

# Compound-risk Aversion and the Demand for Microinsurance: Evidence from a WTP Experiment in Mali

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## Abstract

Index insurance has been faced with an unexpectedly low uptake, despite efforts to promote it as a tool for poverty alleviation. This paper offers new insights into the behavioral impediments to the uptake of index insurance, and proposes an alternative approach to designing insurance contracts. Beginning from the observation that an index insurance contract appears to the farmer as an ambiguous, compound lottery, this paper argues that the expected utility perspective may systematically overstate the desirability of index insurance and its expected impacts (given the presence of substantial basis risk). Using framed field experiments with 334 cotton farmers in Southern Mali, we elicit the coefficients of risk aversion and compound risk aversion. In the sample, 57% of the surveyed farmers reveal themselves to be compound-risk averse to varying degrees. Using the distributions of compound-risk aversion and risk aversion in this population, we simulate the magnitude of the impact of basis risk on the demand for an index insurance contract. If basis risk were as high as 50% (a not unreasonably high number under the kind of rainfall index insurance contracts that have been utilized in a number of pilots), expected demand would only be 35% of the population as opposed to the 60% of the population that would be expected to demand insurance if individuals were expected utility maximizers. Our results highlight the importance of designing contracts with minimal basis risk under compound-risk aversion. Such a reduction in basis risk would not only enhance the value and productivity impacts of index insurance, but would also assure that the contracts are popular and have the anticipated impact.

JEL Codes: D81, G22, O12, O16, Q12, Q13

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## 1 Introduction

Behavioral economics has flourished over the past 30 years, providing compelling evidence that individuals systematically deviate from the predictions of the classical economic model of rationality. Despite their seemingly rich implications for the design of [economic development] interventions and policies (Datta and

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Malltainathan 2012), policy reliance on behavioral insights has been modest, especially in the rapidly expanding area of microinsurance. Drawing on the related literatures on ambiguity and compound-risk aversion, and using parameter values estimated from framed field experiments in Mali, this paper offers new insights regarding behavioral constraints to the uptake of microinsurance. The findings of the paper justify the proposal for an alternative approach to designing insurance contracts. By increasing insurance uptake, these new kinds of contracts would have greater impacts on poor and rural populations in Africa and elsewhere in the developing world.

Uninsured risk impoverishes people and oftentimes keeps them poor by leading to suboptimal decision-making and forgone income (Alderman and Paxson 1992; Carter et al. 2007). Therefore, formal insurance contracts could improve welfare in developing countries. Conventional individual indemnity insurance contracts are burdened by moral hazard and adverse selection problems that guarantee their failure in rural regions of the developing world. In this context, index insurance contracts—in which payments are based on an easily verifiable index correlated with, but not identical to, individual losses—have emerged as a promising solution to the long-standing problems of uninsured risk. Much of the work on index insurance begins from an implicit expected utility perspective that, although index insurance coverage is partial (i.e., it exhibits what is called basis risk), some insurance is better than no insurance. Therefore, it implies that index insurance contracts will be demanded and have their expected impacts. This paper takes a novel approach, rooted in the observation that an index insurance contract appears to the farmer as an ambiguous, compound lottery. We argue that the expected utility perspective may systematically overstate the desirability of index insurance and its expected impacts. If correct, this behaviorally informed view suggests that an index insurance contract’s design must prioritize the reduction of basis risk and ambiguity to succeed.

To organize the argument, this paper proceeds as follows:

- We start by representing index insurance as compound lottery from the farmer’s perspective.
- Next, based on findings from experimental and behavioral economics, we show that compound lotteries create something akin to ambiguity.
- Third, we theoretically show that compound-risk aversion/ambiguity aversion decreases the demand for conventional index insurance in the presence of basis risk.
- Empirically, we measure the coefficients of risk aversion and compound- risk aversion in a population of cotton farmers in Mali using framed field experiments.
- Using these measures, we show that compound-risk aversion depresses the uptake of index insurance relative to the predictions of standard expected utility theory.
- Finally, we discuss how alternative designs of index insurance should be considered to alleviate the problem of compound-risk aversion.

We begin our analysis by looking at index insurance from the farmer’s perspective. Compared to conventional indemnity insurance, index insurance is itself a probabilistic investment: payouts are not perfectly correlated with the farmer’s loss. The presence of basis risk makes index insurance a compound lottery: the first stage lottery determines the individual farmer’s yield, and the second stage determines whether or not the index triggers an indemnity payout. When individuals satisfy the Reduction of Compound Lotteries (ROCL) axiom of expected utility theory, they are able to consider the resulting simple lottery. This paper examines what happens when this assumption about decision makers is not realistic.

A large body of literature examines alternatives to expected utility models of decision making under uncertainty; we focus here on the interrelated concepts of ambiguity and compound risk aversion. Ambiguity aversion was first demonstrated by Ellsberg (1961), who showed that individuals react much more cautiously when choosing among ambiguous lotteries (with unknown probabilities) than when they choose among lotteries with known probabilities. While the individual probabilities under index insurance are knowable, individuals who cannot reduce a compound lottery to a single lottery are faced with unknown final probabilities as in the Ellsberg experiment. Halvey (2007) corroborates this intuition by experimentally establishing a relationship between ambiguity aversion and compound-risk aversion, showing that those who are ambiguity averse are also compound-risk averse.

Theoretically, we use the smooth model of ambiguity aversion developed by Klibanoff, Marinacci, and Mukerji (2005) to describe the index insurance problem. Maccheroni, Marinacci and Ruffino (2010) derive an ambiguity premium. We interpret this expression as a compound lottery premium, and we use it to derive an expression of the willingness to pay (WTP) for index insurance. We define this WTP as the maximum amount of money that a farmer would pay while being indifferent between buying index insurance and having no insurance. We then show how this measure varies with compound-risk aversion, risk aversion and basis risk. Compound-risk aversion decreases the demand for index insurance relative to what it would be if individuals had the same degree of risk aversion but were compound-risk neutral. In addition, as basis risk increases, demand for index insurance declines. This decline in demand is steeper under compound-risk aversion.

To estimate the magnitude of the impact of basis risk on the demand of index insurance, we implement framed field experiments with cotton farmers in Southern Mali and elicit the coefficients of compound-risk aversion and risk aversion. In this sample, 57% of the surveyed farmers revealed themselves to be compound-risk averse to varying degrees. We then simulate the impact of basis risk on the demand for an index insurance contract, whose structure mimics the structure of an actual index insurance contract distributed to this population in Mali. If basis risk were as high as 50%, only 35% of the population would demand index insurance, in contrast to the 60% who would be willing to purchase the product if individuals were simply maximizing expected utility.

The remainder of the paper is structured as follows. In Section 2, we present the theoretical framework and review the relevant literature. We then derive the willingness to pay in Section 3. In Section 4, we

describe the experimental design. In section 5, we present our main findings. We conclude with policy implications.

## 2 The microinsurance problem

To frame the discussion of the index insurance problem, Figure 1 provides a simple discretized payoff structure under an area yield index insurance contract. Under this structure, the individual farmer gets a good yield  $Y_0$  with probability  $p$ , and a low yield,  $Y_0 - L$ , with probability  $1 - p$ . If the individual farmer experiences poor yields, there is a probability  $q_2 < 1$  that the index insurance will trigger a payoff  $\Pi$ , resulting in an income of  $(Y_0 - L - \tau_1 + \Pi)$  equal to the net income under bad yields, less the insurance premium  $\tau_1$  plus the payoff. However, there is a probability  $1 - q_2$  that the insurance contract fails to pay out, despite the individual's bad yields. In this case, the individual receives a net income of  $Y_0 - L - \tau_1$ . The probability  $1 - q_2$  is the false negative probability (FNP).

If the individual yields are good, there is a probability  $1 - q_1$  that the index is not triggered. In that case, no insurance payments are made and the individual receives an income equal to the net income under good yields less the insurance premium  $(Y_0 - \tau_1)$ . However, there is a probability  $q_1 < 1$  that the index insurance triggers a payoff, resulting in an income of  $(Y_0 - \tau_1 + \Pi)$  equal to the net income under good yields, less the insurance premium plus the value of the insurance indemnity payment. The probability  $q_1$  is the false positive probability (FPP). FNP and FPP are two aspects of basis risk, or the imperfect correlation between the individual farmer's yield and the index.

FNP makes index insurance appear to the farmer as a probabilistic insurance. Experimental evidence has demonstrated that people dislike probabilistic insurance, preferring a regular insurance contract that pays with certainty when a loss occurs (Wakker, Thaler, and Tversky 1997). The economic analysis explaining this behavior consists of two basic strands. The first strand is expected utility theory, as developed by Von Neumann and Morgenstern in 1947. The second strand of research about probabilistic insurance, which is mainly used in behavioral economics, relaxes the rationality assumption of expected utility theory.

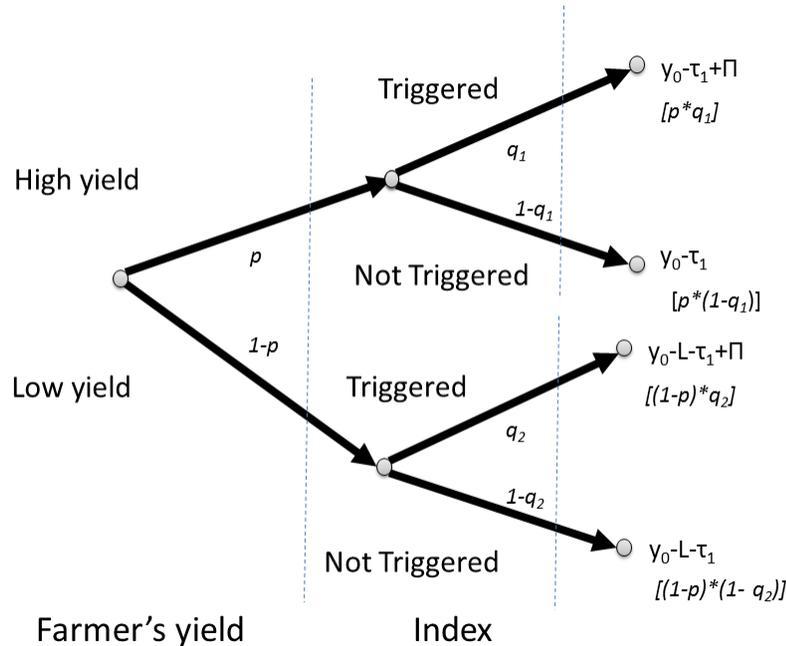


Figure 1: The micro insurance problem

An expected utility maximizer faced with an actuarially fair insurance contract will insure the entire amount at risk. If the risk can only be partially insured (as with an index insurance contract), an expected utility maximizing agent will still purchase whatever partial insurance is available if it is priced at an actuarially fair level. In a realistic setting, when insurance companies impose loadings to cover transaction costs, expected utility theory predicts that a utility maximizer will leave part of the risk uninsured. Index insurance contracts are an example of partial insurance, and typically have a loading of 20%.<sup>1</sup> Therefore, a risk averse agent will purchase index insurance only if basis risk is small enough compared to the fraction of total risk to which he is exposed. In a recent example of this strand of the literature, Clark (2011) analyzes the theoretical relationship between basis risk and the demand for actuarially unfair index insurance within the expected utility framework.<sup>2</sup> His main finding is that increasing risk aversion does not necessarily lead to an increase in the demand for index insurance; the predicted demand follows an inverted U-shape (zero-increasing-decreasing) as the coefficient of risk aversion increases. These results are a direct consequence of the FNP: because index insurance increases the probability of the bad state of the world, the farmers perceive it as risky. With probability  $(1 - q_2) * (1 - p)$  the household end up without payouts in the worst state of the world and yet still must pay premiums. (In figure 1, the final probabilities are given in parentheses). Though Clark (2011)'s use of expected utility theory to justify the aversion to probabilistic insurance is compelling, several experimental and empirical studies suggest that people's decision making often deviates systematically

<sup>1</sup>USDA

<sup>2</sup>Clark (2011) defines basis risk as the joint probability of experiencing a loss and the index failing to trigger. Using the notation of figure 1, this corresponds to the FNP  $1 - q_2$  multiplied by  $1 - p$ .

from the predictions of expected utility theory. In their survey, Wakker et al.(1997) show that the magnitude of the participant's aversion to probabilistic insurance exceeds the predictions of expected utility theory. In their experiments, the sample of respondents demand about a 30% reduction in the premium to compensate for a 1% FNP. Expected utility theory cannot explain these findings. Under reasonable assumptions, an expected utility maximizer would be expected to demand only a 1% decrease in premium to compensate them for the 1% FNP.

Behavioral economics provide many explanations for the magnitude of this disproportionate reaction to probabilistic insurance. Kahneman and Tversky (1979) examine the particular case of a probabilistic insurance in which the premium is paid back in case of a loss. They show that aversion to this specific type of probabilistic insurance is consistent with risk seeking over the loss domain.<sup>3</sup> Segal (1988) provides another non-expected utility explanation of the aversion to probabilistic insurance using the rank dependent utility function developed by Quiggin (1982).<sup>4</sup> He shows that this behavior is explained by a concave utility function provided that the decision maker violates either the reduction of compound lottery axiom of expected utility theory or the independence axiom. In another experiment, Wakker et al. (1997) argue that the paradox is driven primarily by the probability weighting of prospect theory, i.e. the fact that people tend to overweight small probabilities.

Thus far, studies of the uptake of probabilistic insurance have ignored its structure as a compound lottery from the decision maker's perspective. Compound lotteries are lotteries whose outcomes are simple lotteries. They are also referred to as multi- stage lotteries since the final outcomes are determined only after several uncertainties are resolved sequentially. Under expected utility theory, the structure of a lottery should not affect rational decision maker's choices; by the reduction of compound lotteries axiom, a decision maker should reduce the compound lottery to its equivalent simple lottery.<sup>5</sup> In other words, under expected utility theory, the farmer would value the index insurance lottery based only on the final outcomes and their corresponding probabilities. A consequence of the reduction of compound lottery axiom is that simple risk (or risk as represented by simple lotteries) and compound risk (or risk represented by compound lotteries) are indistinguishable.

Although the reduction of compound lotteries axiom is attractive, several experiments have found that decision makers often violate it (see Budescu and Fisher(2001) for an extensive list of these experiments). Abdellaoui et al.(2011) call this particular behavior compound-risk aversion .<sup>6</sup> Psychological studies find that the length and complexity of compound lotteries impact a decision maker emotionally and psychologically (Budescu and Fischer 2001). Furthermore, multiplying out the different probabilities corresponding to the

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<sup>3</sup>Under expected utility theory, this behavior is consistent with risk seeking.

<sup>4</sup>The rank dependent utility function is based on the assumption that a decision maker is not only interested in the the probabilities (as in expected utility theory or prospect theory), but the also the relative ranking of the different payoffs.

<sup>5</sup>The observation that people often violate the reduction of compound lottery axiom provided the impetus of many studies of decision making under uncertainty. Kreps and Porteus (1978) introduced the notion of temporal lotteries to study dynamic choice behavior under uncertainty: the decision maker regards uncertainty resolving at different times as being different

<sup>6</sup>According to the definition of Abdellaoui et al.(2011), a decision maker is compound-risk averse (seeking) if the certainty equivalent for the compound lottery is below (above) the certainty equivalent of the simple lottery.

equivalent simple lottery can be cumbersome to process, and might create something similar to ambiguity.<sup>7</sup> An ambiguous event is not only uncertain, but in addition involves unknown probability distributions. Therefore, it involves a greater degree of uncertainty than risky events (uncertain, with known probabilities). Under the classical subjective expected utility theory developed by Savage (1954), the distinction in the nature of uncertainty does not matter: a decision maker assigns subjective probabilities to all the alternatives and maximizes the corresponding subjective expected utility. The Ellsberg (1961) paradox and many other subsequent experimental observations have provided evidence against subjective expected utility theory, and showed that decision makers tend to be averse to ambiguous events.

A growing body of literature models ambiguity aversion as aversion to compound lotteries. Segal (1987) pioneered this method by representing the Ellsberg problem as a compound lottery. In the first stage, the decision maker assigns the probability of getting the various lotteries in the second stage. Using the recursive non expected utility model, Segal (1987) models ambiguity aversion as aversion to compound lotteries. Several other studies of ambiguity aversion rely on the violation of the reducibility assumption (Klibanoff et al. 2005; Ergin and Gul 2009; Nau 2006; Seo 2009 ).<sup>8</sup> Halevy (2007) corroborates these theoretical findings experimentally by demonstrating the existence of a strong link between ambiguity aversion and compound-risk attitudes. He finds that ambiguity neutral participants are more likely to reduce compound lotteries, behaving according to expected utility theory. Conversely, those who are ambiguity averse are also compound risk averse.

Given the established relationship between compound lottery aversion and ambiguity aversion, we model compound lottery aversion using the theory of ambiguity. Specifically, we use the Smooth Model of Ambiguity Aversion formalized by Kilbanoff, Marinacci and Mukerji (2005) (here the *KMM model*). This model captures risk preferences by the curvature of the utility of wealth function, and ambiguity preferences by a second-stage utility functional defined over the expected utility of wealth. It therefore allows the separation of attitudes towards risk and compound-risk, and makes it possible to elicit them in an experiment.

We apply this model in the more general case of multiple states of the nature. Let  $f_Y$  and  $f_X$  be the respective pdfs of the farmer's yield  $Y$  and the index  $X$ . Denote the final wealth of the farmer after all payments are made and premium paid under the index insurance contract by  $\rho$ , with pdf  $f_\rho(Y, X)$ . Here,  $Y$  is the farmer's yield,  $I(X)$  is the insurance indemnity payment and  $\tau_1$  is the index insurance premium.

Assuming that the individual's risk preferences are captured by the utility function  $u$  defined over final wealth, and assuming that the farmer is risk averse by imposing concavity of  $u$  ( $u$  is as usual also increasing), the objective function of an expected utility maximizer is the following:

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<sup>7</sup>Bryan (2010) also studies the uptake of index insurance under ambiguity aversion. The main assumption of his model is that the farmer faces an ambiguity not only in terms of the probability distribution of the index, but also in terms of the different outcomes. For example, he ignores his yield outcome in case there is a drought and the index is not triggered. This assumption is unrealistic since farmers know how their crops respond to droughts.

<sup>8</sup>Other theories of decision making under ambiguity include the seminal work of Gilboa and Schmeidler (1989) who developed the max min expected utility theory: a decision maker has a set of prior beliefs and the utility of an act is the minimal expected utility in this set.

$$\mathbb{E}_{f_\rho} [u(\rho)] \tag{1}$$

Under the KMM model, for each realization of the index, the farmer’s expected utility is evaluated by an increasing function  $v$  that captures compound risk preferences, and the farmer’s objective function is the expected value of  $v$  given the probability distribution of the yield. Thus, the farmer’s objective function is given by:

$$E_{f_Y} [v (E_{f_{X|Y}} u(\rho))] \tag{2}$$

where  $E_{f_Y}$  denotes the expectation with respect to  $f_Y$ . The expectation  $E_{f_{X|Y}}$  is taken with respect to  $f_{X|Y}$ , the probability distribution function of the index conditional on the realization of the yield. Similar to how risk aversion is imposed by the concavity of  $u$ , compound-risk aversion is obtained by imposing concavity of  $v$ : i.e.  $v' > 0$  and  $v'' \leq 0$  in the KMM model. In the compound-risk neutral case (i.e., when  $v$  is linear), this expression reduces to the conventional Von Neumann-Morgenstern expected utility maximization represented by Equation 1.

Section 3 studies the implication of compound-risk aversion on insurance decisions. The results rely on the concept of compound lottery premium. This premium was derived by Maccheroni et al. (2010) and is an extension of the classical Arrow-Pratt premium, where the preferences are characterized by the KMM model.

### 3 Index insurance and the KMM Model

Maccheroni, Marinacci and Ruffino (2010) (MMR) derive an ambiguity premium under the KMM model. This premium is the analogue of the classic Arrow-Pratt approximation under the presence of ambiguity. We interpret this entity as a compound lottery premium, and use it to study the willingness to pay for index insurance.

#### 3.1 The compound lottery premium

Let’s define the compound lottery premium  $P_X$  of index insurance such that the farmer is indifferent between receiving the net revenue  $\rho$  from the index insurance contract and the certain average revenue  $\rho^* = E_{f_\rho}(\rho)$ . By definition, this premium solves the following equation:

$$E_{f_Y} [v (E_{f_{X|Y}} u(\rho))] = v (u(\rho^* - P_X)) \tag{3}$$

If the farmer is compound risk neutral, then  $v$  is linear, and the compound lottery premium  $P_X^n$  is the regular Pratt premium defined by  $E_\rho u(\rho) = u(\rho^* - P_X^n)$ . Using Jensen's inequality, we have:

$$P_X \geq P_X^n \quad (4)$$

*Proof.* Since  $u$  is concave, using Jensen's inequality:

$$\begin{aligned} v(u(\rho^* - P_X)) &= E_{f_y} [v(E_{f_{X|y}} u(\rho))] \\ &\leq v(E_{f_y} E_{f_{X|y}} u(\rho)) \\ &= v(E_{f_\rho} u(\rho)) \\ &= v(u(\rho^* - P_X^n)) \end{aligned}$$

□

This finding means that compound-risk aversion should increase the compound lottery premium for index insurance relative to what it would be if individuals had the same degree of risk aversion but were compound-risk neutral. In other words, index insurance appears riskier for a compound-risk averse farmer than to his compound-risk neutral counterpart, for the same level of risk aversion.

Intuitively, the compound lottery premium should be a function of the farmer's preference (levels of risk aversion and compound-risk aversion) and the basis risk characterizing the contract. The approximation of the compound lottery premium derived by MMR confirms this intuition. They show that it is the sum of a compound-risk premium and the classical Pratt risk premium:

$$P_X \simeq -\frac{1}{2}\sigma_\rho^2 \frac{u''(\rho^*)}{u'(\rho^*)} - \frac{1}{2}\sigma_{\rho^*}^2 \frac{v''(u(\rho^*)) (u'(\rho^*))}{v'(u(\rho^*))} \quad (5)$$

where the first term,  $P_X^n \equiv -\frac{1}{2}\sigma_\rho^2 \frac{u''(\rho^*)}{u'(\rho^*)}$ , is the classical Pratt premium, and the second term,  $P_X^c \equiv -\frac{1}{2}\sigma_{\rho^*}^2 \frac{v''(u(\rho^*)) (u'(\rho^*))}{v'(u(\rho^*))}$ , is the compound risk premium. Note that  $P_X$  is a function of two variances. The first variance,  $\sigma_\rho^2$ , is the variance of the final net wealth when purchasing the index insurance :

$$\sigma_\rho^2 = E_{f_y} [E_{f_{X|Y}} (\rho - \rho^*)^2] \quad (6)$$

For every realization of the first stage lottery (the yield lottery), the farmer faces a second stage lottery (index lottery) that yields a given expected net wealth. The second variance is the variance of this net wealth measured with respect to the probability distribution of the yield:

$$\sigma_{\rho^*}^2 = E_{f_Y} [E_{f_{X|Y}} (\rho)^2 - [E_{f_y} [E_{f_{X|Y}} (\rho)]]^2] \quad (7)$$

$\sigma_{\rho^*}^2$  reflects the uncertainty on the expected net wealth of the farmer due to the compound structure of the

prospect he faces. Therefore,  $\sigma_{\rho^*}^2 = 0$  for a conventional indemnity insurance (a simple lottery). By the law of total variance, we have the following relationship between  $\sigma_{\rho}^2$  and  $\sigma_{\rho^*}^2$ :

$$\begin{aligned}\sigma_{\rho}^2 &= E_{f_Y} [\text{var}(\rho \mid Y)] + \text{Var} [E_{f_{X|Y}}(\rho \mid Y)] \\ &= E_Y [\text{var}(\rho \mid Y)] + \sigma_{\rho^*}^2\end{aligned}$$

The first component,  $E[\text{var}(\rho \mid Y)]$ , is called the expected value of conditional variances, which is the weighted average of the conditional variances. It is the “within” component of the variance: the expected variance of the net wealth realized in the secondary lottery. The second term,  $\sigma_{\rho^*}^2$ , is the “between” component of the variance. It is the variance of the conditional means, which represents the additional variances as a result of the uncertainty in the realization of the yield.

From Equation 5 note that:

1. For a compound-risk neutral individual,  $P_X^c = 0$ . The compound-lottery premium reduces to the classical Pratt premium:

$$P_X = P_X^n$$

2. For conventional indemnity insurance with  $\sigma_{\rho^*}^2 = 0$ , the compound lottery premium also reduces to the classical Pratt premium, whether the farmer is compound-risk averse or not.
3. A compound-risk averse individual is willing to pay an extra premium to eliminate basis risk compared to his compound-risk neutral counterpart, who has the same level of risk aversion. This extra premium is denoted  $P_X^c$ , and it is a function of the curvature of  $v$ ,  $u$  and of  $\sigma_{\rho^*}^2$ .

### 3.2 Defining an increase in basis risk and its impact on the compound lottery premium

This section aims at studying the impact of an increase in basis risk on the compound lottery premium. First, this section defines an increase in basis risk. Then, it studies the impact of such an increase on  $\sigma_{\rho}^2$  and  $\sigma_{\rho^*}^2$ . The result follows immediately.

First, define the random variable  $q$  as the probability that the index is triggered.  $q$  yields  $q_1$  with probability  $p$ , and  $q_2$  with probability  $1 - p$ . The index insurance contract presented in Figure 1 yields a payment with a probability  $\bar{q}$  given by:

$$\bar{q} = p * q_1 + (1 - p) * q_2 \tag{8}$$

Let’s define an increase in basis risk as a mean preserving spread in the probability of payment  $\bar{q}$  such as the FNP  $(1 - q_2)$  increases. Define  $q'$  as the random variable yielding either  $q_1 + \frac{h(1-p)}{p}$  or  $q_2 - h$ , with probabilities  $p$  and  $1 - p$  respectively:

$$q'(h) = \begin{cases} q_1 + \frac{h(1-p)}{p}, & p \\ q_2 - h, & 1-p \end{cases} \quad (9)$$

Define the random variable  $\epsilon$  as follows:

$$\epsilon = \begin{cases} (1-p) * (q_1 - q_2 + \frac{h}{p}), & p \\ p * (q_2 - q_1 - \frac{h}{p}), & 1-p \end{cases} \quad (10)$$

Then, the variable  $q'$  can be written as the sum of  $\bar{q}$  and  $\epsilon$ :

$$q' = \bar{q} + \epsilon$$

Note also that  $E(\epsilon | \bar{q}) = 0$ . Therefore,  $q'$  is a mean preserving spread of  $\bar{q}$ .

**Lemma 1.** Defining  $\sigma_{\rho'}^2$  as the variance of the farmer's wealth under the new probability distribution  $q'$ ,  $\frac{\partial \sigma_{\rho'}^2}{\partial h} \geq 0$ .

*Proof.* Using the notations defined in Section 2, we have:

$$\begin{aligned} \sigma_{\rho'}^2 &= p \left( q_1 + \frac{h * (1-p)}{p} \right) (y_0 - \tau_1 + \Pi - \rho^*)^2 + p \left( 1 - q_1 - \frac{h * (1-p)}{p} \right) (y_0 - \tau_1 - \rho^*)^2 \\ &+ (1-p) * (q_2 - h) (y_0 - L - \tau_1 + \Pi - \rho^*)^2 + (1-p) * (1 - q_2 + h) (y_0 - L - \tau_1 + \Pi - \rho^*)^2 \\ &= \sigma_{\rho}^2 + h * (1-p) * (y_0 - \tau_1 + \Pi - \rho^*)^2 - h * (1-p) * (y_0 - \tau_1 - \rho^*)^2 \\ &+ (1-p) * (-h) (y_0 - L - \tau_1 + \Pi - \rho^*)^2 + (1-p)h((y_0 - L - \tau_1 - \rho^*)^2 \\ \frac{\partial \sigma_{\rho'}^2}{\partial h} &= (1-p)(2\Pi L) \\ &\geq 0 \end{aligned}$$

since  $L \geq 0$  and  $\Pi \geq 0$ . □

**Lemma 2.** Define  $\sigma_{\rho^*}^2$  as the analogous of  $\sigma_{\rho}^2$  under the probability of payment  $q'$ . Then  $\frac{\partial \sigma_{\rho^*}^2}{\partial h} \geq 0$

*Proof.* Define  $\bar{\rho}_1'$  and  $\bar{\rho}_2'$  as the conditional means of the net wealth under the high yield and low yield, respectively. The variance  $\sigma_{\rho^*}^2$  can be written in the following way:

$$\begin{aligned}
\sigma_{\rho^*}^2 &= p * (\bar{\rho}_1 - \rho^*)^2 + (1 - p) * (\bar{\rho}_2 - \rho^*)^2 \\
&= p * (\bar{\rho}_1 + \frac{h(1-p)}{p} \pi - \rho^*)^2 + (1 - p) * (\bar{\rho}_2 - h\pi - \rho^*)^2 \\
\frac{\partial \sigma_{\rho^*}^2}{\partial h} &= 2 \frac{h(1-p)^2}{p} \pi^2 + 2(1-p)h\pi^2 + 2(1-p)(\bar{\rho}_1 - \bar{\rho}_2) \\
&\geq 0
\end{aligned}$$

since  $\bar{\rho}_1 > \bar{\rho}_2$ . □

Lemma 1 & 2 imply two important results:

1. As basis risk increases, the compound lottery premium  $P_X$  for the index insurance contract increases.
2. Compound-risk aversion exacerbates the impact of an increase in basis risk on the compound-lottery premium.

### 3.3 Willingness to pay for index insurance

This section studies the willingness of a farmer to pay for index insurance ( $WTP_X$ ) accounting for his compound-risk attitudes, and using the compound lottery premium defined in Section 2.2.  $WTP_X$  is defined as the difference between the certainty equivalent of the index insurance contract  $CE_X$ , and the certainty equivalent of the income lottery he faces in the autarkic situation, i.e. if he does not purchase any insurance  $CE_A$ . The certainty equivalent of the index insurance contract  $CE_X$  is defined by:

$$CE_X \equiv \rho^* - P_X$$

The certainty equivalent of the autarkic option is defined by:

$$CE_A \equiv \rho_A^* - P_A$$

where  $\rho_A^* = E_{f_\rho}(\rho)$  is the expected final net wealth the farmer gets without insurance,  $P_A \equiv \frac{1}{2} \sigma_{\rho_A}^2 \frac{u''(\rho_A^*)}{u'(\rho_A^*)}$  is the Arrow Pratt premium corresponding to the autarkic situation, and  $\sigma_{\rho_A}^2$  is the variance of the farmer's final net wealth without insurance. Therefore,  $WTP_X$  is given by:

$$WTP_X = (\rho^* - \rho_A^*) + P_A - P_X \tag{11}$$

Thus, the magnitude of the willingness to pay for index insurance depends on the farmer's risk aversion, compound-risk aversion and on basis risk. If the farmer is compound-risk neutral, then his willingness to

pay reduces to:

$$WTP_X^n = (\rho^* - \rho_A^*) + P_A - F_X^n \quad (12)$$

By equation 4, for a given level of basis risk  $WTP_X \leq WTP_X^n$ . Using lemma 1 & 2, it is straightforward to show the following two main results:

1. As basis risk increases, the  $WTP$  for the index insurance contract decreases.
2. Compound-risk aversion exacerbates the impact of an increase in basis risk on the  $WTP$  for index insurance.

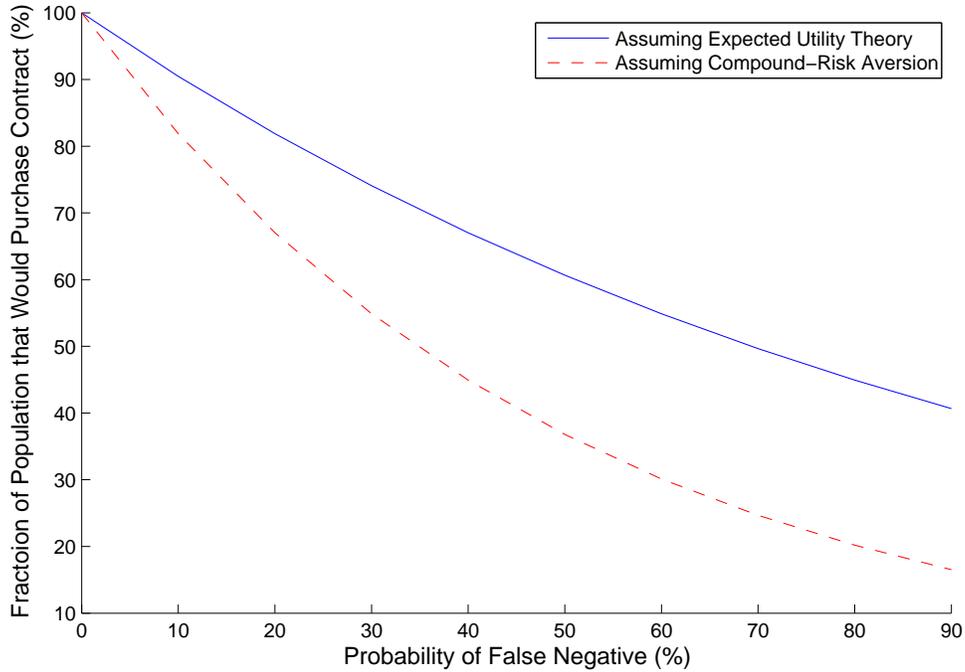


Figure 2: Impact of basis risk on the demand for index insurance

Figure 2 illustrates points 1 and 2 above. The X- axis represents the FNP, and the Y- axis represents the hypothetical demand for index insurance for a given level of FNP. The solid line represents this demand under expected utility theory, and the dotted line represents this demand under compound-risk aversion. As FNP increases, the demand decreases whether the individual is compound-risk averse or not. However, the dotted curve is steeper than the solid one, reflecting the fact that compound-risk aversion exacerbates the impact of an increase in basis risk. To simulate the real magnitude of the impact of FNP on the demand for index insurance, we have to elicit the coefficients of risk aversion and compound-risk aversion from a sample of farmers. Eliciting the coefficients of risk-aversion is a classic problem. The next section describes

a methodology to characterize the compound-risk attitudes of the participants. The idea is to give the participants a choice between the index insurance and some equivalent conventional indemnity insurance. The outcome of this procedure is the elicitation of WTP to eliminate basis risk.

### 3.4 A method to elicit the coefficient of compound-risk aversion

Compared to index insurance, conventional indemnity insurance does not have basis risk. The farmer receives a payment whenever he experiences a loss in his farm. Therefore, a measure of his willingness to pay to eliminate basis risk  $WTP_B$  can be obtained by comparing his attitude towards index insurance and conventional indemnity insurance. Let us imagine the situation where a farmer has to choose between the index insurance contract and a conventional indemnity insurance contract. This latter contract yields a net wealth  $\delta$  and pays for sure when the farmer's yield is low. What is the amount of money that makes the farmer indifferent between the two contracts? By definition,  $WTP_B$  is the maximum amount of money the farmer is willing to give up in order to be indifferent between the index insurance contract, and the individual insurance contract. Equivalently,  $WTP_B$  is defined as the difference between the certainty equivalent of the index insurance contract  $CE_X$ , and the certainty equivalent of the income lottery he faces if he purchases the individual insurance  $CE_I$ .

The certainty equivalent of the individual insurance  $CE_I$  contract is by definition:

$$CE_I \equiv \delta^* - P_I$$

where  $\delta^* = E_{f_y}(\delta)$  is the expected final net wealth the farmer gets with the individual insurance,  $P_I \equiv -\frac{1}{2}\sigma_\delta^2 \frac{u''(\delta^*)}{u'(\delta^*)}$  is the Arrow Pratt premium corresponding to the individual insurance contract, and  $\sigma_\delta^2$  is the variance of the farmer's final net wealth with individual insurance. Therefore,  $WTP_B$  is defined by:

$$WTP_B \equiv CE_X - CE_I$$

or equivalently,

$$WTP_B = (\rho^* - \delta^*) + (P_I - P_X^n - P_X^c) \quad (13)$$

Using the same reasoning as in section 3.2, we can verify that a compound-risk averse individual has a higher WTP compared to his compound-risk neutral counterpart, for the same level of risk aversion.  $WTP_B$  is a measure that can be easily elicited in an experiment. For a given level of basis risk and risk aversion, this measure depends only on compound-risk aversion. Therefore, combining the finding of a game that elicits  $WTP_B$  with the findings of a game that elicits the coefficients of risk aversion allows the elicitation of the

coefficients of compound-risk aversion. Section 4 describes such games.

## 4 Experimental Design and Data

To elicit the coefficients of risk aversion and compound-risk aversion, 331 cotton farmers from 34 cotton cooperatives in Bougouni, Mali participated in a set of framed field experiments. A first game allowed the measurement of their risk aversion coefficients. It was framed in terms of insurance decisions. The second game elicited their  $WTP_B$  to eliminate basis risk as defined in equation 13, which allows the elicitation of the compound-risk aversion coefficients. This last game closely resembles the theoretical framework described in Section 2 with one difference. If the individual yield is high, the index is no longer triggered. The reason for this design is to mimic the structure of an area yield index insurance product that was designed as part of the ongoing project “Index insurance for Cotton farmers in Mali”, and launched by the Index Insurance Innovation Initiative (I4). More details about this project and the structure of the distributed contract can be found in Elabed et al. (2013).

### 4.1 Experimental Procedure

The participants are selected at random from the list of cooperatives participating in the project mentioned above. In addition, a survey gathered detailed information on various socio-economic characteristics of the participating farmers such as demographic characteristics, wealth, assets owned, agricultural production and shocks. Data collection for the survey took place in December 2011 through January 2012, and the experiments took place in January and February 2012.

Three rural area trainers translated the experimental protocol from French to Bambara, the local language, and ensured that it is accessible to a typical cotton farmer. Game trials were conducted with graduate students in Davis, CA, and with high school students and cotton farmers who were not part of the final experimental sample in Bougouni, Mali. Local leaders (secretaries of cotton cooperatives and/or village chiefs) assisted us in recruiting the eligible participants from a list of names that we provided.

The sessions took place in a classroom on weekends and in the village chief’s office on weekdays. The sessions took place with members of the same cooperative, and they lasted around two and a half hours. We divided the sessions into two parts with a short break between each. Each participant played one pure luck game and four decision and luck games. Each decision and luck game started with a set of six “low stakes” rounds aimed at familiarizing the participants with the rules, which were followed by a set of six “high stakes” rounds. The only difference between these two types of rounds was the exchange rate used to compute the gains in cash: the gains from a high stake round were 5 times higher than the gains from a low stake round. At the end of the session, we paid the players for only one of the low stake rounds and one of the high stake rounds of every game by having a farmer roll a six-sided die. We used this random incentive device in order to encourage the players to choose carefully. The animator announced the selection

procedure to the players at the beginning of every game. In order to incentivize the players to think more carefully about their decisions, we repeated the following sentence “There is no right or wrong answer. You should do what you think is best for you and your family whether it is choice #1, choice #2, etc.”.

At the end of the session, participants received their game winnings in cash, in addition to a show up fee of 100 CFA. Minimum and maximum earnings, excluding show up fee, were 85 CFA and 2720 CFA and mean earnings was 1905 CFA. The daily wage for a male farm labor in the areas where we ran the experiments were between 500 CFA (0.93 USD) and 2000 CFA (3.75 USD) and on average 1040 CFA (1.95 USD). Since literacy rates are very low in the area, we presented the games orally with the help of visual aids. In addition to the main presenter, two rural trainers assisted the players with the various materials.

## 4.2 The insurance contracts

The players, endowed with one “hectare of land”, had to take decisions framed in terms most familiar to them: their decisions were centered on cotton -their main cash crop. Before playing the risk aversion game, the participants learned how to determine their yields and the resulting revenue. Then participants had to choose among different insurance contracts.

### 4.2.1 Determining the Yield:

Based on historical yield distributions and pooling all the available data across years and cooperatives, we discretized the density of cotton yields into six sections with the following probabilities (in percent): 5, 5, 5, 10, 25 and 50, respectively. The individual yield values corresponding to the mid-point of those sections are (in kg/ha): 250, 450, 645, 740, 880 and 1530, respectively. Table 1 shows the yield distribution and the corresponding revenue in d, the local rural currency.

Yield range (kg/ha)	Mid point	Probability	Revenue (in d)
<300	250	5%	2400
300-600	450	5%	10400
600-690	645	5%	18200
690-790	745	10%	22000
790-780	880	25%	27600
>980	1530	50%	53600

Table 1: Yield distribution and corresponding revenues

Understanding the notion of probability associated with the yield determination is a challenge that we addressed by using the randomization procedure used by Galarza and Carter (2011) in Peru to simulate the realizations of the individual yields. Every participating farmer drew his yield realizations from a bag containing 20 blocks (1 black, 1 yellow, 1 red, 2 orange, 5 green and 10 blue) which reproduce the probability distribution mentioned earlier, going from the lowest to the highest yield. Figure 3 shows the visual aid provided to farmers to help them understand the game better. Equation 14 computes the individual farmer’s

per hectare profits in d without any insurance contract:

$$profit_i = p * y_i - Inputs \quad (14)$$

where the price ( $p$ ) of a kg of cotton is set at d40, the cost of the inputs is set at d7600 in order to guarantee that the players never incur a real loss in the games with the different contracts.

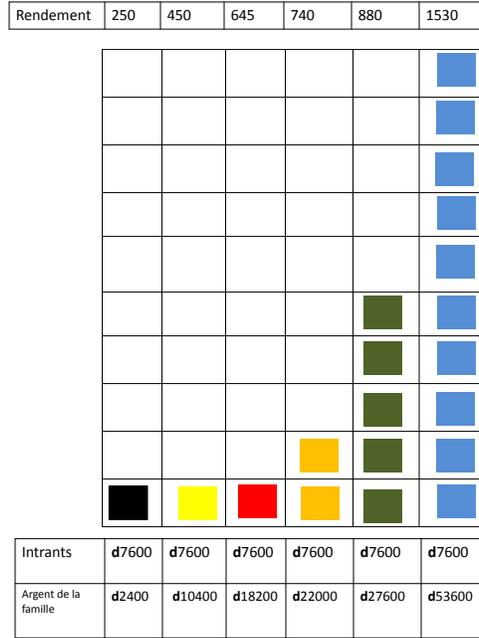


Figure 3: Visual aid for yield distribution

#### 4.2.2 Conventional Indemnity Insurance Contract

After having practiced determining their yields and the corresponding revenue, the player, indexed by  $i$  had to decide whether to purchase an insurance contract. The contract is linear and the payment occurs if the yield falls below the strike point  $T$ . The strike point  $T$  represents an exogenous reference point, or the yield level below which the farmer feels that he experiences a loss. In case the farmer is eligible for an insurance payment, the insurance reimburses the difference between the individual yield and the strike point such that the farmer is guaranteed to have an income corresponding to yield  $T$ . The premium is set to include a loading cost of 20%, such that the amount paid is 120% the amount received on average. Thus, the payment schedule is the following:

$$payment(y_i) = \begin{cases} p * (T - y_i), & y_i \leq T \\ 0 & y_i > T \end{cases} \quad (15)$$

### 4.2.3 The index insurance contract

The index insurance contract is characterized by a strike point  $T$  at the individual level, and by another strike point  $T_z$  at the ZPA (aggregate agricultural area) level. Every participant farmer was explicitly told that he represents a separate agricultural production area in order to emphasize the fact that the index is independent from the realizations of the other farmers in the group. Thus, compared to the regular indemnity insurance, in order to be eligible for a payment, the farmer has to satisfy an extra condition. The payment schedule is the following:

$$payment(y_i) = \begin{cases} p * (T - y_i) & : y_i \leq T \text{ and } y_z \leq T_z \\ 0 & \text{otherwise} \end{cases} \quad (16)$$

Thus, from the player's point of view, once he suffers a loss (i.e. his yield is below the individual strike point), he risks not getting a payment with positive probability. This FNP is set at 20%, which is a rough calibration related to the level of FNP in the contract distributed in the index insurance project described above. Further, the individual-level trigger is set at 70% of the median historical yield, and the contract was priced with a loading cost of 20%. If a farmer decides to purchase an index insurance contract, then he faces a two-stage game. First, he determines his own yield by drawing a block from the yield sack. Then, if the yield is below the individual strike point, he draws another block from a second sack which contains 4 brown blocks (i.e. the index triggered) and one green block (i.e. the index is not triggered).

## 4.3 The Games

### 4.3.1 Game 1: Eliciting risk preferences

The risk aversion game was framed in terms of an insurance decision to elicit risk preferences. While alternative unframed methodologies exist in the literature, this framed design is chosen for pedagogical reasons. Each subject had six different possibilities: don't purchase an insurance contract, or choose among five different insurance contracts that differ in their strike points, which were 100%, 80%, 70%, 60%, and 50% of the median historical yield (980 kg/ha). In terms of actual yields, this corresponds to 980 kg/ha, 784 kg/ha, 686 kg/ha, 588 kg/ha, and 490 kg/ha, respectively. The net revenue of farmer  $i$  if he purchases contract  $j$  is given by the following formula:

$$profit_{ij} = p * y_i + Indemnity_j - premium_j \quad (17)$$

where *indemnity* is an indicator function for the insurance payment, and *premium* is the premium of the insurance contract. Table 2 shows the different revenues associated with each choice and the corresponding risk aversion ranges.

Yield (kg/ha) Proba.	Contract #	Trigger (% ybar)	Premium (d)	Net Profit (d)						CRRA range
				250	450	645	740	880	1530	
				5%	5%	5%	10%	25%	50%	
	0	0	0	2400	10400	18200	22000	27600	53600	( $\infty$ ; 0.08)
	1	50	600	4280	10280	18080	21880	27480	53480	(0.08; 0.16)
	2	60	1200	15200	15200	17000	20800	26400	52400	(0.16; 0.27)
	3	70	1740	18260	18260	18260	20260	25860	52860	(0.27; 0.36)
	4	80	2700	21300	21300	21300	21300	24900	50900	(0.36; 0.55)
	5	100	6180	25420	25420	25420	25420	25420	47420	(0.55; $\infty$ )

Table 2: Individual insurance contracts and risk aversion coefficient

In this game, each player had to determine whether he wanted to purchase an insurance contract, and if so which one. Then, an assistant asked him to draw a block in order to determine his revenue. The last column of Table 2 exhibits the CRRA ranges corresponding to every contract choice, assuming a CRRA utility function. Let's assume that the player chose the third contract. Assuming monotonic preferences, this implies that he preferred this contract to contracts 2 and contract 4. The upper (lower) bounds of the CRRA range is found by equalizing the expected utility that the farmer derives from contract 2 and 3 (3 and 4). In this case, as Table 2 shows, the CRRA range of the player is (0.27; 0.36). Note that as the level of coverage (measured by the trigger as percentage of the median yield) increases, the CRRA increases.

The last column of Table 3 below shows the distribution of the levels of CRRA of the participants, based on the results of Game 1. The majority of the farmers (78%) chose an insurance contract, and 30% of them chose the highest level of coverage which corresponds to a coefficient of risk aversion of more than 0.55. The median player chose the third insurance contract, which corresponds to a coefficient of risk aversion between 0.27 and 0.36.

Contract #	CRRA range	%
0	( $\infty$ ; 0.08)	22.56
1	(0.08; 0.16)	7.32
2	(0.16; 0.27)	9.76
3	(0.27; 0.36)	10.67
4	(0.36; 0.55)	17.99
5	(0.55; $\infty$ )	31.71

Table 3: Distribution of the CRRAs in the sample

#### 4.3.2 Game 2: Eliciting the WTP to eliminate basis risk

After having practiced determining his revenue under the index insurance contract, every participant played a game that aimed at eliciting the WTP measure defined above (the amount of money the farmer is willing to pay above the price of the indemnity insurance contract). Specifically, we wanted to see whether the player, whom we call Mr. Toure, preferred the indemnity contract to the index contract as we increase the price of the individual contract from its base price (d1340) to d3540, by increments of d200.

The elicitation procedure was the following: The animator presented players with the following scenario: Mr. Toure’s friend, Mr. Cisse, is going to Bamako (the capital of Mali, 90 miles away). Mr. Toure asks Mr. Cisse to buy an insurance contract for Mr. Toure. Mr. Toure knows that the price of the individual contract can vary depending on the day, but the price of an index contract is always the same. After highlighting the fact that at the price of d1340, it is always more profitable to buy the individual insurance contract, Mr. Toure was asked to tell Mr. Cisse at which price Mr. Toure should switch to favoring the index insurance contract over the individual insurance contract. Thus, by the end of the game, we have the switching price for every player from which we deduce his willingness to pay to eliminate basis risk.

The game reduces to ten choices between 10 paired insurance contracts whose net revenues are listed in table 3. Notice that the price of the index insurance contract does not vary, whereas the price of the individual insurance contract increases by d200 as we move down the table.

Index Insurance contract	Indemnity insurance contract	Implied WTP	Implied CRRA under EUT
d1450	d1740	0	(0; 0.49)
d1450	d1940	d200	(0.49; 0.71)
d1450	d2140	d400	(0.71; 0.87)
d1450	d2340	d600	(0.87; 0.99)
d1450	d2540	d800	(0.99; 1.09)
d1450	d2740	d1000	(1.09; 1.18)
d1450	d2940	d1200	(1.18; 1.25)
d1450	d3140	d1400	(1.25; 1.32)
d1450	d3340	d1600	(1.32; 1.37)
d1450	d3540	d1800	(1.37; $+\infty$ )

Table 4: Game 2: Eliciting WTP measure.

In order to deduce the compound-risk aversion of a player, we impose a functional form on the function  $v$  we defined earlier. For computational convenience, we impose constant relative compound risk aversion. Thus, the function  $v$  defined in Section 2 is given by:

$$v(y) = \begin{cases} \frac{g^{1-y}}{1-g} & \text{if } g \in [0, 1) \\ \log(y) & \text{if } g = 1 \end{cases} \quad (18)$$

where  $g$  is the coefficient of constant relative compound-risk aversion, and  $y$  is measured in d.

Table 5 below lists the predicted coefficients of compound-risk aversion based on the player’s choices in Games 1 and 2. To simplify the calculations, these measures are made after taking the midpoint of every risk aversion range. For example, if the player chose contract 4 in Game 1, then the corresponding CRRA is 0.45. The corresponding  $g$  is obtained using the definition of  $WTP_B$  expressed in equation 13.

WTP (d)	Contract choice in Game 1:					
	0	1	2	3	4	5
0	0.01	0.00	0.00	0.00	0.00	0.00
200	0.08	0.07	0.06	0.05	0.01	0.00
400	0.14	0.14	0.14	0.13	0.10	0.00
600	0.21	0.21	0.21	0.21	0.20	0.00
800	0.27	0.28	0.29	0.29	0.29	0.00
1000	0.34	0.35	0.36	0.38	0.39	0.00
1200	0.40	0.42	0.44	0.46	0.48	0.13
1400	0.47	0.49	0.51	0.54	0.58	0.29
1600	0.53	0.56	0.59	0.62	0.67	0.46
1800	0.59	0.62	0.66	0.70	0.76	0.63

Table 5: Predictions of the Coefficients of Compound-Risk Aversion.

Figure 4 below displays the distribution of the farmer's WTP to eliminate basis risk as elicited from Game 2. 60% of the participants prefer the individual insurance contract (their WTP is strictly positive). These participants are willing to pay on average 2135, which represents extra premium of 27.25 % of the price of the individual contract. This implies that for these participants, if an individual insurance contract is priced with a loading of 20%, the equivalent index insurance contract should be priced with a loading of almost 47.25%.

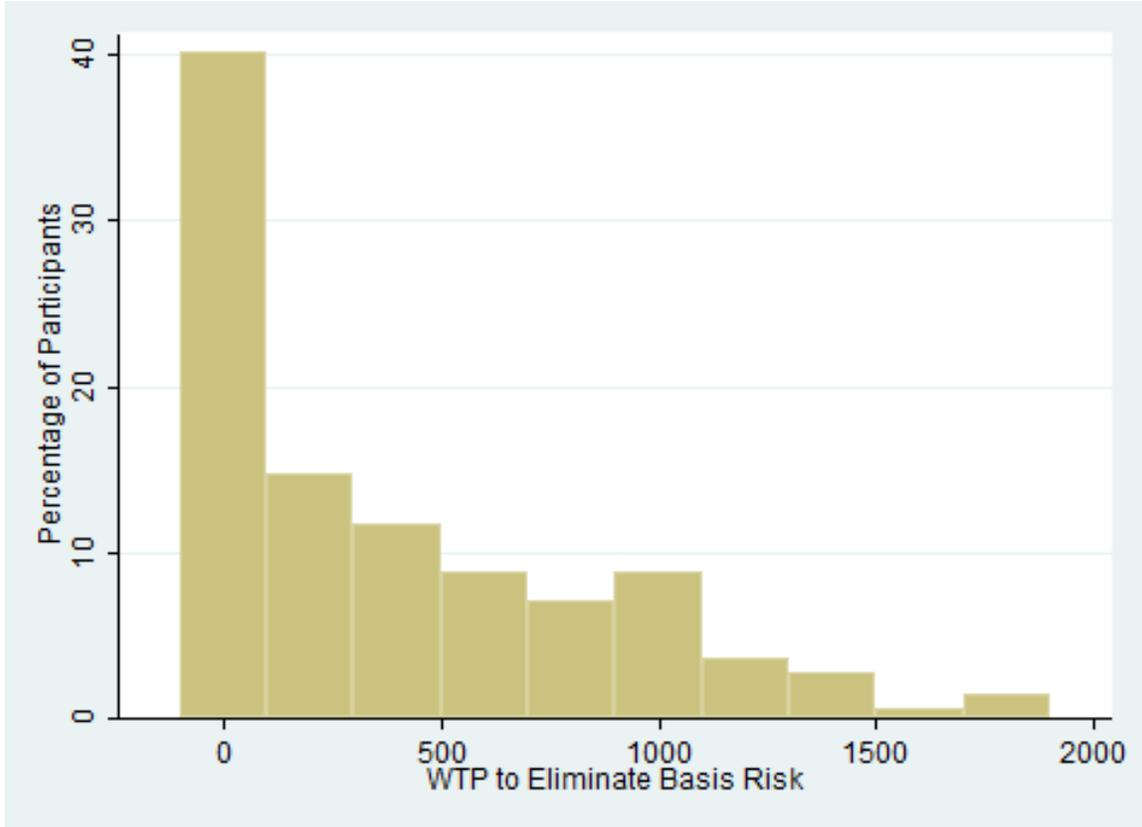


Figure 4: WTP to eliminate basis risk

## 5 Results

This section analyzes the results of the experiments. First, it describes the sample of participants. Then it compares the results of the risk aversion game to those of the WTP game. Third, it tests the hypothesis of whether farmers behave according to EUT or not, and classifies the participants by their degrees of compound-risk aversion. Fourth, it simulates the impact of FNP on the uptake of index insurance under compound-risk aversion.

### 5.1 Participants characteristics

Table 5 provides the descriptive statistics for the experiment participants. All the participants are male, which is not surprising given the division of labor in the area of study: cotton production is mainly a male responsibility. The average participant is approximately 47 years old, has limited formal education (three years of schooling), and belongs to a household with almost 19 members. 71% of the participants are the head of their households, and almost all of them have heard of the cotton insurance contract distributed

in the field. The average household head has been a member in the cooperative for almost 8.6 years. The average household economic status is represented by a total livestock value of 1.8 million CFA, a house worth 400,000 CFA and a total land area of 9.62 ha.

Variable	Mean	sd/percent
Participants characteristics:		
head (1 if male)	0.7	
Age	47.07	13.21
Gender	1	
Years of schooling (#)	4.55	6.57
knowledge of insurance (1 if heard about cotton insurance before)	0.92	
Head characteristics:		
Age (years)	5.55	15.22
Gender (1 if male)	1	
Cooperative experience (# years)	8.62	6.28
Household characteristics:		
Household size (#)	18.82	11.88
livestock owned in 2012 (CFA)	1,822,602	5,634,664
Value of agricultural assets 2012 (CFA)	171,299	247,236
Value of household's assets in CFA	204,200	164,468
House value (CFA)	396,952	1,042,061
Area of land owned (ha)	9.62	7.81

Table 6: Descriptive Statistics of the Participants

## 5.2 Comparing the results of Game 1 and Game 2

Under the hypothesis that the participants are expected utility maximizers, it is possible to elicit their coefficients of constant relative risk aversion by looking at their decisions in Game 2. The last column of Table 7 presents the risk aversion ranges implied by the measured  $WTP_B$  if the player is compound-risk neutral. For example, if a player's  $WTP_B$  is d800, then the expected utility he derives from the index insurance contract is larger than the expected utility of the individual contract priced at d2340 and smaller than the expected utility he derives from the individual contract priced at d2540:  $EU(\pi + 600) \leq EU(\rho) \leq EU(\pi + 800)$ . However, if a participant is compound-risk averse, then the CRRA model does not hold and the elicited coefficient of risk aversion does not correspond to the true coefficient of risk aversion of the player.

Index Insurance contract	Indemnity insurance contract	Implied WTP	Implied CRRA under EUT
d1400	d1740	0	(0; 0.49)
d1400	d1940	d200	(0.49; 0.71)
d1400	d2140	d400	(0.71; 0.87)
d1400	d2340	d600	(0.87; 0.99)
d1400	d2540	d800	(0.99; 1.09)
d1400	d2740	d1000	(1.09; 1.18)
d1400	d2940	d1200	(1.18; 1.25)
d1400	d3140	d1400	(1.25; 1.32)
d1400	d3340	d1600	(1.32; 1.37)
d1400	d3540	d1800	(1.37; $+\infty$ )

Table 7: Game 2: Eliciting WTP measure.

If players do not react to the compound structure of the index insurance contract, the two games should reveal the same coefficients of constant relative risk aversion. Figure 5 plots the empirical probability distributions of the CRRAs coefficients elicited from the two games among the participants. The solid line in Figure 6 shows the CDF of the CRRAs elicited from the first game, while the dashed line shows the CDF of the CRRA's elicited from the second game, assuming compound-risk neutrality. As this figure shows, the CDF of the coefficients from game 2 is more to the right of the CDF of the coefficients elicited from game 1. The participating farmers seem to behave much more cautiously when faced with the index insurance contract. Therefore, attitudes towards risk are not enough to represent the farmer's attitude towards index insurance. Figure 5 constitutes a first evidence against the assumption that farmers are compound-risk neutral. The following section test this result statistically.

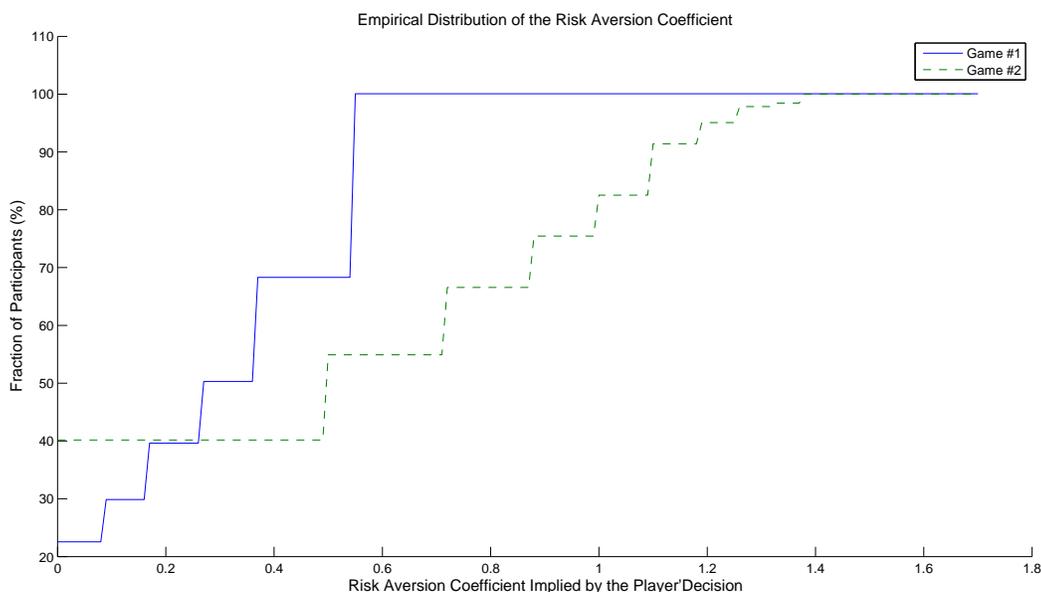


Figure 5: CDFs of CRRAs elicited from Game 1 and Game 2

### 5.3 The participating farmers do not behave according to EUT

In this section we test the hypothesis that farmers are compound-risk neutral or equivalently expected utility maximizers. To do so, we compare the distribution of the coefficients of risk aversion elicited from game 1 to those elicited from game 2, assuming that the expected utility model holds. Games 1 and 2 do not elicit the actual constant relative risk aversion coefficients, but provide constant relative risk aversion coefficient ranges that are not directly comparable. Therefore, before performing the hypothesis test, we begin by fitting a continuous probability distribution to the coefficients of risk aversion elicited from both games.

Instead of conducting an exhaustive search of every possible probability distribution, it is more practical to fit a general class distribution to the data. Ideally, this distribution will be flexible enough to reasonably represent the underlying parameters. This section uses the Beta of the first kind (B1), a three-parameter distribution, as the continuous model that represents the data. The Beta distribution of the first kind is one member of a class of distributions called Generalized Beta distributions (GB), a family of five-parameter distributions that encompasses a number of commonly used distributions (Gamma, Pareto, etc.). The GB is a flexible unimodal distribution and is widely used when modeling bounded continuous outcomes, such as income distribution. Since the B1 distribution is defined for bounded variables, one should make assumptions about the range of the CRRAs. The participants are assumed to be risk-averse. We allow the upper bound of the elicited CRRA to be 1.7. We conducted robustness checks and showed that the result does not change with the upper bound being either 2 or 3.

Let  $B1(b, p_1, q_1)$  and  $B1(b, p_1, q_1)$  be the probability distribution functions of the CRRAs elicited from Game 1 and Game 2 respectively. The parameter  $b$  is the upper bound of the CRRAs and is set at the value 1.7. As explained in the appendix, we use maximum likelihood method to estimate the parameters  $p_1, q_1, p_2$ , and  $q_2$ . Table 8 presents the results of the estimation method. We estimate the confidence intervals for the different parameters using the bootstrap method. Table 8 shows the confidence intervals of parameters  $p_1, q_1, p_2$  and  $q_2$  at the 5% significance level, obtained after 10000 simulations. It is clear that the bootstrap parameters are consistent estimates for the actual ones.

		mean	[95% conf	Interval]
Game 1	$p_1$ parameter	0.67	0.63	0.84
	$q_1$ parameter	1.98	1.80	2.58
Game 2	$p_1$ parameter	2.07	1.92	2.57
	$q_1$ parameter	4.37	4.16	5.09

Table 8: Bootstrap confidence intervals for the parameters.

The test of equality of the distributions of the two CRRAs elicited from the games is performed using 10 000 bootstrapped simulations of the data. We reject the hypothesis that the parameters of the two distributions are the same at the 5% level. Therefore, on average, farmers are not compound-risk neutral.

## 5.4 Participants are compound-risk averse to varying degrees

Table 9 presents the coefficient of compound-risk aversion for each demonstrated category of WTP. Using these coefficients, we derive the number of participants who are compound-risk averse and dis-aggregate this number by risk aversion range. As shown in Table 9, 57% of the players are compound-risk averse. Furthermore, most of the compound-risk averse farmers are also the least risk averse (22.39%). While the existence of compound-risk aversion is important in and of itself, we will study its impact on the demand for index insurance in the next section.

	CRRR Range						
	( $\infty$ ; 0.08)	(0.08; 0.16)	(0.16; 0.27)	(0.27; 0.36)	(0.36; 0.55)	(0.55; 1.7)	
Compound-risk averse participants	73	24	32	35	59	103	186
<i>% of CRRR range</i>	<i>100</i>	<i>37.5</i>	<i>75.0</i>	<i>74.2</i>	<i>66.1</i>	<i>14.6</i>	
<i>% of total participants</i>	<i>22.39</i>	<i>2.76</i>	<i>7.36</i>	<i>7.98</i>	<i>11.96</i>	<i>4.60</i>	<b><i>57.07</i></b>

Table 9: Distribution of Compound- risk Attitudes by CRRR levels

## 5.5 Simulating the impact of FNP on the uptake of index insurance under compound-risk aversion

This section draws on the theoretical findings of section 3.2 and the measured coefficients of risk aversion and compound-risk aversion, and simulates the impact of FNP on the demand of the index insurance contract presented in the games (and described in Section 4) under expected utility maximization (equivalently, compound-risk neutrality), and compound-risk aversion. In the following discussion, we assume that the distributions of risk aversion and of compound-risk aversion among the farmers reflect the distributions in the overall population.

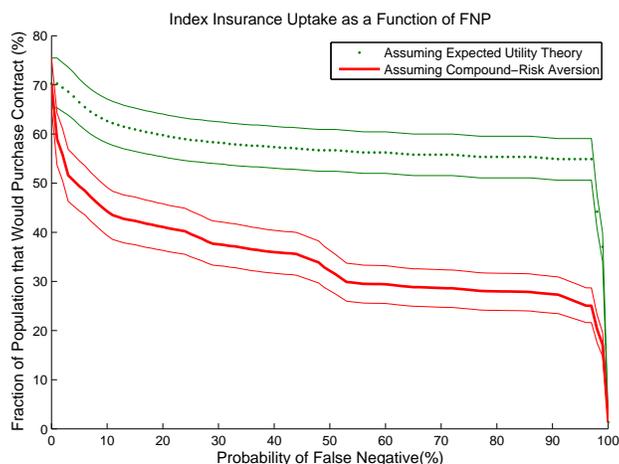


Figure 6: Index insurance uptake as a function of the false negative probability

The dotted curve of Figure 6 illustrates the impact of FNP on the demand for index insurance with 95%

confidence interval using equation 12 and assuming that:

1. Individuals are expected utility maximizers,
2. The price of index insurance is 20% above the actuarially fair price, and
3. The distribution of risk aversion in the population of farmers matches the distribution revealed by the experimental games played in Mali.

As the FNP increases under this contract structure, the probability of a payout decreases, and the price of the insurance contract in turn declines. However, because the contract is not actuarially fair, a number of agents drop out of the market as FNP increases. As can be seen in Figure 6, increasing FNP in an index insurance contract will discourage demand. For a contract with zero FNP, i.e. one that pays off for sure in case of a loss, moderately and highly risk averse farmers (70% of the population in the Mali experiment) ask for index insurance. As FNP increases, the farmers with the highest risk aversion coefficient are the first to stop demanding the contract. This drop in demand reaches as high as 15% for extremely high levels of FNP (90%). Despite this decrease in demand, the demand for the partial insurance provided by this index insurance contract remains relatively robust even as FNP increases (assuming that individuals maximize expected utility).

FNP matters even more when people are compound-risk averse. The solid line in Figure 6 shows, using equation 11 and the distribution of compound-risk aversion in the population of the farmers, the impact of FNP on demand for index insurance. As expected, compound risk aversion decreases the demand for index insurance relative to what it would be if individuals had the same degree of risk aversion but were compound-risk neutral. In addition, as can be seen in the figure, demand declines more steeply as FNP increases under compound-risk aversion. If FNP were as high as 50% (a not unreasonably high number under the kind of rainfall index insurance contracts that have utilized in a number of pilots), demand would be expected to be only 35% of the population as opposed to the 60% demand that would be expected if individuals were simply expected utility maximizers. In short, under compound-risk aversion, designing contracts with minimal FNP is important, not only to enhance the value and productivity impacts of index insurance, but also to assure that the contracts are demanded.

## 6 Conclusion

In the absence of formal insurance markets, poor rural households in developing countries may rely on costly risk-management mechanisms, including income smoothing strategies that entail avoiding riskier technologies with higher expected returns. Although the partial coverage provided by index insurance would appear to provide a good alternative to these households in theory, demand has been surprisingly low. This paper draws on insights from behavioral economics and framed field experiments to provide an explanation for the low uptake.

We begin our analysis by examining the farmer’s perspective of index insurance. To the farmer, index insurance appears as a compound lottery with two stages: the first stage lottery determines the individual farmer’s yield, and the second stage determines whether or not the index triggers an indemnity payout. Drawing on the literature on compound risk aversion and ambiguity aversion, we derive an expression of the willingness to pay for index insurance. This measure depends on two parameters: the coefficients of risk aversion and compound-risk aversion.

In Mali, we designed a set of framed field experiments with 334 cotton farmers to elicit the two parameters that define and individual’s attitude toward index insurance. We framed the first game in terms of insurance decisions to elicit risk aversion coefficients. The second game elicited the excess willingness to pay of farmers to get rid of the second stage lottery of the index insurance contract. Fitting an expected utility model to this measure allows us to elicit another set of coefficients of risk aversion. Using both graphical evidence and a statistical test, we find that the distributions of these two parameters are different. This finding suggests that farmers are not neutral to compound-risk. Using the smooth model of ambiguity aversion of KMM, we combine the findings of the two games to pin down the coefficients of compound-risk aversion. We find that 57% of game participants revealed themselves to be compound-risk averse to varying degrees. In fact, the willingness to pay to avoid the secondary lottery of those individuals who demand index insurance is on average considerably higher than the predictions of expected utility theory. Using the distribution of compound-risk aversion and risk aversion in this population, we simulated the impact of changes in basis risk on the demand for index insurance. As we expected we found that compound risk aversion decreases the demand for index insurance relative to what it would be if individuals had the same degree of risk aversion but were compound-risk neutral. In addition demand declines more steeply as basis risk increases under compound-risk aversion.

Our results highlight the importance of designing contracts with minimal basis risk under compound-risk aversion. Reducing basis risk would not only enhance the value and productivity impacts of index insurance, but would also assure that the contracts are popular and have the anticipated impact.

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## A Appendix:

### A.1 Fitting a B1 distribution to the CRRA

In this section, we estimate the probability density function  $f$  of the coefficient of constant relative risk aversion  $r$  we elicited from an experiment.

We use Maximum Likelihood estimation assuming that  $r$  follows a Generalized Beta distribution of first kind (GB1). The GB1 distribution is defined by the following pdf:

$$f(r; b, p, q) = \frac{\left(r^{p-1} \left(1 - \frac{r}{b}\right)^{q-1}\right)}{b^p B(p, q)}$$

for  $0 < r < b$  where  $b$ ,  $p$  and  $q$  are positive. The scaling factor  $B(p, q)$  is the Beta function:  $B(p, q) = \frac{\Gamma(p)\Gamma(q)}{\Gamma(p+q)}$  where  $\Gamma(p) = (p-1)!$ .

By construction, our data is partitioned in 6 intervals. Therefore, we do not observe the continuous variable  $r$ . Following McDonald and Xu (1995), we obtain the parameters of interest ( $p$  and  $q$ ) using a Maximum Likelihood estimator based on a multinomial with an underlying density  $f(r; b, p, q)$  and cumulative function  $F(r; b, p, q)$ .

We now derive the log-likelihood function. Let  $j$  denote the risk aversion interval  $[r_j, r_{j+1}]$ . Player  $i$ 's true risk aversion coefficient  $r$  has a probability  $p_i = F(r_{j+1}; a, b, p, q) - F(r_j; a, b, p, q)$  of being in interval  $j$ . Denoting  $m_j$  the number of observations in interval  $j$ , the likelihood function  $\mathbf{L}_N$  is the joint probability function:

$$\mathbf{L}_N = \prod_{i=1}^N p_i$$

Maximizing  $\mathbf{L}_N$  is equivalent to maximizing the log-likelihood function:

$$\begin{aligned} \mathcal{L}_N(b, p, q) &= \log \mathbf{L}_N(b, p, q) \\ &= \sum_{j=1}^6 m_j \log(p_j) \end{aligned}$$

Where  $m_j$  is the number of observations in the interval  $[r_j, r_{j+1}]$ . The probability  $p_j$  of being in that

interval is

$$p_j = F(r_{j+1}; a, b, p, q) - F(r_j; a, b, p, q)$$

Since  $r$  is a Beta distribution of the first kind, its cumulative  $F$  is:

$$\begin{aligned} F(r; b, p, q) &= \int_0^{\frac{r}{b}} \frac{t^{p-1} (1-t)^{q-1}}{B(p, q)} dt \\ &= I_{\left(\frac{r}{b}\right)}(p, q) \end{aligned}$$

where  $I_{\left(\frac{r}{b}\right)}(p, q)$  the regular beta function is the cumulative distribution function of the Beta variable with parameters  $p$  and  $q$  evaluated at  $\frac{r}{b}$ .

*Proof.* By definition:

$$F(r; a, b, p, q) = \int_0^r \frac{t^{p-1} \left(1 - \frac{t}{b}\right)^{q-1}}{b^p B(p, q)} dt$$

using the change of variable  $x = \frac{t}{b}$ , we obtain the result. □

## A.2 Goodness of fit of the fitted distribution

Figure 7 demonstrates that the parameters follow a normal distribution with mean close to the observed values. Therefore, the estimation strategy provides a good fit for the data.

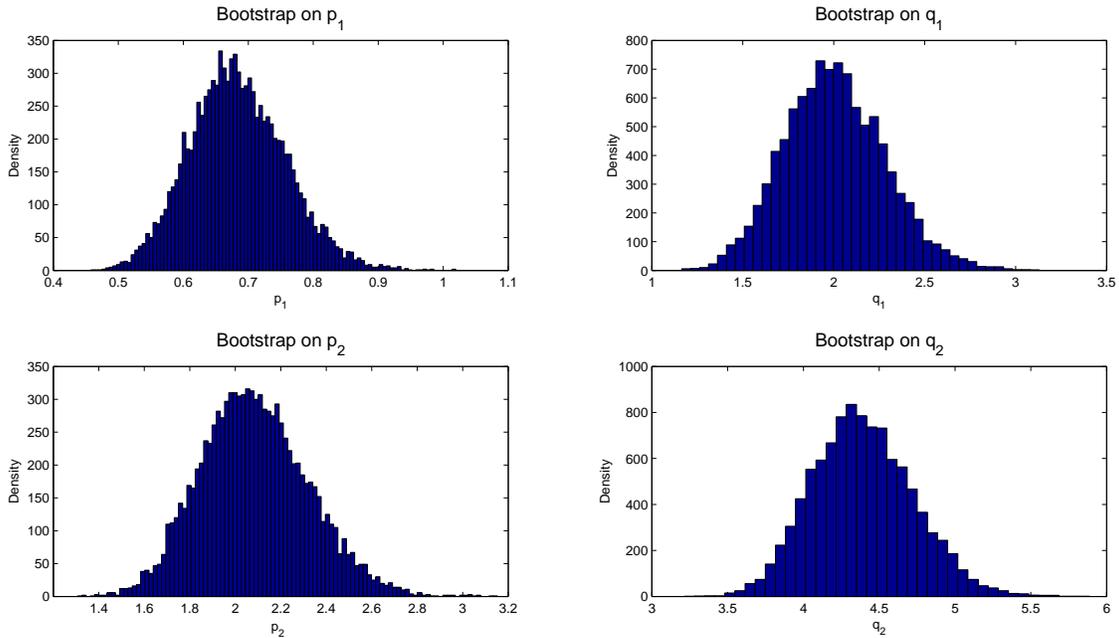


Figure 7: Histogram of bootstrap for parameter  $p$  and  $q$ .

### A.3 Individual Characteristics

In this section we explore the possible determinants of the heterogeneity in compound-risk aversion by examining whether individual characteristics such as age, education or wealth can predict the level of compound-risk aversion. We also compare these results with the determinants of the coefficients of risk aversion. Since the elicited coefficients are intervals, we run an ordered probit estimation:

$$y_{ic}^* = X_{ic}'\beta + \varepsilon_{ic}$$

where  $y_{ic}^*$  is the latent variable of interest (either compound-risk aversion or risk aversion) of individual  $i$  from cooperative  $c$ .

In Table A.3 we analyze the correlation between the individual characteristics and risk aversion. We find that educated farmers are significantly more risk averse than less educated farmers. This result is counter intuitive, but confirms the finding of Galarza (2009). Since the risk elicitation game is framed in terms of insurance decisions, farmers who are more educated and more experienced in cotton production are more likely to buy an insurance contract than their counterparts. There is also evidence that experience in cotton growing as proxied by the number of years spent in the cotton cooperative is significantly positively correlated with risk aversion.

Next, we analyze the correlation between the individual characteristics and compound-risk aversion. We perform this analysis in two different ways. First, as Table 11 shows, we classify individuals by compound-risk attitudes. Here, the compound-risk aversion variable is set at the value of 0 if the farmer is compound-risk neutral, and 1 if he is compound-risk averse. Contrary to the case of risk aversion, education is negatively correlated with compound-risk aversion. One year of education decreases the likelihood of being compound-risk averse by 0.036. In addition, the value of agricultural assets is significantly correlated with compound-risk aversion. Farmers who have spent more time in their cooperatives are also more averse to compound-risk.

In Table 12, we present another way of studying the relationship between individual characteristics and compound-risk aversion. As suggested by the theory, compound-risk aversion is defined for a given level of risk aversion. Therefore, we control for the risk aversion coefficient, and run the following ordered probit:

$$cra_{ic}^* = X_{ic}'\beta + r_{ic} + \varepsilon_{ic}$$

where  $cra_{ic}^*$  is the latent coefficient of compound-risk aversion, and  $r_{ic}$  is the coefficient of constant relative risk aversion. As shown in Table 12, education is still negatively correlated with compound-risk aversion as well as wealth measured by land owned.

	(1)
	risk_aversion
risk_aversion	
age	0.0016 (0.0046)
education	0.0262* (0.0140)
livestock_2012	-0.0000 (0.0000)
ag_value	0.0000 (0.0000)
assets_value	-0.0000 (0.0000)
house_value	0.0000 (0.0000)
land_owned	0.0017 (0.0094)
coop_years	-0.0314* (0.0179)
nbre_exp_cf	0.0037 (0.0055)
knowledge_ins	-0.2457 (0.3855)
<i>N</i>	248
adj. $R^2$	

Standard errors in parentheses

\*  $p < .1$ , \*\*  $p < .05$ , \*\*\*  $p < .01$

Table 10: Determinants of risk aversion

	(1)
	cra
cra	
age	0.0014 (0.0064)
education	-0.0354* (0.0183)
livestock_2012	0.0000 (0.0000)
ag_value	0.0000* (0.0000)
assets_value	0.0000 (0.0000)
house_value	0.0000 (0.0000)
land_owned	-0.0103 (0.0157)
coop_years	0.0365** (0.0168)
nbre_exp_cf	-0.0057 (0.0059)
knowledge_ins	0.0530 (0.3252)
<i>N</i>	251
adj. $R^2$	
Standard errors in parentheses	
* p<.1, ** p<.05, *** p<.01	

Table 11: Determinants of compound-risk aversion

	(1)
	compound_risk_aversion
compound_risk_aversion	
risk_aversion	0.0986* (0.0507)
age	0.0061 (0.0050)
education	-0.0279** (0.0141)
livestock_2012	0.0000 (0.0000)
ag_value	0.0000*** (0.0000)
assets_value	-0.0000 (0.0000)
house_value	0.0000* (0.0000)
land_owned	-0.0289*** (0.0102)
coop_years	0.0143 (0.0127)
nbre_exp_cf	-0.0074 (0.0059)
knowledge_ins	-0.2595 (0.3319)
<i>N</i>	247
adj. <i>R</i> <sup>2</sup>	

Standard errors in parentheses

\*  $p < .1$ , \*\*  $p < .05$ , \*\*\*  $p < .01$

Table 12: Determinants of compound-risk aversion