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Basis Risk and Compound-Risk Aversion: Evidence from a WTP Experiment in Mali

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

Ghada Elabed and Michael R. Carter

Preliminary and Incomplete

Abstract

We present a novel way to understand the low uptake of index insurance using the interlinked concepts of ambiguity and compound-lottery aversion. Noting that the presence of basis risk makes index insurance a compound lottery, we derive an expression of the willingness to pay (WTP) to eliminate basis risk. Empirically, we implement this WTP measure using framed field experiments with cotton farmers in Southern Mali. In this 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 impact of basis risk on the demand for an index insurance contract. 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 than it does under risk neutrality. Our results highlight the importance of designing contracts with minimal basis risk if potential buyers are compound-risk averse.

Keywords: Index Insurance, Risk and Uncertainty, Compound Risk, Ambiguity, Field Experiments

1 Introduction

Informal risk mitigation mechanisms in developing countries typically insure against idiosyncratic shocks, which affect a single individual, and the remaining uninsured risk leads to suboptimal decision-making and forgone income (Alderman and Paxson 1992; Carter et al. 2007). Covariate shocks, which affect a group of people simultaneously, remain widely uninsured in developing countries, contributing to household vulnerability (Jalan and Ravallion 2001). A growing body of research has produced compelling evidence that uninsured risk impedes economic growth; it leads to a persistence of inefficient traditional agricultural technologies (Morduch 1995) and may thereby contribute to poverty traps (Dercon and Christiaensen 2011; Carter and Lybbert 2012). Therefore, formal insurance contracts could be a crucial instrument for improving welfare in developing countries.

Index insurance is an example of an innovative financial product designed to insure poor households against such shocks. The index is chosen to be some variable that closely correlates with farmers' yields, and an individual farmer receives his indemnity if the index falls below a pre-determined strike point. Index insurance overcomes informational problems and reduces transaction costs of conventional indemnity insurance, and is therefore cheaper. This type of insurance can therefore offer coverage for poor, small-scale farmers who are typically excluded from existing formal insurance markets. However, uptake of the product remains unexpectedly low, despite a decade of efforts to promote index insurance as a tool for poverty reduction in developing countries (Gine and Yang 2007; Cole et al. 2010; Boucher and Mullally 2010; Meherette 2009).

This paper hypothesizes and tests a mechanism that can help explain the low uptake rates of index insurance. 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. For example, in the case of an area-yield insurance contract, the farmer's yield can be low when the average yield in the area is high, and the farmer's yield can be high when the average yield in the area is low. The probability of the first event is known as *false negative probability* (FNP), and the probability of the second event is known as *false positive probability* (FPP). FNP and FPP are two components of *basis risk*, the imperfect correlation between the index and the farmer's yield. 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 lottery 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 known, 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 entity as a compound lottery premium, and we use it to derive an expression of the willingness to pay *(WTP)* to eliminate basis risk. We define this WTP as the maximum amount of money that a farmer is willing to pay and be indifferent between index insurance and the corresponding conventional indemnity insurance contract. We then show how this measure varies with compound-risk aversion and risk aversion. Empirically, we implement the WTP measure using framed field experiments with cotton farmers in Southern Mali. 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.

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. If basis risk were as high as 50%, only 35% of the population would demand index insurance, as opposed 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 the next section, we review the relevant literature. We then present the theoretical framework and the derivation of the willingness to pay. In subsequent sections, we describe and present the results of the field experiment in Mali. We conclude with policy recommendations.

2 The microinsurance problem

The payout to agricultural index insurance is not based directly on damages to an individual farmer's crop, but rather the value of an external index such as the average yield, rainfall or temperature in a given region. Farmers receive a payout when the value of the index falls below a critical threshold. This section provides a basic framework for thinking about the index insurance problem from the perspective of the farmer, accounting for two main features of this type of insurance contract: First, because of basis risk, index insurance is a probabilistic insurance. Second, because of the index lottery, index insurance appears to the decision maker as a compound lottery. We then discuss the potential implications of these two features on the uptake of index insurance, based on the findings of the literature.

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 Π, resulting in an income of $(Y_0 - L - \tau_1 + \Pi)$ equal to the net income under bad yields, less the insurance premium τ_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. Expected utility theory assumes that individuals make rational choices so as to maximize a utility function.

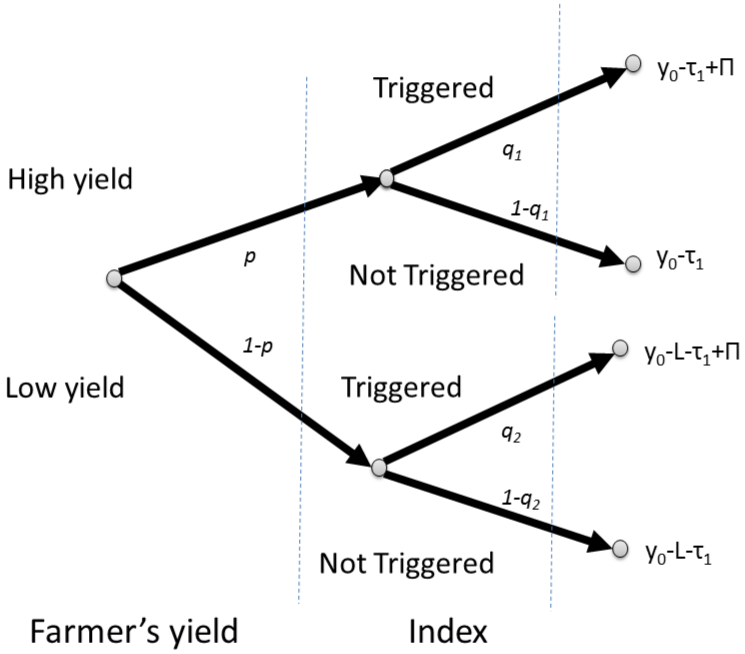

Figure 1: The micro insurance problem

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%.[1] 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.[2] 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. 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 from the predictions of expected utility theory.

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[1] USDA

The second strand of research about probabilistic insurance, which is mainly used in behavioral economics, relaxes the rationality assumption of expected utility theory. 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.[3] Segal (1988) provides another non-expected utility explanation of the aversion to probabilistic insurance using the rank dependent utility function developed by Quiggin (1982).[4] 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.[5]

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.[6] 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. (In figure 1, the final probabilities are given in parentheses). 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). Hence, decision makers are compound-risk averse.[7] 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 equivalent simple lottery can be cumbersome to process, and might create something similar to ambiguity.[8]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.

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[2] 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 $1 - p$.),

[3] Under expected utility theory, this behavior is consistent with risk seeking.

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

[5] In their survey, Wakker et al.(1997) show the 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.

[6] 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

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).[9] 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) (referred to as 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 under the index insurance contract by ρ, with pdf $f_\rho(y, X)$. Here, y is the farmer's yield, $I(X)$ is the insurance indemnity payment and τ_1 is the index insurance premium.

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[7] 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.

[8] 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.

[9] 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.

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:

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

However, as explained above, compound lotteries create something akin to ambiguity. While the individual probabilities for the index insurance are known, decision makers perceive the final probabilities as unknown. 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:

$$\mathbb{E}_{f_y}\left[v\left(\mathbb{E}_{f_{X\|y}}u\left(\rho\right)\right)\right] \tag{2}$$

where $\mathbb{E}_{f_y}$ denotes the expectation with respect to f_y. The expectation $\mathbb{E}_{f_{X\|y}}$ 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

This section applies the concept of compound lottery premium derived by Maccheroni, Marinacci and Ruffino (2010) (MMR) to the index insurance case. This premium is the analogue of the classic Arrow-Pratt approximation under the presence of compound lotteries. Then this section uses this new concept to study the willingness to pay for index insurance and the willingness to pay to eliminate basis risk.

3.1 The compound lottery premium

In the case of index insurance, the compound lottery premium P_X is defined such that the farmer is indifferent between receiving the net revenue from the index insurance contract and the certain average revenue $\rho^* = E_{f_\rho}(\rho)$. Under compound-risk aversion, this premium solves the following equation:

$$\mathbb{E}_{f_y}\left[v\left(\mathbb{E}_{f_{X|y}}u(\rho)\right)\right] = v\left(u\left(\rho^* - P_X\right)\right) \tag{3}$$

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 $\mathbb{E}_\rho u(\rho) = u\left(\rho^* - P_X^N\right)$. Using Jensen's inequality, we have:

$$P_X \geq P_X^N$$

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.

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

$$\begin{aligned}
v\left(u\left(\rho^* - P_X\right)\right) &= \mathbb{E}_{f_y}\left[v\left(\mathbb{E}_{f_{X|y}}u(\rho)\right)\right] \\
&\leq v\left(\mathbb{E}_{f_y}E_{f_{X|y}}u(\rho)\right) \\
&= v\left(E_{f_\rho}u(\rho)\right) \\
&= v\left(u\left(\rho^* - P_X^N\right)\right)
\end{aligned}$$

□

Intuitively, the compound lottery premium should be a function of the farmer's preference (level 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 showed that it is the sum of a compound-risk premium and the classical Pratt risk premium:

$$P_X \simeq -\frac{1}{2}\sigma_\rho^2\frac{u''(\rho^*)}{u'(\rho^*)} - \frac{1}{2}\sigma_{\rho^*}^2\frac{v''\left(u(\rho^*)\right)\left(u'(\rho^*)\right)}{v'\left(u(\rho^*)\right)} \tag{4}$$

where σ_ρ^2 is the variance of the final net wealth when purchasing the index insurance contract :

$$\sigma_\rho^2 = \mathbb{E}_{f_y}\left[\mathbb{E}_{f_{X|y}}\left[\rho - \rho^*\right]^2\right]$$

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. $\sigma^2_{\rho^*}$ is the variance of this net wealth measured with respect to the probability distribution of the yield:

$$\sigma^2_{\rho^*} = \mathbb{E}_{f_y}\left[\mathbb{E}_{f_{X|y}}[\rho]\right]^2 - \left[E_{f_y}\left[E_{x|y}(\rho)\right]\right]^2$$

$\sigma^2_{\rho^*}$ reflects the uncertainty on the expected net wealth of the farmer due to the compound structure of the prospect he faces. Therefore, if he faces a conventional indemnity insurance (a simple lottery) then $\sigma^2_{\rho^*} = 0$. By the law of total variance, we have the following relationship between σ^2_ρ and $\sigma^2_{\rho^*}$:

$$\begin{aligned}\sigma^2_\rho &= E_y\left(var\left[\rho \mid y\right]\right) + Var\left(E_{X|y}\left[\rho \mid y\right]\right)\\ &= E_y\left(var\left[\rho \mid y\right]\right) + \sigma^2_{\rho^*}\end{aligned}$$

The first component $E\left(var\left[\rho \mid y\right]\right)$ 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 $\sigma^2_{\rho^*}$ 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 4 note that:

1. For a compound-risk neutral individual, the compound-lottery premium reduces to the classical Pratt premium,
$$P^N_X \simeq -\frac{1}{2}\sigma^2_{\rho^*}\frac{u''(\rho^*)}{u'(\rho^*)}$$

2. For conventional indemnity insurance, the compound lottery premium also reduces to the classical Pratt premium, whether the farmer is compound-risk averse or not. This is because $\sigma^2_{\rho^*} = 0$ in the case of a conventional indemnity insurance.

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^c, and it is a function of the curvature of v, u and of $\sigma^2_{\rho^*}$.

$$P^c \simeq -\frac{1}{2}\sigma^2_{\rho^*}\frac{v''\left(u\left(\rho^*\right)\right)\left(u'\left(\rho^*\right)\right)}{v'\left(u\left(\rho^*\right)\right)} \tag{5}$$

Let's define an increase in basis risk as in increase in FNP, keeping the probability that the index triggers a payment constant. This increase in basis risk leads to an increase in σ_ρ^2 and in $\sigma_{\rho*}^2$. Proposition 1 states the impact of an increase in basis risk on the compound lottery premium.

Proposition 1. *As basis risk increases, the compound lottery premium P_X for the index insurance contract increases for a compound-risk averse participant. This increase in compound lottery premium is higher than under expected utility theory.*

The following proof is for the discrete framework presented in Figure 1. The result can be generalized to the continuous case.

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 $\overline{q}$ given by:

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

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:

$$q^{'}(h) = \begin{cases} q_1 + \frac{h(1-p)}{p} & , \ p \\ q_2 - h, & 1-p \end{cases} \tag{6}$$

Define the random variable ϵ as follows:

$$\epsilon = \begin{cases} (1-p) * (q_1 - q_2 + \frac{h}{p} \quad), & p \\ p * (q_2 - q_1 - \frac{h}{p}), & 1-p \end{cases} \tag{7}$$

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

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

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

Claim. 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 $\Pi \geq 0$. □

Claim. 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:

$$\begin{aligned}
\sigma_{\rho^*}^{2'} &= p*(\bar{\rho}_1^{'}-\rho^*)^2+(1-p)*(\bar{\rho}_2^{'}-\rho^*)^2\\
&= p*(\bar{\rho_1}+\frac{h(1-p)}{p}\pi-\rho^*)^2+(1-p)*(\bar{\rho_2}-h\pi-\rho^*)^2\\
\frac{\partial\sigma_{\rho^*}^{'2}}{\partial h} &= 2\frac{h(1-p)^2}{p}\pi+2(1-p)h\pi^2+2(1-p)(\bar{\rho_1}-\bar{\rho_2})\\
&\geq 0
\end{aligned}$$

since $\bar{\rho_1} > \bar{\rho_2}$. □

An increase in basis risk leads to an increase in both the Pratt premium and the compound-risk premium. Therefore, the impact of basis risk is exacerbated by compound-risk aversion.

3.2 Implication 1: willingness to pay for index insurance

This section investigates *the willingness of a farmer to pay for index insurance* WTP_X using his compound-risk attitudes. 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 if he does not purchase any insurance CE_{NI}.The certainty equivalent of the index insurance contract CE_X is defined by:

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

The certainty equivalent of the no insurance option is defined by:

$$CE_{NI} \equiv \rho^*_{NI} + \frac{1}{2}\sigma^2_{\rho_{NI}}\frac{u^{"}\left(\rho^*_{NI}\right)}{u^{'}\left(\rho^*_{NI}\right)}$$

where $\rho^*_{NI}{=}E_{f_\rho}\left(\rho\right)$ is the expected final net wealth the farmer gets without insurance, and $\sigma^2_{\rho_{NI}}$ is the variance of the farmer's final net wealth without insurance. Therefore, WTP$_X$ is given by:

$$WTP_X = \left(\rho^* - \rho^*_{NI}\right) + \left(\frac{1}{2}\sigma^2_\rho\frac{u^{''}\left(\rho^*\right)}{u^{'}\left(\rho^*\right)} - \frac{1}{2}\sigma^2_{\rho_{NI}}\frac{u^{"}\left(\rho^*_{NI}\right)}{u^{'}\left(\rho^*_{NI}\right)}\right) + \frac{1}{2}\sigma^2_{\rho^*}\frac{v^{''}\left(u\left(\rho^*\right)\right)\left(u^{'}\left(\rho^*\right)\right)}{v^{'}\left(u\left(\rho^*\right)\right)}$$

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:

$$WTP^N_X = \left(\rho^* - \rho^*_{NI}\right) + \left(\frac{1}{2}\sigma^2_\rho\frac{u^{''}\left(\rho^*\right)}{u^{'}\left(\rho^*\right)} - \frac{1}{2}\sigma^2_{\rho_{NI}}\frac{u^{"}\left(\rho^*_{NI}\right)}{u^{'}\left(\rho^*_{NI}\right)}\right)$$

Notice that for a given level of basis risk, $WTP_X \leq WTP^N_X$. If basis risk increases, since σ^2_ρ increases and u is concave, WTP^N_X decreases. Since an increase in basis risk leads to an increase in $\sigma^2_{\rho^*}$, the effect of basis risk on WTP_X is exacerbated under compound-risk aversion.

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 *the willingness to pay to eliminate basis risk.*

3.3 Implication 2: willingness to pay to eliminate basis risk

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_{BR} 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 δ 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_{BR} 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_{BR} 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_{II}.

The certainty equivalent of the individual insurance CE$_{II}$ contract is by definition:

$$CE_{II} \equiv \delta^* - \frac{1}{2}\sigma_{\delta}^2 \frac{u''(\delta^*)}{u'(\delta^*)}$$

where $\delta^*{=}E_{f_y}(\delta)$ is the expected final net wealth the farmer gets with the individual insurance, and σ_{δ}^2 is the variance of the farmer's final net wealth with individual insurance. Therefore, WTP_{BR} is defined by:

$$WTP_{BR} \equiv CE_{IX} - CE_{II}$$

or equivalently,

$$WTP_{BR} = (\rho^* - \delta^*) + \left(\frac{1}{2}\sigma_{\rho}^2 \frac{u''(\rho^*)}{u'(\rho^*)} - \frac{1}{2}\sigma_{\delta^*}^2 \frac{u''(\delta^*)}{u'(\delta^*)}\right) + \frac{1}{2}\sigma_{\rho^*}^2 \frac{v''(u(\rho^*))\left(u'(\rho^*)\right)}{v'(u(\rho^*))}$$

Using the same reasoning as in section 3.1, 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_{BR} 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_{BR} 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 test these hypothesis, 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 to eliminate basis risk as defined in Section 3, 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 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 331 members of 34 cotton cooperatives 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 animators 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 them 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 animator, two rural animators assisted the players with the various materials.

4.2 The Games

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 currency.

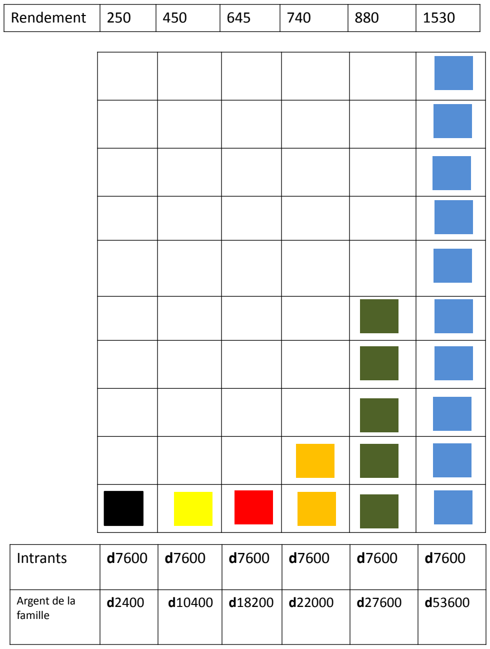
Yield range (kg/ha)	Mid point	Probability	Revenue (in d)
<300	250	5%	2400
300-600	450	5%	10400
600-690	645	5%	18200
690-790	745	10%	22000
790-780	880	25%	27600
>980	1530	50%	53600

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 2 shows the visual aid provided to farmers to help them understand the game better. Equation 8 computes the individual farmer's per hectare profits in d without any insurance contract:

$$profit_i = p * y_i - Inputs \tag{8}$$

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.



Rendement	250	450	645	740	880	1530
Intrants	d7600	d7600	d7600	d7600	d7600	d7600
Argent de la famille	d2400	d10400	d18200	d22000	d27600	d53600

Figure 2: 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:

$$payment(y_i) = \begin{cases} p*(T-y_i), & y_i \leq T \\ 0 & y_i > T \end{cases} \tag{9}$$

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:

$$payment(y_i) = \begin{cases} p * (T - y_i) : & y_i \leq T \text{ and } y_z \leq T_z \\ 0 & \text{otherwise} \end{cases} \tag{10}$$

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. Based on historical data from the area, this probability is set at 20%. 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).

4.2.4 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, 790 kg/ha, 690 kg/ha, 600 kg/ha, and 300 kg/ha, respectively.

The net revenue of farmer i if he purchases contract j is given by the following formula:

$$profit_{ij} = p * y_i + Indemnity_j - premium_j \tag{11}$$

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.

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.

	Contract #	Trigger (% ybar)	Premium (d)	Net Profit (d) (d)						CRRA range
Yield (kg/ha)				250	450	645	740	880	1530	
Proba.				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

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.

4.2.5 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
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 3: Game 2: Eliciting WTP measure.

The last column of Table 3 presents the CRRA ranges implied by the measured WTP if the player behaves according to the predictions of expected utility theory, i.e if he reduces the index insurance compound lottery to a simple lottery. For example, if a player's i WTP 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 then the expected utility he derives from the individual contract priced at d2540: $EU(\pi + 600) \leq EU(\rho) \leqslant EU(\pi + 800)$. However, if a participant is compound-risk averse, then the elicited CRRAs do not correspond to the true CRRA of the player.

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:

$$v\left(y\right) = \begin{cases} \frac{g^{1-y}}{1-g} & \text{if } g \in [0,1) \\ \log\left(y\right) & \text{if } g = 1 \end{cases} \tag{12}$$

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

Table 4 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 defintion of WTP.

	Contract choice in Game 1:					
WTP (d)	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 4: Predictions of the Coefficients of Compound-Risk Aversion.

5 Descriptive analysis of the experimental results

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 is a male crop. 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	Definition	mean	sd/percent
Participant Characteristics	head	1 if the participant is head of household	0.7	
	age	Participant's agent	47.07	13.21
	gender	1 if participant is male	1	
	education	Participant's years of schooling	4.55	6.57
	knowledge_ins	1 if participant heard about cotton insurance before	0.92	
Head Characteristics	age_hh	Head of the household's age	55.55	15.22
	gender_hh	1 if head of the household is male	1	
	coop_years	Number of years of household's head membership in the cotton cooperative	8.62	6.28
Household Characteristics	hh_size	Size of the household	18.82	11.88
	livestock_2012	Value of livestock in CFA	1,822,602	5,634,664
	ag_value	Value of agricultural equipment in CFA	171,299	247,236
	assets_value	Value of household's assets in CFA	204,200	164,468
	house_value	Value of the house in CFA	396,952	1,042,061
	land_owned	Total area of land owned in ha	9.62	7.81

Table 5: Descriptive Statistics of the Participants

5.2 Description of the results of Game 1

The last column of Table 6 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 CRRA level of more than 0.55.

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 6: Distribution of the CRRAs in the sample

6 Empirical analysis of the experimental results

6.1 On average, the participating farmers do not behave according to EUT

As we have seen in Section 3, a compound-risk averse farmer is willing to pay more money to switch from the index insurance contract to the individual insurance contract, compared to his compound-risk neutral counterpart who has the same level of risk aversion. Therefore, in order to empirically test the hypothesis that farmers are on average compound-risk neutral (i.e. expected utility maximizers), one should compare the distribution of the CRRA coefficients elicited from Game 1 (column of Table 2) to those elicited from Game 2 (last column of Table 4.2.5). Games 1 and 2 do not elicit the actual CRRAs coefficients, but provide CRRA classes that are not directly comparable. Therefore, before performing the hypothesis test, we begin by fitting a continuous probability distribution to the CRRAs 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.

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

		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.

1.7. The appendix explains the methodology used to estimate these parameters

Table 7 presents the results of the estimation method:

Game	Game 1	Game 2
First parameter	0.68	2.07
Second parameter	1.99	4.36

Table 7: Estimated parameters of the distribution

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.

From Figure 6.1, it is clear that the parameters follow a normal distribution whose mean is close to the observed values. Therefore, the estimation strategy provides a good fit for the data.

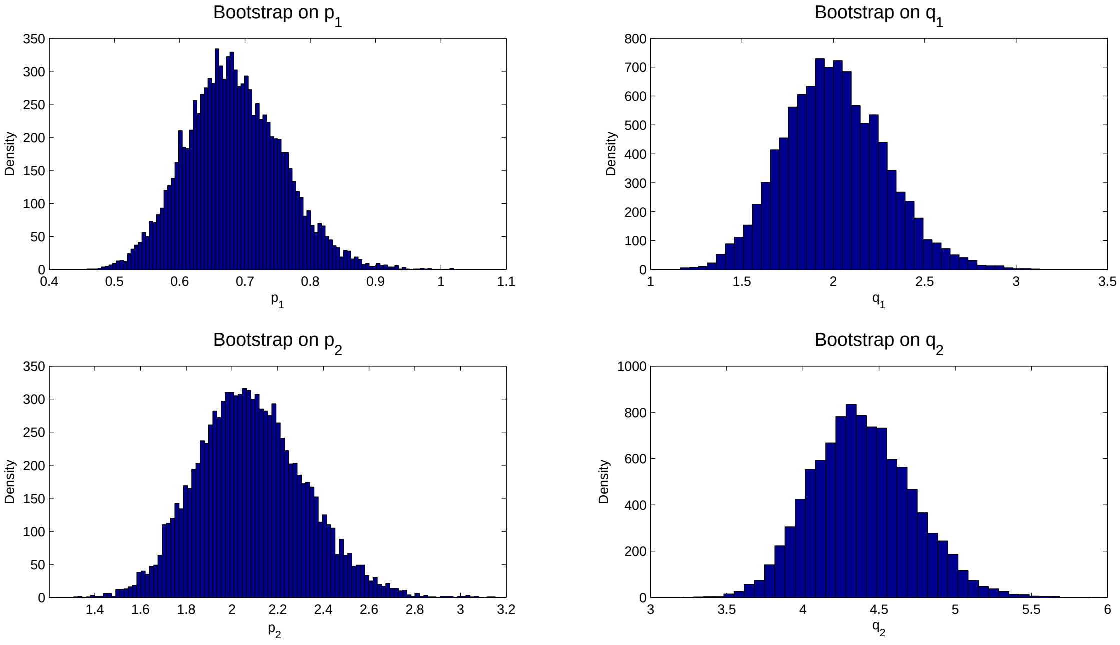


Figure 3: Histogram of bootstrap for parameter p and q.

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 parameters of the two distributions are the same at the 5% level. Therefore, on average, farmers are not compound-risk neutral.

6.2 Participants are compound-risk averse to varying degrees

Overall, only 40.18% of the participants were indifferent between the index insurance contract and the individual insurance contract. This supports the hypothesis that basis risk reduces the demand for index insurance. The remaining 60.82% participants have an average WTP of 395d, which represents 22% of the price of the individual insurance contract.

We presented the coefficient of compound-risk aversion for each demonstrated category of WTP in Table 4. Using the Table 4 coefficients of compound-risk aversion, we derive the number of participants who are compound-risk averse and disaggregate 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.

	CRRA 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
% of CRRA range	*100*	*37.5*	*75.0*	*74.2*	*66.1*	*14.6*	
% of total participants	*22.39*	*2.76*	*7.36*	*7.98*	*11.96*	*4.60*	***57.07***

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

6.3 Simulating the impact of basis risk under compound-risk aversion

Drawing on the findings of the experiments described above, this section simulates the impact of basis risk on the demand of index insurance 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.

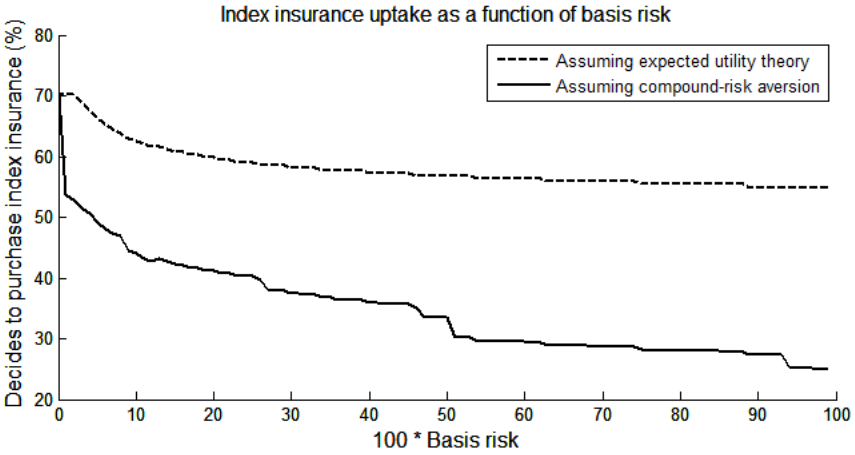


Figure 4: Impact of basis risk.

The dotted curve of Figure 4 illustrates the impact of basis risk on the demand for index insurance 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.

Here, basis risk is the probability of getting a payment in the case the farmer experiences a loss. As the basis risk 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 basis risk increases. As can be seen in Figure 4 , increasing basis risk in an index insurance contract will discourage demand because it fails to sufficiently reduce the risk of collateral loss. For a contract with zero basis risk, 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 basis risk 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 basis risk (90%). Despite this decrease in demand, the demand for the partial insurance provided by this index insurance contract remains relatively robust even as basis risk increases (assuming that individuals maximize expected utility).

Basis risk matters even more when people are compound-risk averse. The solid line in Figure 4 shows , using the distribution of compound-risk aversion in the population of the farmers, the impact of basis risk on demand for index insurance, using the distribution of compound-risk aversion in the population of the farmers. 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 basis risk increases under compound-risk aversion. Were basis risk 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 basis risk is important, not only to enhance the value and productivity impacts of index insurance, but also to assure that the contracts are demanded.

7 Conclusion

In the absence of traditional insurance markets, poor households in developing countries rely on costly risk-managing mechanisms. Although index insurance provides a good alternative to these households in theory, demand has been surprisingly low. In this paper, we presented a novel way to understand these low uptake rates, using the interlinked concepts of *ambiguity* and *compound lottery aversion.*

In a framed field experiments conducted with cotton farmers in Bougouni, Mali we elicited the coefficients of risk-aversion and the WTP measure, and we derived the compound-risk aversion coefficients of the farmers. Individuals generally did not behave in accordance with expected utility theory. Instead we observed 57% of game participants revealed themselves to be compound-risk averse to varying degrees. In fact, the willingness to pay 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 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. This 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: 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:

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

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

By construction, our data is paritioned 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 $F\left(r;b,p,q\right)$.

We now derive the log-likelihood function. Let j denote the risk aversion interval $\left[r_{j,},\, r_{j1}\right]$. Player i's true risk aversion coefficient r has a probability $p_i=F\left(r_{j+1};a,b,p,q\right)-F\left(r_j;a,b,p,q\right)$ of being in interval j. Denoting m_j the number of observations in interval j, the likelihood function L_N is the joint probability function:

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

Maximizing $\mathrm{L}_\mathrm{N}$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 $[r_{j,}, r_{j1}]$. 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:

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

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:

$$F(r;a,b,pq) = \int\limits_0^r \frac{t^{p-1}\left(1-\frac{r}{b}\right)^{q-1}}{b^p B(p,q)} dt$$

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