Notes: Table reports the results from regressions of take-up for rainfall-index insurance on group size (i.e., number of households that received “Group” cues), along with controls for basis risk and exogenous changes in premium at the household level. Columns (1)-(4) differ based on the included controls. Column (1) excludes all controls, column (2) adds a control for sensitivity to [downside] basis risk, column (3) adds controls for both downside and upside basis risks, while column (4) sequentially adds a control for premium discounts. Errors are clustered at the village level. Stars indicate significance: ***, **, and * stand for significance at the 1%, 5%, and 10% level, respectively.
Notes: Figures display the distribution of household wealth. Wealth is estimated using Factor analysis and based on eight (8) household asset holdings: \(1(\text{Electricity}=\text{Yes}), 1(\text{Mobile Phone}=\text{Yes}), 1(\text{Sew Machine}=\text{Yes}), 1(\text{Tractor}=\text{Yes}), 1(\text{Thresher}=\text{Yes}), 1(\text{Bull cart}=\text{Yes}), 1(\text{Bicycle}=\text{Yes}), \) and \(1(\text{Motorcycle}=\text{Yes})\). \(1(.)\) is a logical indicator that equals 1 whenever the argument in the bracket is true, and 0 otherwise. Q3 is missing, as there are few to no households in this bracket.
Table 2.13: Hindu cues: Does Larger Group size lead to Lower Index Demand?

<table>
<thead>
<tr>
<th>VARIABLES</th>
<th>(1) bought</th>
<th>(2) bought</th>
<th>(3) bought</th>
<th>(4) bought</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group size</td>
<td>-0.107***</td>
<td>-0.117***</td>
<td>-0.104***</td>
<td>-0.111***</td>
</tr>
<tr>
<td></td>
<td>(0.00552)</td>
<td>(0.00545)</td>
<td>(0.00514)</td>
<td>(0.00538)</td>
</tr>
<tr>
<td>brisk DOWNSIDE</td>
<td>-0.162***</td>
<td>-0.102***</td>
<td>-0.101***</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.0210)</td>
<td>(0.0210)</td>
<td>(0.0211)</td>
<td></td>
</tr>
<tr>
<td>brisk UPSIDE</td>
<td></td>
<td>0.632***</td>
<td>0.623***</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.0235)</td>
<td>(0.0239)</td>
<td></td>
</tr>
<tr>
<td>discount</td>
<td></td>
<td></td>
<td></td>
<td>0.00328***</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(0.000544)</td>
</tr>
<tr>
<td>Constant</td>
<td>0.278***</td>
<td>0.453***</td>
<td>0.429***</td>
<td>0.470***</td>
</tr>
<tr>
<td></td>
<td>(0.0386)</td>
<td>(0.0425)</td>
<td>(0.0412)</td>
<td>(0.0416)</td>
</tr>
<tr>
<td>Observations</td>
<td>4,299</td>
<td>4,299</td>
<td>4,299</td>
<td>4,222</td>
</tr>
<tr>
<td>No. of Villages</td>
<td>53</td>
<td>53</td>
<td>53</td>
<td>53</td>
</tr>
<tr>
<td>R-squared</td>
<td>0.146</td>
<td>0.162</td>
<td>0.288</td>
<td>0.292</td>
</tr>
<tr>
<td>Mkt Year FEs</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Village FEs</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Notes: Table reports the results from regressions of take-up for rainfall-index insurance on group size (i.e., number of households that received “Hindu” cues), along with controls for basis risk and exogenous changes in premium at the household level. Columns (1)-(4) differ based on the included controls. Column (1) excludes all controls, column (2) adds a control for sensitivity to [downside] basis risk, column (3) adds controls for both downside and upside basis risks, while column (4) sequentially adds a control for premium discounts. Errors are clustered at the village level. Stars indicate significance: ***, **, and * stand for significance at the 1%, 5%, and 10% level, respectively.
Table 2.14: Muslim cues: Does Larger Group size lead to Lower Index Demand?

<table>
<thead>
<tr>
<th>VARIABLES</th>
<th>(1) bought</th>
<th>(2) bought</th>
<th>(3) bought</th>
<th>(4) bought</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group size</td>
<td>-0.0267***</td>
<td>-0.0291***</td>
<td>-0.0261***</td>
<td>-0.0278***</td>
</tr>
<tr>
<td></td>
<td>(0.00138)</td>
<td>(0.00136)</td>
<td>(0.00129)</td>
<td>(0.00135)</td>
</tr>
<tr>
<td>brisk DOWNSIDE</td>
<td>-0.162***</td>
<td>-0.102***</td>
<td>-0.101***</td>
<td>-0.0211</td>
</tr>
<tr>
<td></td>
<td>(0.0210)</td>
<td>(0.0210)</td>
<td>(0.0211)</td>
<td>(0.0211)</td>
</tr>
<tr>
<td>brisk UPSIDE</td>
<td>0.632***</td>
<td>0.623***</td>
<td>0.623***</td>
<td>0.0239</td>
</tr>
<tr>
<td></td>
<td>(0.0235)</td>
<td>(0.0235)</td>
<td>(0.0239)</td>
<td>(0.0239)</td>
</tr>
<tr>
<td>discount</td>
<td>0.00328***</td>
<td>-</td>
<td>-</td>
<td>0.00544</td>
</tr>
<tr>
<td></td>
<td>(0.00345)</td>
<td>-</td>
<td>-</td>
<td>(0.00544)</td>
</tr>
<tr>
<td>Constant</td>
<td>0.278***</td>
<td>0.453***</td>
<td>0.429***</td>
<td>0.470***</td>
</tr>
<tr>
<td></td>
<td>(0.0386)</td>
<td>(0.0425)</td>
<td>(0.0412)</td>
<td>(0.0416)</td>
</tr>
<tr>
<td>Observations</td>
<td>4,299</td>
<td>4,299</td>
<td>4,299</td>
<td>4,222</td>
</tr>
<tr>
<td>No. of Villages</td>
<td>53</td>
<td>53</td>
<td>53</td>
<td>53</td>
</tr>
<tr>
<td>R-squared</td>
<td>0.146</td>
<td>0.162</td>
<td>0.288</td>
<td>0.292</td>
</tr>
<tr>
<td>Mkt Year FE's</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Village FE's</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Notes: Table reports the results from regressions of take-up for rainfall-index insurance on group size (i.e., number of households that received “Muslim” cues), along with controls for basis risk and exogenous changes in premium at the household level. Columns (1)-(4) differ based on the included controls. Column (1) excludes all controls, column (2) adds a control for sensitivity to [downside] basis risk, column (3) adds controls for both downside and upside basis risks, while column (4) sequentially adds a control for premium discounts. Errors are clustered at the village level. Stars indicate significance: ***, **, and * stand for significance at the 1%, 5%, and 10% level, respectively.
Table 2.15: Reported-Crop Loss Experience on Household Characteristics

<table>
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<th>VARIABLES</th>
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<th>(3)</th>
<th>(4)</th>
<th>(5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I(Head=Male)</td>
<td>0.000248</td>
<td>0.00116</td>
<td>0.000837</td>
<td>0.00282</td>
<td>0.00257</td>
</tr>
<tr>
<td>(0.0151)</td>
<td>(0.0154)</td>
<td>(0.0155)</td>
<td>(0.0156)</td>
<td>(0.0157)</td>
<td></td>
</tr>
<tr>
<td>Log(Age)</td>
<td>0.0164</td>
<td>0.0140</td>
<td>-0.00161</td>
<td>-0.00434</td>
<td>-0.00495</td>
</tr>
<tr>
<td>(0.0584)</td>
<td>(0.0587)</td>
<td>(0.0601)</td>
<td>(0.0600)</td>
<td>(0.0604)</td>
<td></td>
</tr>
<tr>
<td>Log(Household Size)</td>
<td>0.0191</td>
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<td>0.0215</td>
<td>0.0234</td>
<td>0.0278</td>
</tr>
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<td>(0.0155)</td>
<td>(0.0162)</td>
<td>(0.0163)</td>
<td>(0.0175)</td>
<td></td>
</tr>
<tr>
<td>I(&gt;=Secondary Educ)</td>
<td>-0.0111</td>
<td>-0.00758</td>
<td>-0.00691</td>
<td>-0.00845</td>
<td></td>
</tr>
<tr>
<td>(0.0207)</td>
<td>(0.0208)</td>
<td>(0.0209)</td>
<td>(0.0209)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I(Electricity=Yes)</td>
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<td>0.0122</td>
<td>0.0150</td>
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<td></td>
</tr>
<tr>
<td>(0.0162)</td>
<td>(0.0163)</td>
<td>(0.0165)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I(Mobile Phone=Yes)</td>
<td>0.0313</td>
<td>0.0299</td>
<td>0.0350</td>
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<td></td>
</tr>
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<td>(0.0359)</td>
<td>(0.0360)</td>
<td>(0.0360)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I(Sew Machine=Yes)</td>
<td>0.0272</td>
<td>0.0303</td>
<td>0.0319</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(0.0315)</td>
<td>(0.0316)</td>
<td>(0.0317)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I(Tractor=Yes)</td>
<td>0.0575</td>
<td>0.0530</td>
<td>0.0626</td>
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</tr>
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<td>(0.0713)</td>
<td>(0.0719)</td>
<td>(0.0737)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I(Thresher=Yes)</td>
<td>0.121</td>
<td>0.124</td>
<td>0.120</td>
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<td></td>
</tr>
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<td>(0.0785)</td>
<td>(0.0786)</td>
<td>(0.0819)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I(Bull cart=Yes)</td>
<td>-0.0168</td>
<td>-0.0180</td>
<td>-0.0214</td>
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<td></td>
</tr>
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<td>(0.0388)</td>
<td>(0.0392)</td>
<td>(0.0394)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I(Bicycle=Yes)</td>
<td>0.00114</td>
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<td>0.00197</td>
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</tr>
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<td>(0.0142)</td>
<td>(0.0143)</td>
<td>(0.0144)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I(Motorcycle=Yes)</td>
<td>-0.0366</td>
<td>-0.0364</td>
<td>-0.0389</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(0.0323)</td>
<td>(0.0324)</td>
<td>(0.0331)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I(Any insurance=Yes)</td>
<td>-0.0132</td>
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<td></td>
</tr>
<tr>
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<td>(0.0142)</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Log(1+Per Capita m.Exp)</td>
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<tr>
<td>(0.0107)</td>
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<td></td>
<td></td>
<td></td>
</tr>
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<td></td>
<td></td>
<td></td>
</tr>
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<td>(0.0221)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I(Muslim name=Yes)</td>
<td>-0.0343</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(0.0285)</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>I(Irrigate=Yes)</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(0.0413)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Constant</td>
<td>86.43***</td>
<td>86.44***</td>
<td>85.77***</td>
<td>85.78***</td>
<td>85.13***</td>
</tr>
<tr>
<td>Observations</td>
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<td>4,293</td>
<td>4,272</td>
<td>4,238</td>
<td>4,206</td>
</tr>
<tr>
<td>No. of Villages</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>R-squared</td>
<td>0.274</td>
<td>0.274</td>
<td>0.275</td>
<td>0.276</td>
<td>0.278</td>
</tr>
<tr>
<td>Linear Trend</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Village FEs</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Notes: Table reports the results from regressions of reported-crop loss experience on a vector of household characteristics. \(1(\_\_\_)\) is a logical indicator that equals 1 whenever the argument in the bracket is true, and 0 otherwise. Columns (1)-(5) differ based on the included controls. Column (1) includes only demographic characteristics, column (2) adds a control for educational level, column (3) adds controls for household assets, column (4) adds an indicator for whether the household has any formal insurance, while column (5) adds controls for per capita monthly expenditure, risk aversion, and indicators for whether respondent has a muslim name and irrigates farm. Errors are robust to heteroskedasticity. Stars indicate significance: ***, **, and * stand for significance at the 1%, 5%, and 10% level, respectively.
Table 2.16: Balance on Household Characteristics

<table>
<thead>
<tr>
<th>VARIABLES</th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>l(Head=Male)</td>
<td>l(HinduT=Yes)</td>
<td>l(MuslimT=Yes)</td>
</tr>
<tr>
<td>1(Head=Male)</td>
<td>-0.00967</td>
<td>-0.000126</td>
<td>-0.0117*</td>
</tr>
<tr>
<td></td>
<td>(0.00828)</td>
<td>(0.00691)</td>
<td>(0.00698)</td>
</tr>
<tr>
<td>Log(Age)</td>
<td>-0.0152</td>
<td>0.0298*</td>
<td>0.0173</td>
</tr>
<tr>
<td></td>
<td>(0.0187)</td>
<td>(0.0169)</td>
<td>(0.0141)</td>
</tr>
<tr>
<td>Log(Household Size)</td>
<td>-0.0101</td>
<td>0.00575</td>
<td>0.00517</td>
</tr>
<tr>
<td></td>
<td>(0.00848)</td>
<td>(0.00700)</td>
<td>(0.00682)</td>
</tr>
<tr>
<td>1(=Secondary Educ)</td>
<td>0.000470</td>
<td>0.00660</td>
<td>0.00176</td>
</tr>
<tr>
<td></td>
<td>(0.0117)</td>
<td>(0.0104)</td>
<td>(0.0107)</td>
</tr>
<tr>
<td>1(Electricity=Yes)</td>
<td>-0.00720</td>
<td>-0.00691</td>
<td>0.00262</td>
</tr>
<tr>
<td></td>
<td>(0.00791)</td>
<td>(0.00729)</td>
<td>(0.00719)</td>
</tr>
<tr>
<td>1(Mobile Phone=Yes)</td>
<td>0.0151</td>
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<td>0.00197</td>
</tr>
<tr>
<td></td>
<td>(0.0176)</td>
<td>(0.0140)</td>
<td>(0.0155)</td>
</tr>
<tr>
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<td>0.00966</td>
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</tr>
<tr>
<td></td>
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<td>(0.0121)</td>
<td>(0.0142)</td>
</tr>
<tr>
<td>1(Tractor=Yes)</td>
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<td>-0.00773</td>
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<tr>
<td></td>
<td>(0.0160)</td>
<td>(0.0141)</td>
<td>(0.0274)</td>
</tr>
<tr>
<td>1(Thresher=Yes)</td>
<td>-0.0168</td>
<td>0.0288</td>
<td>-0.00903</td>
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<tr>
<td></td>
<td>(0.0170)</td>
<td>(0.0135)</td>
<td>(0.0169)</td>
</tr>
<tr>
<td>1(Bull cart=Yes)</td>
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<td>0.0100</td>
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<td>(0.0176)</td>
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</tr>
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<td>1(Bicycle=Yes)</td>
<td>0.00492</td>
<td>0.00767</td>
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<td>(0.00675)</td>
<td>(0.00633)</td>
</tr>
<tr>
<td>1(Motorcycle=Yes)</td>
<td>-0.0236</td>
<td>0.00167</td>
<td>0.00264</td>
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<tr>
<td></td>
<td>(0.0145)</td>
<td>(0.0152)</td>
<td>(0.0161)</td>
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<tr>
<td>1(Any Insurance=Yes)</td>
<td>0.00529</td>
<td>0.00132</td>
<td>-0.00491</td>
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<tr>
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<td>(0.00696)</td>
<td>(0.00578)</td>
<td>(0.00604)</td>
</tr>
<tr>
<td>Log(1=Per Capita m.Exp)</td>
<td>-0.00262</td>
<td>-0.000892</td>
<td>0.00382</td>
</tr>
<tr>
<td></td>
<td>(0.00502)</td>
<td>(0.00449)</td>
<td>(0.00417)</td>
</tr>
<tr>
<td>Risk Aversion</td>
<td>-0.0135</td>
<td>0.000140</td>
<td>-0.00283</td>
</tr>
<tr>
<td></td>
<td>(0.0113)</td>
<td>(0.00927)</td>
<td>(0.00933)</td>
</tr>
<tr>
<td>1(Muslim name=Yes)</td>
<td>-0.0116</td>
<td>-0.0167</td>
<td>0.00908</td>
</tr>
<tr>
<td></td>
<td>(0.0133)</td>
<td>(0.0104)</td>
<td>(0.0116)</td>
</tr>
<tr>
<td>1(Irrigate=Yes)</td>
<td>-0.0189</td>
<td>-0.0260**</td>
<td>-0.00407</td>
</tr>
<tr>
<td></td>
<td>(0.0150)</td>
<td>(0.0115)</td>
<td>(0.0134)</td>
</tr>
<tr>
<td>Constant</td>
<td>54.98***</td>
<td>38.03***</td>
<td>39.49***</td>
</tr>
<tr>
<td></td>
<td>(3.777)</td>
<td>(3.196)</td>
<td>(3.257)</td>
</tr>
</tbody>
</table>

Notes: Table reports the results from regressions of risk-sharing treatment groups on a vector of household characteristics. \(1(.)\) is a logical indicator that equals 1 whenever the argument in the bracket is true, and 0 otherwise. Columns include the set of all seventeen (17) demographic characteristics. Errors are robust to heteroskedasticity. Stars indicate significance: ***, **, and * stand for significance at the 1%, 5%, and 10% level, respectively.
Table 2.17: Wealth Control: Index Demand-Group Identity linkages

<table>
<thead>
<tr>
<th>VARIABLES</th>
<th>(1)</th>
<th>(2)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>bought</td>
<td>bought</td>
</tr>
<tr>
<td>Group cues</td>
<td>-0.188***</td>
<td>-0.188***</td>
</tr>
<tr>
<td></td>
<td>(0.0273)</td>
<td>(0.0270)</td>
</tr>
<tr>
<td>Discount</td>
<td>0.00290***</td>
<td>0.00279***</td>
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<tr>
<td></td>
<td>(0.000549)</td>
<td>(0.000548)</td>
</tr>
<tr>
<td>Group cues X Discount</td>
<td>0.0992***</td>
<td>0.0995***</td>
</tr>
<tr>
<td></td>
<td>(0.00768)</td>
<td>(0.00771)</td>
</tr>
<tr>
<td>Hindu cues</td>
<td>-0.317***</td>
<td>-0.317***</td>
</tr>
<tr>
<td></td>
<td>(0.0372)</td>
<td>(0.0369)</td>
</tr>
<tr>
<td>Hindu cues X Discount</td>
<td>0.156***</td>
<td>0.156***</td>
</tr>
<tr>
<td></td>
<td>(0.00713)</td>
<td>(0.00714)</td>
</tr>
<tr>
<td>Muslim cues</td>
<td>-0.294***</td>
<td>-0.294***</td>
</tr>
<tr>
<td></td>
<td>(0.0350)</td>
<td>(0.0349)</td>
</tr>
<tr>
<td>Muslim cues X Discount</td>
<td>0.150***</td>
<td>0.150***</td>
</tr>
<tr>
<td></td>
<td>(0.00494)</td>
<td>(0.00489)</td>
</tr>
<tr>
<td>brisk DOWNSIDE [Crop]</td>
<td>-0.0233</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.0183)</td>
<td></td>
</tr>
<tr>
<td>brisk UPSIDE [Crop]</td>
<td>0.630***</td>
<td></td>
</tr>
<tr>
<td></td>
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<td></td>
</tr>
<tr>
<td>Wealth score</td>
<td>0.00262</td>
<td>0.00337</td>
</tr>
<tr>
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<td>(0.00613)</td>
<td>(0.00544)</td>
</tr>
<tr>
<td>brisk DOWNSIDE [Revenue]</td>
<td></td>
<td>0.00747</td>
</tr>
<tr>
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<td></td>
<td>(0.0235)</td>
</tr>
<tr>
<td>brisk UPSIDE [Revenue]</td>
<td></td>
<td>0.691***</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.0220)</td>
</tr>
<tr>
<td>Constant</td>
<td>0.245***</td>
<td>0.226***</td>
</tr>
<tr>
<td></td>
<td>(0.0454)</td>
<td>(0.0410)</td>
</tr>
<tr>
<td>Observations</td>
<td>4,848</td>
<td>4,848</td>
</tr>
<tr>
<td>R-squared</td>
<td>0.276</td>
<td>0.326</td>
</tr>
<tr>
<td>Mkt Year FE s</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Household FE s</td>
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<td>No</td>
</tr>
<tr>
<td>Mismatch</td>
<td>CROP</td>
<td>REVENUE</td>
</tr>
<tr>
<td>Effects</td>
<td>PRICE</td>
<td>PRICE</td>
</tr>
</tbody>
</table>

Notes: Table shows the results from regressions of take-up for rainfall-index insurance on basis risk and discount assignments—exogenous variation in insurance premium, and interactions with risk-sharing treatments, while controlling for potential wealth effects. Columns (1) and (2) differ based on how basis risk is defined: mismatch between payouts and crop losses in column (1) versus mismatch between payouts and revenue losses in column (2). Errors are clustered at the village level. Stars indicate significance: ***, **, and * stand for significance at the 1%, 5%, and 10% level, respectively.
Table 2.18: Wealth Control: Index Demand-Group Identity linkages

<table>
<thead>
<tr>
<th>VARIABLES</th>
<th>(1) bought</th>
<th>(2) bought</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group cues</td>
<td>-0.0351</td>
<td>-0.0402</td>
</tr>
<tr>
<td></td>
<td>(0.0544)</td>
<td>(0.0521)</td>
</tr>
<tr>
<td>brisk DOWNSIDE [Crop]</td>
<td>-0.0250</td>
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</tr>
<tr>
<td></td>
<td>(0.0195)</td>
<td></td>
</tr>
<tr>
<td>Group cues X brisk DOWNSIDE[Crop]</td>
<td>-0.0492</td>
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</tr>
<tr>
<td></td>
<td>(0.106)</td>
<td></td>
</tr>
<tr>
<td>Hindu cues</td>
<td>-0.0102</td>
<td>-0.0120</td>
</tr>
<tr>
<td></td>
<td>(0.0688)</td>
<td>(0.0654)</td>
</tr>
<tr>
<td>Hindu cues X brisk DOWNSIDE[Crop]</td>
<td>-0.0727</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.102)</td>
<td></td>
</tr>
<tr>
<td>Muslim cues</td>
<td>-0.0744</td>
<td>-0.0567</td>
</tr>
<tr>
<td></td>
<td>(0.0663)</td>
<td>(0.0616)</td>
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<tr>
<td>Muslim cu X brisk DOWNSIDE[Crop]</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>(0.0892)</td>
<td></td>
</tr>
<tr>
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<td>0.00324***</td>
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<tr>
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<td>(0.000527)</td>
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<tr>
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<td>(0.00572)</td>
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<tr>
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</tr>
<tr>
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<tr>
<td></td>
<td>(0.244)</td>
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</tr>
<tr>
<td>Hindu cues X brisk DOWNSIDE [Rev]</td>
<td>-0.0330</td>
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</tr>
<tr>
<td></td>
<td>(0.192)</td>
<td></td>
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<tr>
<td>Muslim cu X brisk DOWNSIDE [Rev]</td>
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<tr>
<td>brisk UPSIDE [Revenue]</td>
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<td></td>
</tr>
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<td></td>
<td>(0.0221)</td>
<td></td>
</tr>
<tr>
<td>Constant</td>
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<td>0.226***</td>
</tr>
<tr>
<td></td>
<td>(0.0459)</td>
<td>(0.0411)</td>
</tr>
</tbody>
</table>

Notes: Table shows the results from regressions of take-up for rainfall-index insurance on basis risk and discount assignments—exogenous variation in insurance premium, and interactions with risk-sharing treatments, while controlling for potential wealth effects. Columns (1) and (2) differ based on how basis risk is defined: mismatch between payouts and crop losses in column (1) versus mismatch between payouts and revenue losses in column (2). Errors are clustered at the village level. Stars indicate significance: ***, **, and * stand for significance at the 1%, 5%, and 10% level, respectively.
Table 2.19: Wealth Control: Does Larger Group lead to Lower Demand?

<table>
<thead>
<tr>
<th>VARIABLES</th>
<th>(1) bought</th>
<th>(2) bought</th>
<th>(3) bought</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group size [Group cu.]</td>
<td>-0.0128***</td>
<td></td>
<td>-0.105***</td>
</tr>
<tr>
<td></td>
<td>(0.00466)</td>
<td></td>
<td>(0.0181)</td>
</tr>
<tr>
<td>brisk DOWNSIDE</td>
<td>-0.101***</td>
<td>-0.0999***</td>
<td>-0.105***</td>
</tr>
<tr>
<td></td>
<td>(0.0182)</td>
<td>(0.0175)</td>
<td>(0.0181)</td>
</tr>
<tr>
<td>brisk UPSIDE</td>
<td>0.633***</td>
<td>0.636***</td>
<td>0.633***</td>
</tr>
<tr>
<td></td>
<td>(0.0201)</td>
<td>(0.0194)</td>
<td>(0.0200)</td>
</tr>
<tr>
<td>Discount</td>
<td>-0.000851</td>
<td>-0.000836</td>
<td>-0.000876</td>
</tr>
<tr>
<td></td>
<td>(0.000538)</td>
<td>(0.000537)</td>
<td>(0.000544)</td>
</tr>
<tr>
<td>Wealth score</td>
<td>0.00143</td>
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<td>0.00309</td>
</tr>
<tr>
<td></td>
<td>(0.00606)</td>
<td>(0.00609)</td>
<td>(0.00643)</td>
</tr>
<tr>
<td>Group size [Hindu cu.]</td>
<td></td>
<td>-0.0175***</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>(0.00570)</td>
<td></td>
</tr>
<tr>
<td>Group size [Muslim cu.]</td>
<td></td>
<td></td>
<td>-0.0104*</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>(0.00594)</td>
</tr>
<tr>
<td>Constant</td>
<td>0.418***</td>
<td>0.416***</td>
<td>0.400***</td>
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<td>(0.0273)</td>
<td>(0.0266)</td>
<td>(0.0247)</td>
</tr>
<tr>
<td>Observations</td>
<td>4,848</td>
<td>4,848</td>
<td>4,848</td>
</tr>
<tr>
<td>R-squared</td>
<td>0.157</td>
<td>0.157</td>
<td>0.152</td>
</tr>
<tr>
<td>Mkt Year FEs</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Village FEs</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Group size definition</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\sum_v 1(\text{GroupT} = \text{Yes})$</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>$\sum_v 1(\text{HinduT} = \text{Yes})$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\sum_v 1(\text{MuslimT} = \text{Yes})$</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes: Table reports the results from regressions of take-up for rainfall-index insurance on group size, along with controls for basis risk, exogenous changes in premium and potential wealth effects. $1(.)$ is a logical indicator that equals 1 whenever the argument in the bracket is true, and 0 otherwise. Columns (1)-(3) differ based on how group size is defined. In column (1), group size refers to the number of households that received “Group” cues. In column (2), group size refers to the number of households that received “Hindu” cues. In column (3), group size refers to the number of households that received “Muslim” cues. Errors are clustered at the village level. Stars indicate significance: ***, **, and * stand for significance at the 1%, 5%, and 10% level, respectively.
Table 2.20: Nonlinear Wealth Control: Does Larger Group lead to Lower Demand?

<table>
<thead>
<tr>
<th>VARIABLES</th>
<th>(1) bought</th>
<th>(2) bought</th>
<th>(3) bought</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group size [Group cu.]</td>
<td>-0.0127***</td>
<td>-0.109***</td>
<td>-0.109***</td>
</tr>
<tr>
<td></td>
<td>(0.00468)</td>
<td>(0.0179)</td>
<td>(0.0201)</td>
</tr>
<tr>
<td>brisk DOWNSIDE</td>
<td>-0.105***</td>
<td>-0.104***</td>
<td>-0.109***</td>
</tr>
<tr>
<td></td>
<td>(0.0181)</td>
<td>(0.0172)</td>
<td>(0.0201)</td>
</tr>
<tr>
<td>brisk UPSIDE</td>
<td>0.632***</td>
<td>0.635***</td>
<td>0.632***</td>
</tr>
<tr>
<td></td>
<td>(0.0203)</td>
<td>(0.0195)</td>
<td>(0.0201)</td>
</tr>
<tr>
<td>Discount</td>
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<tr>
<td></td>
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</tr>
<tr>
<td>Wealth Quintile 2</td>
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<tr>
<td></td>
<td>(0.0230)</td>
<td>(0.0232)</td>
<td>(0.0235)</td>
</tr>
<tr>
<td>Wealth Quintile 4</td>
<td>-0.0342</td>
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<td>-0.0367</td>
</tr>
<tr>
<td></td>
<td>(0.0249)</td>
<td>(0.0247)</td>
<td>(0.0246)</td>
</tr>
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<td>Wealth Quintile 5</td>
<td>0.0460*</td>
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</tr>
<tr>
<td></td>
<td>(0.0250)</td>
<td>(0.0256)</td>
<td>(0.0256)</td>
</tr>
<tr>
<td>Group size [Hindu cu.]</td>
<td>-0.0178***</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>(0.00568)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group size [Muslim cu.]</td>
<td></td>
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<tr>
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<td>0.416***</td>
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<td>(0.0298)</td>
<td>(0.0309)</td>
</tr>
<tr>
<td>Observations</td>
<td>4,848</td>
<td>4,848</td>
<td>4,848</td>
</tr>
<tr>
<td>R-squared</td>
<td>0.159</td>
<td>0.160</td>
<td>0.155</td>
</tr>
<tr>
<td>Mkt Year FEs</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Village FEs</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Group size definition</td>
<td>$\sum_{F} 1(\text{GroupT} = \text{Yes})$</td>
<td>$\sum_{F} 1(\text{HinduT} = \text{Yes})$</td>
<td>$\sum_{F} 1(\text{MislimT} = \text{Yes})$</td>
</tr>
</tbody>
</table>

Notes: Table reports the results from regressions of take-up for rainfall-index insurance on group size, along with controls for basis risk, exogenous changes in premium and potential nonlinear wealth effects (i.e., include wealth quintile dummies: Q1-Q5 with Q1 being omitted category). The coefficient on Q3 is not estimable, since there are no households in the third quintile of the distribution. $1(.)$ is a logical indicator that equals 1 whenever the argument in the bracket is true, and 0 otherwise. Columns (1)-(3) differ based on how group size is defined. In column (1), group size refers to the number of households that received “Group” cues. In column (2), group size refers to the number of households that received “Hindu” cues. In column (3), group size refers to the number of households that received “Muslim” cues. Errors are clustered at the village level. Stars indicate significance: ***, **, and * stand for significance at the 1%, 5%, and 10% level, respectively.
2.7 Bibliography


### 2.8 Appendix

**Proof of Lemma 1**

The proof for Lemma 1 is similar to arguments in Wang (2014).

Let $z_i$ and $z_g$ denote the income of individual $i$ and representative individual $g$. Suppose $i$ and $g$ form a pair. We denote the combined income of the pair, $z_{i^*} \equiv z_i + z_g$. If $i$ wishes to promise utility $\xi$ to his partner $g$, then the corresponding efficient sharing rule $(z_{i^*} - s(z_{i^*}, \xi), s(z_{i^*}, \xi))$ must satisfy

$$s^*(z_{i^*}, \xi) \equiv \arg \max_s EU_i(z_{i^*} - s) \quad s.t. \quad EU_g(s) \geq \xi \quad (2.1)$$

Varying $\xi$, the solutions $s^*$ describe the set of efficient sharing rules.

Let $f(z_{i^*})$ denote the joint density function for combined income. Plugging in the utility functions of the individuals allows us to restate the above optimization program as

$$\max \int -e^{-\gamma_i(z_{i^*} - s(z_{i^*}))} f(z_{i^*}) dz$$

$$s.t. \int -e^{-\gamma_g s(z_{i^*})} f(z_{i^*}) dz \geq -e^{-\xi}$$

The inequality in the constraint will hold with equality since transferring income to individual $g$ comes at the cost of reducing $i$'s income.
Solving the constrained optimization problem gives us

\[ s^*(z_i) = \frac{\gamma_i}{\gamma_i + \gamma_g} z_i + \frac{1}{\gamma_g} \log(\int -e^{-\frac{\gamma_i \gamma_g}{\gamma_i + \gamma_g} z_i} f(z_i)dz) + \frac{1}{\gamma_g} \xi \]

This allows us to rewrite individual \( i \)'s expected utility as

\[ Eu_i(\xi) = -e^{\frac{\gamma_i \xi}{\gamma_g}} \left( \int -e^{-\frac{\gamma_i \gamma_g}{\gamma_i + \gamma_g} z_i} f(z_i)dz \right)^{\frac{\gamma_i + \gamma_g}{\gamma_g}} \]

where as individual \( g \)'s expected utility can be written as

\[ Eu_g(\xi) = -e^{-\xi} \]

For individual \( i \) with CARA utility function with income \( z_i \), there is a simple relation between the certainty equivalent (\( CE_i \)) and the expected utility:

\[ -e^{-\gamma_i CE_i} = E(-e^{-\gamma_i z_i}) \]

which gives us

\[ CE_i = -\frac{1}{\gamma_i} \log E(e^{-\gamma_i z_i}) \]

We apply this to the efficient risk sharing problem to get

\[ CE_g = \frac{\xi}{\gamma_g} \]

and

\[ CE_i = -\left(\frac{1}{\gamma_i} + \frac{1}{\gamma_g}\right) \log(\int -e^{-\frac{\gamma_i \gamma_g}{\gamma_i + \gamma_g} z_i} f(z_i)dz) - \frac{1}{\gamma_g} \xi \]

Thus we observe that increasing certainty individual of individual \( g \) by one unit leads to a reduction in certainty equivalent of individual \( i \) by one unit. Hence certainty equivalents are transferable across individuals and since expected utility is a monotonic transformation of certainty equivalent, we get that the expected utility is transferable as well. This concludes the proof of Lemma 1.
Proof of Lemma 2

From the proof of Lemma 1, we found that if risk is shared efficiently then we get

\[ CE_i + CE_g = -\left(\frac{1}{\gamma_i} + \frac{1}{\gamma_g}\right) \log(\int -e^{-\gamma_{ig}z_i^*} f(z_i^*) dz) \]
\[ = -\frac{1}{\gamma_i^*} \log(\int -e^{-\gamma_i z_i^*} f(z_i^*) dz) \]
\[ = -\frac{1}{\gamma_i^*} \log E(e^{-\gamma_i z_i^*}) \]

With TU, the sum of the CEs correspond to the joint maximization of the group \((i, g)\)'s welfare. From the last equality, this is identical to the maximization problem of a representative individual with risk aversion parameter \(\gamma_i^*\) and income process \(z_i^*\).

Further, since \(\frac{1}{\gamma_i^*} = \frac{1}{\gamma_i} + \frac{1}{\gamma_g}\) we have that \(\gamma_i^* = \frac{\gamma_i \gamma_g}{\gamma_i + \gamma_g} < \min(\gamma_i, \gamma_g)\).

Proof of Lemma 3

Let \(CE^0_g, CE^0_{i^*}\) denote the certainty equivalent for the group \(g\) without individual \(i\) and the certainty equivalent for group \(g\) with individual \(i\) joining respectively. We want to show that \(CE^0_{i^*} > CE^0_g + CE^0_i\). Notice that:

\[ CE^0_{i^*} = w_i + w_g - \frac{\gamma_{i^*}(\sigma_i^2 + \sigma_g^2)}{2} - \frac{1}{\gamma_{i^*}} \log([1 - p] + pe^{\gamma_{i^*}L}) \]

and

\[ CE^0_g = w_g - \frac{\gamma_g \sigma_g^2}{2} \]

Hence it is sufficient to show that

\[ w_i + w_g - \frac{\gamma_{i^*}(\sigma_i^2 + \sigma_g^2)}{2} - \frac{1}{\gamma_{i^*}} \log([1 - p] + pe^{\gamma_{i^*}L}) > w_g - \frac{\gamma_g \sigma_g^2}{2} + w_i - \frac{\gamma_i \sigma_i^2}{2} - \frac{1}{\gamma_i} \log([1 - p] + pe^{\gamma_i L}) \]

The last inequality follows from the following two claims:
CLAIM 1: \[
\frac{\gamma g^2}{2} + \frac{\sigma^2}{2} > -\frac{\gamma^* (\sigma^2 + \sigma_g^2)}{2}
\]

Proof: This follows from observing that \(\gamma^* < \min(\gamma_g, \gamma_i)\) by lemma 2.

CLAIM 2: \[
-\frac{1}{\gamma^*} \log([1 - p] + pe^{\gamma^* L}) > -\frac{1}{\gamma_i} \log([1 - p] + pe^{\gamma L})
\]

Proof: This follows from observing that the LHS is the CE for a representative agent with risk aversion \(\gamma^*\) for a gamble \(v\) while the RHS is the CE for an individual with risk aversion \(\gamma_i > \gamma^*\) for the same gamble \(v\). Since CE is decreasing in risk aversion, the claim follows.
Chapter 3

Investment Timing, Moral Hazard and Overconfidence

Bikramaditya Datta

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3.1 Introduction

Innovation is an important factor of economic growth and hence, much research has been devoted to studying its determinants. A recent strand of the literature has focussed on the attributes of entrepreneurs and CEOs in innovative industries to identify characteristics associated with innovation and one finding is that overconfidence, defined as “the tendency of individuals to think that they are better than they really are in terms of characteristics such as ability, judgment, or prospects for successful life outcomes”, is associated with higher innovation (e.g., Galasso and Simcoe 2011; Gervais, Heaton, and Odean 2011; Hirshleifer, Low, and Teoh 2012). A second strand of the literature has focussed on how agency problems in financing of innovation, arising from the separation of financier and innovator, leads to inefficiencies (e.g., Bergemann and Hege 2005; Hall and Lerner 2010; Hörner and Samuelson 2012). In this paper, I study how overconfidence and financial frictions impact entrepreneurs by shaping their incentives to learn. Some natural questions arise in the light of the above findings such as, does overconfidence of entrepreneurs lead to more efficient experimentation? What does the interaction of the overconfident entrepreneurs and the agency problems in financing imply for welfare? How do the answers to the above questions depend on the nature of financing?

To study these issues, I consider a continuous time model in which an entrepreneur has an irreversible project. The outcome of the project depends on both the quality of the project and the ability of the entrepreneur, both of which are unknown. The implementation of the project can be postponed, enabling learning about the quality of the project as long as the project has not been launched\(^2\). In the benchmark case, the entrepreneur has correct belief about his own ability and has sufficient funds to implement the project. The entrepreneur, when deciding on when to implement the project, faces a trade-off between discounting and learning: waiting delays the realization of payoff, but leads to better information about the

\(^2\)This is meant to capture the idea that entrepreneurs experiment by running tests to learn about the quality of the projects before implementing them.
quality of the project. The efficient experimentation time is a decreasing function of his belief regarding his ability and a positive function of the cost of implementing the project.

In case the entrepreneur has no funds of his own to implement the project, he has to rely on investors for funds. I analyze two polar cases which differ in the allocation of bargaining power among the investor and the entrepreneur. In the first case, the investor has the bargaining power. She funds the project, decides on when to implement the project and also on the division of the surplus in case of the project succeeding. In the second case, the entrepreneur decides when to implement the project, and seeks funding from a competitive market of investors at the time of implementation of project. The moral hazard problem arises from the fact that while the funds are supplied by the investor, the entrepreneur controls the allocation of the funds. He can either use the funds to implement the project, or can divert the funds to his private uses. Hence, the contract between the investor and entrepreneur has to ensure that the entrepreneur uses the fund properly. Under investor bargaining power, the agency problem leads to delayed implementation and over-experimentation since the “effective” cost of implementation includes the cost of implementing the project as well as the cost of incentivizing the agent to properly use the funds. Under entrepreneur bargaining power, the main friction comes from the fact the implementation has to be delayed till the point where the probability of success is high enough so that the expected surplus received by the entrepreneur exceeds the benefits of diverting funds to private uses.

I next consider the case of an overconfident entrepreneur who overestimates his ability. Such overconfidence leads to under-experimentation and early implementation of the project compared to efficient experimentation if the project is self-financed by the entrepreneur. However, if the project is funded by investors, then the presence of an overconfident entrepreneur leads to a more efficient experimentation compared to an entrepreneur who has accurate beliefs about himself. This is because, under investor bargaining power, it is cheaper to incentivize an entrepreneur who overestimates his probability of success. Un-
der entrepreneur bargaining power, the increase in efficiency comes from the fact that the
cutoff point for providing financing is lower. This is because, the entrepreneur overesti-
mates his chance of succeeding and hence one can implement the project at an earlier date
where beliefs about the quality of the project is lower. Thus, overconfidence alleviates the
inefficiency caused due to the agency problems.

The paper contributes to the literature on agency problems and financing of innovation.
Bobtcheff and Levy (2017) considers a real option model\(^3\) in which a cash-constrained en-
trepreneur learns prior to investing, at a speed which is private information and use the time
of investment to signal his learning ability. The paper demonstrates that, depending on the
learning speed of the entrepreneur types, it is possible to have both hurried and delayed
investment compared to the efficient investment timing. In contrast, I focus on the impact
of moral hazard in an investment timing model in which the speed of learning is known and
demonstrate that moral hazard might lead to either delayed investment or have no impact
on efficient investment timing depending on the allocation of bargaining power.

The paper is also related to Bergemann and Hege (2005) which studies contracting for ex-
perimentation and moral hazard\(^4\). Bergemann and Hege consider the financing of a research
project under uncertainty about the time of completion and the probability of eventual suc-
cess and find that agency effect leads to an under-experimentation. In contrast, I find that
agency problem leads to over-experimentation. In both the models, agency problems lead
to an effective increase in the cost of implementing projects. However, learning in my model
serves to save on the cost of implementing bad projects and hence, the higher the cost of
implementing projects leads to more learning.

The paper contributes to the literature on overconfidence and moral hazard\(^5\). De la Rosa
(2011) suggests that an overconfidence has conflicting effects on agent’s incentives. On the

\(^{3}\)See also Grenadier and Wang (2005), Grenadier, Malenko, and Malenko (2016) for agency problems in
a real option model.

\(^{4}\)See also Hörner and Samuelson (2013); Halac, Kartik and Liu (2016); Manso (2011) for moral hazard
and experimentation.

\(^{5}\)see Köszegi (2014) for a survey
one hand, the agent values success-contingent payments, and thus prefers higher-powered incentives. On the other hand, if the agent overestimates the extent to which his actions affect outcomes, lower-powered incentives are sufficient to induce any given effort level. In my model, only the second channel operates and this leads to a decrease in the effective cost of implementing project which leads to more efficient learning.

Finally, the paper also contributes to the literature on overconfidence and innovation. Galasso and Simcoe (2010) develop a career concern model to demonstrate that overconfident CEOs who underestimate the probability of failure are more likely to pursue innovation. Hirshleifer, Low, and Teoh (2012) suggests that overconfidence leads to CEOs to invest in more riskier projects. In contrast, I focus on a new channel, learning via investment timing and indicate that even though overconfident entrepreneurs/CEOs invest more, it may not be welfare maximizing to do so.

The rest of the paper is organized as follows. In Section 2, I describe the model setup and solve for the benchmark case in which the agent funds the project and has accurate beliefs regarding his ability. I also describe the moral hazard problem and analyze its implication under different allocation of bargaining power. In Section 3, I consider the case of overconfident agents and analyze the outcome under self funding as well as funding from investors under different allocation of bargaining power and I conclude in Section 4.

3.2 Model

A risk neutral entrepreneur has a project with unknown return. With probability \( p_0 \), the project is of good quality, and with probability \( 1 - p_0 \), the project is of bad quality. The success of the project depends on both its quality as well as the ability of the entrepreneur. The ability of the entrepreneur is persistent and is either high or low. The entrepreneur’s true ability is unknown and the probability that he is high ability is \( \alpha \in (0,1) \). A bad project, if
implemented, fails regardless of the ability of the entrepreneur, while a good project succeeds with probability $1^6$ if the entrepreneur is of high ability. It costs $c > 0$ to implement the project and success in the project creates a surplus of $R$. If the project results in failure or if the project is not implemented, a surplus of 0 is generated.

Time $t$ is continuous with an infinite horizon and the future is discounted at rate $r > 0$. The decision of whether to implement the project need not be taken at $t = 0$, but can be delayed. The advantage of delaying implementation is that it enables information to be collected about the quality of the project. Following Décamps and Mariotti (2004) and Bobtcheff and Levy (2017), information about the project is modeled as a Poisson process. If the project is bad, then the probability news arrives by time $t$ is $1 - e^{\lambda t}$, where $\lambda > 0$. If the project is good, no news arrives. Hence, information here is modeled as a “bad news”: the arrival of news immediately indicates the project is bad. Let $s_t$ denote the probability that no news arrives till time $t$:

$$ s_t = p_0 + (1 - p_0)e^{-\lambda t}. $$

Following Bayes’ rule, the belief at date $t$ that the project is good given no bad news till $t$ is given by

$$ p_t = \frac{p_0}{s_t} = \frac{p_0}{p_0 + (1 - p_0)e^{-\lambda t}}. $$

Note that $p_t$ is an increasing function of $t$. The Poisson process is observed for free and news is also public.

I analyze the project implementation problem under three different scenarios. In the first scenario, the entrepreneur has enough funds to implement project. In the second scenario, the entrepreneur has no money of his own, a risk neutral investor with a discount rate $r$ funds the project, decides on when to implement the project and also on the division of the surplus. I refer to this as the scenario in which the investor the bargaining power. In the third scenario, the entrepreneur decides when to implement the project, but does not have

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6This is without loss of generality, the results hold if one assumes that the good project succeeds with probability $\gamma > 0$ if the entrepreneur is of high ability.
funds of his own to implement the project. Hence, the entrepreneur seeks funding from a competitive market of investors at the time of implementation of project. The competitive market of investors is represented by a single investor who can only accept or reject the division of surplus proposed by the entrepreneur. I refer to this as the scenario in which the entrepreneur has the bargaining power.

In the scenarios, where the funds are supplied by the investor, the entrepreneur controls the allocation of the funds. He can either use the funds to implement the project, or can divert the funds to his private use. This is the source of the agency problem in the model.

Assumption on Parameters: I make two assumptions regarding parameters of the model:

Assumption 1: $p_0 \alpha R < c$.

Assumption 2: $\alpha R > 2c$.

The first assumption implies that the project is not implemented at $t = 0$, while the second assumption implies that the project is implemented if it known that the project quality is good. These two assumptions guarantee a strictly positive solution for the time of implementation of project.

### 3.2.1 Entrepreneur Uses Own Funds

I first analyze the case in which the entrepreneur funds the project. The entrepreneur chooses to wait till time $t$ before implementing the project at a cost of $c$. If the entrepreneur receives news before time $t$, he chooses to not implement the project. Thus the entrepreneur’s problem is to choose the time of implementation $t$, to maximize\(^8\)

\(^7\)Following Biais, Mariotti, Plantin and Rochet (2007), the agency problem is thus one in which the entrepreneur can divert cash that is being advanced to finance the project. However, one can also equivalently describe the model as the simplest case of the canonical hidden-action model as in Holmström (1979), in which the entrepreneur needs to exert costly hidden effort in order to have a chance of success.

\(^8\)Note that the stopping problem can be solved by maximizing the date 0 expected payoff, as the entrepreneur can perfectly forecast at date 0 his posterior beliefs at future dates.
\[ \Pi_t = e^{-rt} s_t (p_t \alpha R - c) = e^{-rt} (p_0 \alpha R - c + (1 - s_t)c) = e^{-rt} (p_0 (\alpha R - c) - (1 - p_0)e^{-\lambda t} c) \]

The expression reflects the trade-off the entrepreneur faces between discounting and learning: waiting delays the realization of payoff, but it also allows the option to not implement. Thus waiting allows to avoid the cost \( c \) in case bad news arrives.

The optimal stopping belief \( p_t^{FB} \) (see the Appendix for the proof) is given by

\[ p_t^{FB} = \frac{(r + \lambda)c}{r\alpha R + \lambda c}. \]

Observe that the optimal stopping belief is a decreasing function of \( r, \alpha, R \) and \( \lambda \) and an increasing function of \( c \).

### 3.2.2 Investor Has the Bargaining Power

In this case, the investor decides to wait till time \( t \) before implementing the project at a cost of \( c \). She also decides on the division of surplus to offer to the entrepreneur. Suppose that the investor offers a share\(^9\) \( 1 - y_t \) of the surplus to the entrepreneur if the project is implemented at time \( t \) and succeeds. The investor receives the remaining share \( y_t \).

The investor wants to make sure that the entrepreneur allocates the fund properly. If the entrepreneur diverts the funds, he gets \( c \). If the entrepreneur uses the fund to implement the project at time \( t \), his expected payoff is given by \( (1 - y_t)p_t \alpha R \). Hence the incentive compatibility condition, which states that for the entrepreneur the expected return from

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\(^9\)Given that the only possible outcomes are success or failure if the project is implemented, there is no loss of generality in restricting the investor to offering the entrepreneur a share of the surplus generated by a success. In particular, allowing payments conditional on failure would not change the results, as such payments dampen incentives.
allocating the funds to implement the project must exceed the value of diverting the funds, is given by

\[(1 - y_t)\alpha R \geq c\]

In equilibrium, the above incentive compatibility condition has to hold with equality, for otherwise the investor can reduce the share of the surplus offered to the entrepreneur and increase her profit. Thus, one obtains

\[(1 - y_t) = \frac{c}{p_t \alpha R}\]

Given the distribution of surplus, the investor chooses the time of implementation \(t\) to maximize\(^{10}\)

\[\Pi^I_t = e^{-rt}s_t(p_t\alpha y_t R - c) = e^{-rt}s_t(p_t\alpha R - 2c)\]

Comparing the expression for \(\Pi^I_t\) to \(\Pi_t\) in section 2.1 one observes that the “effective” cost of implementing the project is higher, \(2c\), compared to \(c\) in the case in which the entrepreneur funds the project. This is because, the cost includes both the actual cost of implementing the project, as well as the cost of incentivizing the entrepreneur to allocate funds properly. The optimal stopping belief \(p_t^I\) is given by

\[p_t^I = \frac{(r + \lambda)2c}{r \alpha R + \lambda 2c}\]

**Proposition 1**: Under investor bargaining power and accurate beliefs about ability, the optimal stopping belief is higher and there is delayed implementation compared to the first best. There is thus over-experimentation compared to the efficient investment policy.

\(^{10}\)Clearly, the investor will choose not to implement the project if news arrives before \(t\).
3.2.3 Entrepreneur Has the Bargaining Power

In this case, the entrepreneur decides to wait till time $t$ before implementing the project. He seeks funding from the investor at time $t$ and also decides on the division of surplus to offer to the investor. Suppose, that the entrepreneur offers a share $x_t$ of the surplus to the investor if the project is implemented at time $t$ and succeeds. The entrepreneur receives the remaining share $1 - x_t$.

The incentive compatibility condition requires that at the time of implementation, for the entrepreneur the expected return from allocating the funds to implement the project exceeds the value of diverting the funds. If the entrepreneur diverts the funds, he gets $c$. If the entrepreneur uses the fund to implement the project at time $t$, his expected payoff is $(1 - x_t)p_t\alpha R$. Hence the incentive compatibility condition is given by

$$(1 - x_t)p_t\alpha R \geq c.$$ 

Also if the entrepreneur offers a share $x_t$ to the investor, the investor will accept it only if her participation constraint is satisfied, or

$$x_t p_t \alpha R \geq c.$$ 

From the participation and the incentive constraint, it follows that financing is provided only if

$$p_t \geq \frac{2c}{\alpha R}.$$ 

The entrepreneur offers a share to the investor that solves the participation constraint with equality, hence one obtains that

$$x_t = \frac{c}{p_t \alpha R}.$$ 

\[11\] Given that the surplus generated is either $R$ or 0, the security that is issued (debt or equity) is irrelevant. It is without loss of generality to assume that the entrepreneur raises cash by issuing equity, that is selling a fraction of the project in exchange for funds.
Given the division of surplus, the entrepreneur chooses the time of implementation $t$ to maximize

$$\Pi_t^E = e^{-rt} s_t (p_t \alpha (1 - x_t) R)$$

$$= e^{-rt} s_t (p_t \alpha R - c)$$

The optimal stopping belief $p_t^E$ (see the Appendix for the proof) is given by

$$p_t^E = \max\left(\frac{2c}{\alpha R}, \frac{(r + \lambda)c}{raR + \lambda c}\right).$$

One thus observes that if $\frac{(r + \lambda)c}{raR + \lambda c} \geq \frac{2c}{\alpha R}$, then the first best as obtained in Section 2.1 is implemented. However, if the parameters are such that $\frac{(r + \lambda)c}{raR + \lambda c} < \frac{2c}{\alpha R}$, then there is late implementation compared to the first best. This is summarized in the following proposition.

**Proposition 2:** Under entrepreneur bargaining power and accurate beliefs about ability, the optimal stopping belief is either higher or same as the first best and there is either delayed implementation compared to the first best or efficient implementation. There is thus either over-experimentation compared to the efficient investment policy or the efficient investment policy is implemented.

### 3.3 Overconfidence

In this section, I consider the case where the entrepreneur overestimates the probability of him being of high ability. The entrepreneur believes that the probability he is of high ability is given by $\alpha_E \in (0, 1)$, where $\alpha_E > \alpha$. The investor’s belief about the probability of the entrepreneur being of high ability is given by $\alpha$, and the investor’s belief as well as the entrepreneur’s belief is common knowledge. Such disagreement about beliefs is plausible for

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12Since news is observable to the investor as well as the entrepreneur, the investor will fund the project only if there is no news before $t$. 

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instance, in situations in which the investor judges the entrepreneur’s ability according to the population mean, knowing that entrepreneurs tend to be overconfident. If the entrepreneur’s beliefs are independent of true ability, then the investor disregards such beliefs as uninformative. Similarly, since the investor’s beliefs are made on the basis of the population mean and does not take into account the individual entrepreneur, the entrepreneur can also disregard the investor’s belief about his ability. There is also empirical backing for individuals overestimating probability of favorable events, especially in situations in which they have some control over the outcome of events (e.g., Taylor and Brown 1988; Camerer and Lovallo 1999). Such overconfidence is especially common among entrepreneurs and CEOs (e.g., Larwood and Whittaker 1977; Cooper, Woo, and Dunkelberg 1988; Shane 2003).

**Assumption on Parameters**: I make the following additional assumption regarding parameters of the model:

**Assumption 3**: \( p_0 \alpha ER < c \)

This assumption implies that the overconfident entrepreneur will not implement the project at \( t = 0 \), and along with Assumption 2, guarantees a strictly positive solution for the time of implementation of project.

### 3.3.1 Entrepreneur Uses Own Funds

The entrepreneur chooses the time of implementation \( t \), to maximize

\[
\Pi^O_t = e^{-rt}s_t(p_t \alpha ER - c) = e^{-rt}(p_0 \alpha ER - c + (1 - s_t)c) = e^{-rt}(p_0(\alpha ER - c) - (1 - p_0)e^{-\lambda t}c)
\]

The optimal stopping belief \( p_t^O \) is given by
\[
p_t^O = \frac{(r + \lambda)c}{r\alpha ER + \lambda c}.
\]

**Proposition 3**: If the entrepreneur is overconfident about his ability and uses his own funds to implement the project, the optimal stopping belief is lower and there is hurried implementation compared to the first best. There is thus under-experimentation compared to the efficient investment policy.

### 3.3.2 Investor Has the Bargaining Power

In this case, the investor decides to wait till time \( t \) before implementing the project at a cost of \( c \). She also decides on the division of surplus to offer to the entrepreneur. Suppose, that the investor offers a share \( 1 - y_t^O \) of the surplus to the entrepreneur if the project is implemented at time \( t \) and succeeds. The investor receives the remaining share \( y_t^O \).

The incentive compatibility condition in this case requires that at the time of implementation, the expected return to the entrepreneur from allocating the funds to implement the project exceeds the value of diverting the funds. If the entrepreneur diverts the funds, he gets \( c \). If the entrepreneur uses the fund to implement the project at time \( t \), his expected payoff is \((1 - y_t^O)p_t\alpha ER\). Hence the incentive compatibility condition is given by
\[
(1 - y_t^O)p_t\alpha ER \geq c.
\]

In equilibrium, the incentive compatibility condition will hold with equality, hence one obtains
\[
(1 - y_t^O) = \frac{c}{p_t\alpha ER} < 1 - y_t
\]

Comparing \( 1 - y_t^I \) and \( 1 - y_t^O \), one observes that a lower share of the surplus is sufficient to incentive an overconfident entrepreneur, since the overconfident believes that he has a higher probability of succeeding compared to an entrepreneur with accurate beliefs. This
result is similar to that in De la Rosa (2011), who finds that if the agent overestimates the extent to which his actions affect outcomes, lower-powered incentives are sufficient to induce any given effort level.

Given the distribution of surplus, the investor chooses the time of implementation $t$ to maximize

$$
\Pi_t = e^{-rt}s_t(p_t\alpha y_t^ORG - c)
$$

$$
= e^{-rt}s_t(p_t\alpha R - c - \frac{\alpha}{\alpha E}c)
$$

The optimal stopping belief $p_t^{IO}$ is given by

$$
p_t^{IO} = \frac{(r + \lambda)(1 + \frac{\alpha}{\alpha E})c}{r\alpha E R + \lambda(1 + \frac{\alpha}{\alpha E})c}.
$$

Since $1 < 1 + \frac{\alpha}{\alpha E} < 2$, as $\alpha_E > \alpha$, one obtains that

$$
p_t^{FB} < p_t^{IO} < p_t^I.
$$

**Proposition 4:** If the entrepreneur is overconfident about his ability, then under investor bargaining power, the optimal stopping belief is higher and the time of implementation is delayed compared to the first best. Compared to the case with accurate beliefs, the optimal stopping belief and the time of implementation under overconfidence is closer to the first best optimal stopping belief and the first best time of implementation. Thus overconfidence assists in reducing the inefficiency due to the agency problem.

### 3.3.3 Entrepreneur Has the Bargaining Power

In this case, the entrepreneur decides to wait till time $t$ before implementing the project. He seeks funding from the investor at time $t$ and also decides on the division of surplus to offer to the investor. Suppose, that the entrepreneur offers a share $x_t^O$ of the surplus to the investor if the project is implemented at time $t$ and succeeds. The entrepreneur receives the remaining share $1 - x_t^O$. 

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The incentive compatibility condition requires that at the time of implementation, for the entrepreneur the expected return from allocating the funds to implement the project exceeds the value of diverting the funds. If the entrepreneur diverts the funds, he gets $c$. If the entrepreneur uses the fund to implement the project at time $t$, his expected payoff is $(1 - x_t^O)p_t\alpha ER$. Hence incentive compatibility condition is given by

$$(1 - x_t^O)p_t\alpha ER \geq c.$$ 

Also if the entrepreneur offers a share $x_t^O$ to the investor, the investor will accept it only if her participation constraint is satisfied, or

$$x_t^O p_t\alpha R \geq c.$$ 

The entrepreneur offers a share to the investor that solves the participation constraint with equality, hence we get

$$x_t^O = \frac{c}{p_t\alpha R}.$$ 

From the participation and incentive constraint, it follows that financing is provided only if

$$p_t \geq \frac{c}{\alpha E R} (1 + \frac{\alpha E}{\alpha}).$$ 

Compared to the case with accurate beliefs on behalf of the entrepreneur, one observes that the cutoff belief for providing financing is lower. This is because, the entrepreneur overestimates his chance of succeeding and hence the entrepreneur’s incentive compatibility condition is satisfied for a lower value of $p_t$ compared to the case with accurate beliefs. Note that, in contrast to the scenario under investor bargaining, the share of the surplus going to the entrepreneur remains unchanged regardless of the belief of the entrepreneur, that is,

$$1 - x_t^O = 1 - x_t.$$
Given the division of surplus, the entrepreneur chooses the time of implementation $t$ to maximize

$$\Pi_t = e^{-rt_s}(p_t \alpha_E (1 - x_t^O) R)$$

$$= e^{-rt_s}(p_t \alpha_E R - \frac{\alpha_E}{\alpha})$$

$$= e^{-rt_s} \frac{\alpha_E}{\alpha} (p_t \alpha R - c)$$

The optimal stopping belief $p_t^{EO}$ is given by

$$p_t^{EO} = \max \left( \frac{c}{\alpha_E R} (1 + \frac{\alpha_E}{\alpha}), \frac{(r + \lambda)c}{r \alpha R + \lambda c} \right).$$

One can compare $p_t^{EO}$ to the expression for $p_t^E$ obtained in Section 2.3, to study the impact of overconfidence under entrepreneur bargaining power. Observe that $\frac{c}{\alpha_E R} (1 + \frac{\alpha_E}{\alpha}) < \frac{2c}{\alpha R}$ and hence,

$$\frac{(r + \lambda)c}{r \alpha R + \lambda c} \geq \frac{2c}{\alpha R} > \frac{c}{\alpha E R} (1 + \frac{\alpha_E}{\alpha}).$$

The above inequalities imply that if under entrepreneur bargaining power and accurate belief of the entrepreneur, the investment policy was efficient, then it is also efficient if the entrepreneur is overoptimistic. Finally, if $\frac{(r + \lambda)c}{r \alpha R + \lambda c} < \frac{2c}{\alpha R}$, then one obtains either $p_t^{EO} = p_t^{FB}$, if $\frac{c}{\alpha E R} (1 + \frac{\alpha_E}{\alpha}) \leq \frac{(r + \lambda)c}{r \alpha R + \lambda c} < \frac{2c}{\alpha R}$, or

$$p_t^{EO} = p_t^{FB} \text{ if } \frac{c}{\alpha E R} (1 + \frac{\alpha_E}{\alpha}) \leq \frac{(r + \lambda)c}{r \alpha R + \lambda c}$$

$$p_t^{FB} < p_t^{EO} < p_t^E \text{ if } \frac{c}{\alpha E R} (1 + \frac{\alpha_E}{\alpha}) > \frac{(r + \lambda)c}{r \alpha R + \lambda c}$$

Hence, overconfidence leads to an improvement in terms of getting closer to efficient investment policy and can also implement the efficient investment policy.

**Proposition 5:** If the entrepreneur is overconfident about his ability, then under entrepreneur bargaining power, the optimal stopping belief is either higher or the same as the first best and there is either delayed implementation compared to the first best or efficient implementation. Compared to the case with accurate beliefs, the optimal stopping belief and
the time of implementation under overconfidence is closer to the first best optimal stopping belief and the first best time of implementation. Thus overconfidence assists in reducing the inefficiency due to the agency problem and can also lead to the implementation of the efficient investment policy.

The analysis in Sections 2 and 3 also allows one to compare the investment decisions of the entrepreneur with accurate belief and the overconfident entrepreneur.

**Proposition 6:** An overconfident entrepreneur implements (1) strictly more projects compared to an entrepreneur with accurate belief if the project is self financed by the entrepreneur or if the project is financed by an investor who has bargaining power and (2) weakly more projects compared to an entrepreneur with accurate belief if the project is financed by an investor and the entrepreneur has the bargaining power. Overconfidence creates inefficiency in case of self financing by the entrepreneur but weakly improves efficiency if the project is financed by an investor.

### 3.4 Conclusion

This paper studied a model in which an entrepreneur learns about the quality of project before deciding whether to implement the project. The outcome of project depends on the quality as well as the unknown ability of the entrepreneur. The possibility of the entrepreneur diverting funds, received from investors and meant for project implementation, to his private uses leads to delayed investment and over-experimentation. An entrepreneur who is overconfident regarding his ability under-experiments and over invests compared to an entrepreneur who has accurate beliefs regarding his ability. Such overconfidence on behalf of the entrepreneur creates inefficiencies when projects are self financed but reduces inefficien-
cies due to moral hazard in case of funding by investors. There are some questions related to the issues analyzed in the paper that may be of interest for future research. One possibility is to relax the common knowledge assumption and consider situations in which there is a mixture of entrepreneurs with heterogeneous beliefs and abilities and find out under what circumstances might entrepreneurs overconfident, even if they have accurate beliefs about their abilities. Another interesting question to study is what happens if there are multiple projects, and entrepreneurs and investors learn about the entrepreneur’s ability over time through performance in projects.

3.5 Bibliography


3.6 Appendix

3.6.1 Proof for Section 3.2.1

The entrepreneur chooses $t \geq 0$ to maximize

$$\Pi_t = e^{-rt} s_t (p_t \alpha R - c).$$

Taking derivative of the above expression with respect to $t$ and setting it equal to 0, one obtains

$$-r(p_0 \alpha R - s_t c) + c \lambda (1 - p_0) e^{-\lambda t} = 0,$$

which upon simplification yields,

$$\frac{1 - p_0}{p_0} e^{-\lambda t} = \frac{r(\alpha R - c)}{c(\lambda + r)}.$$

Observing that

$$p_t = \frac{p_0}{p_0 + (1 - p_0) e^{-\lambda t}},$$

we obtain the optimal stopping probability

$$p^{FB}_t = \frac{(r + \lambda)c}{r \alpha R + \lambda c}.$$

Given Assumptions 1 and 2, one can show that $p^{FB}_t \in (p_0, 1)$.

Let $t^{FB}$ be such that

$$p_t^{FB} = \frac{p_0}{p_0 + (1 - p_0) e^{-\lambda t^{FB}}},$$

One can verify that

$$\frac{d^2 \Pi_t(t^{FB})}{dt^2} = -r e^{-rt} \frac{ds_t}{dt} - ce^{-rt} \frac{d^2 s_t}{dt^2} < 0.$$

One further obtains $\Pi_t(0) = p_0 \alpha R - c < 0$, $\Pi_t(t^{FB}) = \frac{\lambda(\alpha R - c)}{\lambda + r} > 0$ and $\Pi_t(\infty) = 0$, which implies that $\Pi_t$ is maximized at $t = t^{FB}$, as claimed.
3.6.2 Proof for Section 3.2.3

**Step One:** \( \frac{d\Pi_t}{dt}(t) \) is continuous and differentiable for \( t > 0 \).

**Proof:** The proof follows from observing
\[
\frac{d\Pi_t}{dt} = -re^{-rt}(p_0R - (p_0 + (1 - p_0)e^{-\lambda t})c) + e^{-(r+\lambda)t}c\lambda(1 - p_0).
\]

**Step Two:** There exists a unique \( t^{FB} > 0 \) such that \( \frac{d\Pi_t}{dt}(t^{FB}) = 0 \). Further, \( \frac{d^2\Pi_t}{dt^2}(t^{FB}) < 0 \)

**Proof:** Already proved in Section 3.6.1.

**Step Three:** There exists \( t > t^{FB} \) such that \( \frac{d\Pi_t}{dt}(t) < \frac{d\Pi_t}{dt}(t^{FB}) = 0 \).

**Proof:** Assume, for contradiction that \( \frac{d\Pi_t}{dt}(t) \geq 0 \) for all \( t > t^{FB} \).
\[
0 < \frac{d^2\Pi_t}{dt^2}(t^{FB}) = \lim_{h \to 0^+} \frac{\frac{d\Pi_t}{dt}(t^{FB} + h) - \frac{d\Pi_t}{dt}(t^{FB})}{h}.
\]
\[
= \lim_{h \to 0^+} \frac{\frac{d\Pi_t}{dt}(t^{FB} + h)}{h}.
\]
By assumption, the right-hand side can either be positive or zero but never negative, a contradiction.

**Step Four:** For each \( t > t^{FB} \), \( \frac{d\Pi_t}{dt}(t) < 0 \).

**Proof:** From Step Two, one obtains that \( \frac{d\Pi_t}{dt}(t) = 0 \) has a unique solution, namely \( t = t^{FB} \). Hence, there cannot be a \( z > t^{FB} \) such that \( \frac{d\Pi_t}{dt}(z) = 0 \). Assume, for contradiction, that there exists a \( z > t^{FB} \) such that \( \frac{d\Pi_t}{dt}(z) > 0 \). From step Three, we know that there exists, \( n > t^{FB} \) such that \( \frac{d\Pi_t}{dt}(n) < 0 \). If \( z > n \), then there exists a \( z > y > n > t^{FB} \) such that \( \frac{d\Pi_t}{dt}(y) = 0 \) (since \( \frac{d\Pi_t}{dt} \) is a continuous function, from Step One), which contradicts \( t^{FB} \) being
a unique solution of $\frac{dn_t}{dt}(t) = 0$. If $z < n$, then there exists a $n > x > z > t^{FB}$ such that $\frac{dn_t}{dt}(x) = 0$ (since $\frac{dn_t}{dt}$ is a continuous function, from Step One), which contradicts $t^{FB}$ being a unique solution of $\frac{dn_t}{dt}(t) = 0$. Hence, for each $t > t^{FB}$, $\frac{dn_t}{dt}(t) < 0$.

**Step Five:** $p_t^E = \max(\frac{2c}{\alpha R}, \frac{(r+\lambda)c}{\alpha R + \lambda c})$.

**Proof:** Observe that, $\Pi_t^E = e^{-rt} s_t(p_t \alpha R - c) = \Pi_t$.

Define $t(p)$, such that $p = \frac{p^0}{p^0 + (1-p^0)e^{-mx(p)}}$. Clearly, $t(p)$ is an increasing function of $p$ and $t(p^{FB}) = t^{FB}$ and let $t(\frac{2c}{\alpha R}) = t^L$.

From the participation and the incentive constraint, it follows that financing is provided only if

$$p_t \geq \frac{2c}{\alpha R}.$$  

This implies, that the project can only be implemented after $t \geq t^L$.

Suppose, $\frac{2c}{\alpha R} \leq \frac{(r+\lambda)c}{\alpha R + \lambda c} = p^{FB}$. This implies that $t(p^{FB}) \geq t^L$. Hence, $t^{FB}$ is a feasible choice, and thus for all $t \geq t^L$, we obtain $\Pi_t^E(t^{FB}) = \Pi_t(t^{FB}) \geq \Pi_t(t) = \Pi_t^E(t)$. Thus, the project is implemented at $t = t^{FB}$ and the optimal stopping belief is given by $p_t^E = p^{FB} = \frac{(r+\lambda)c}{\alpha R + \lambda c}$.

Suppose, $p^{FB} = \frac{(r+\lambda)c}{\alpha R + \lambda c} < \frac{2c}{\alpha R}$. Thus, we get $t^{FB} < t^L$. Since, for each $t > t^{FB}$, $\frac{dn_t}{dt}(t) < 0$ (from Step Four), we obtain that for each $t \geq t^L > t^{FB}$, $\Pi_t^E(t) = \Pi_t(t) < \Pi_t(t^L) = \Pi_t^E(t^L)$. Hence, the project is implemented at $t = t^L$ and the optimal stopping belief is given by $p_t^E = \frac{2c}{\alpha R}$.