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Managing basis risk with multiscale index insurance

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Abstract

Agricultural index insurance indemnifies a farmer against losses based on an index that is correlated with, but not identical to, her or his individual outcomes. In practice, the level of correlation may be modest, exposing insured farmers to residual, basis risk. In this article, we study the impact of basis risk on the demand for index insurance under risk and compound risk aversion. We simulate the impact of basis risk on the demand for index insurance by Malian cotton farmers using data from field experiments that reveal the distributions of risk and compound risk aversion. The analysis shows that compound risk aversion depresses demand for a conventional index insurance contract some 13 percentage points below what would be predicted based on risk aversion alone. We then analyze an innovative multiscale index insurance contract that reduces basis risk relative to conventional, single-scale index insurance contract. Simulations indicate that demand for this multiscale contract would be some 40% higher than the demand for an equivalently priced conventional contract in the population of Malian cotton farmers. Finally, we report and discuss the actual uptake of a multiscale contract introduced in Mali.

JEL classifications: D81, O12, O16, Q12, Q13

Keywords: Index insurance; Microinsurance; Crop insurance; Risk and uncertainty

1. Introduction

Yield fluctuations inherent to rain-fed agriculture may discourage investment in profitable, but risky crops, even when farmers have ample access to agricultural loans. As will be discussed later, small-scale cotton farmers in Mali exhibit precisely this form of behavior, keeping them poorer than they otherwise need be.[1] In principal, risk management instruments that reduce income fluctuations and decrease default risk would also increase investment and thus raise farmer's expected income.[2]

Agricultural index insurance has been put forward as an instrument to achieve these goals, especially for small-scale agriculture where transactions cost, moral hazard, and adverse selection problems rule out the use of insurance that payouts based on individual outcomes (Carter, 2012). However, a weakness of index insurance is that the average yield, weather, or other indexes on which it is based are imperfect predictors of individual farmer's losses. Under index insurance, insured farmers are thus exposed to a residual or basis risk that creates a probability that the farmer will not be indemnified even when losses occur.[3] The magnitude of this "false negative" probability depends on the type insurance index used (e.g., a weather index versus an area yield index), and on the geographic scale covered by the index. Intuitively if this false negative probability (FNP) is large, then the value of the index insurance for the farmer would be low and she may choose not to buy it, eliminating the possibility that index insurance can resolve the problems of risk rationing and underinvestment in profitable agricultural opportunities.

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#Work completed when Bellemare was at the Sanford School, Duke University.

[1] Boucher et al. (2008) call this outcome risk rationing. Risk rationing occurs when lenders, constrained by asymmetric information, shift so much contractual risk to the borrower that the borrower voluntarily withdraws from the credit market even when she has the collateral wealth needed to qualify for a loan contract.

[2] In a recent paper, Karlan et al. (2012) find that farmers invest more in their farms and take riskier production choices when offered rainfall index insurance.

[3] In practice, individual agricultural insurance also has this characteristic as the insurance company may deny claims. In a recent study of a small farmer insurance program in Ecuador, Castillo et al. (2012) show that the level of this residual risk under individual insurance is only modestly smaller than the basis risk that these farmers would face under index insurance.

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This article explores this intuition by analyzing the impact of basis risk on the demand for two types of index insurance contracts under two alternative models of decision making under risk. Both types of contracts were designed to reduce basis risk for Malian cotton growers and are based on average yield indexes. The first contract is a conventional single-trigger contract, where the payment of indemnity is triggered by the level of average yield in the district that surrounds and includes the insured village of cotton farmers. The second one is an innovative two-scale contract. Under this contract structure, the first trigger (set at the district level) controls the moral hazard problem. It tells villagers that a low yield in their village will only trigger payment if district yields are sufficiently low to make it likely that low village yields reflect misfortune and not opportunistic behavior. The lower geographic scale trigger at the village is then meant to offer protection to farmers at the yield level for which they actually need insurance protection.

In order to compare the quality of these contracts and the demand they may generate, we conduct an *ex ante* demand analysis using two frameworks. First we explore the impact of basis risk on the demand for marked-up (actuarially unfair) index insurance under standard expected utility theory. Second, we explore the impact of compound risk or ambiguity aversion on insurance demand. In both cases, in order to gauge the importance of these aversions on the potential demand for index insurance in Mali, we utilize data from field experiments that reveal the distributions of risk and compound risk aversion among the Malian cotton farming population.

Our analysis of demand under compound risk aversion is motivated by the observation that index insurance appears to the individual as a compound lottery. A growing literature suggests that many individuals cannot reduce a compound lottery to the equivalent simple lottery. In this case, the payoff prospects under index insurance are effectively ambiguous to the individual, and we might expect her to exhibit the same sort of ambiguity aversion explored by Ellsberg (1961) in his classic experiments.

Our analysis shows that basis risk significantly discourages demand for a conventional single-scale index insurance contract. Ambiguity or compound risk aversion further decreases the demand for index insurance at every level of basis risk. The analysis also shows that the two-scale contract performs considerably better than the single-scale contract. First, it sharply reduces the incidence of false negatives, or situations wherein a group whose yield is below the local threshold fails to get a payoff. Second, the two-scale contract completely eliminates false positives, or situations when a group whose yield is above the zone-specific threshold receives a payout. All things considered, multiscale contracts would be expected to generate a higher demand from the farmers relative to single-strike contracts under the two types of decision-making processes.

The remainder of the article is structured as follows. We start by providing empirical evidence on the importance of risk rationing and suboptimal investment among cotton growers in Mali. In Section 3, we discuss the concept of basis risk and propose concrete measures of the quality of an index-insurance contract. In Section 4, we then analyze the demand for conventional single-scale contracts under risk and compound risk aversion. In Section 5, we turn to the double-scale contract and demonstrate its greater ability to decrease basis risk and stimulate demand. In Section 6, we describe an index insurance pilot project launched in 2010 in Mali and report actual the demand for the double-scare contract. Section 7 concludes.

2. Risk rationing and cotton production in Mali

In Southern Mali, most farmers grow a mix of subsistence crops and cotton. Cotton is their main (and often only) source of cash. Cotton is a profitable, but risky crop. Due to erratic rains and pests, cotton yields can fluctuate substantially from year to year. Low yields translate in low farm revenue and often financial difficulties, as farmers rely heavily on credit to finance their cotton production. In a sample of 505 farming households surveyed in 2006 and 2007, all cotton growers had received an input loan from the parastatal.[4] This is hardly surprising, as the input package represents a large investment compared to the net revenue obtained from the activity, and so few cotton growers would be able to undertake that investment without a loan from the parastatal.[5]

Loans are part of an exclusive contract between farmers and the parastatal cotton company, the Compagnie Malienne des Textiles (CMDT), which has a monopsony on cotton in Mali.[6] The CMDT organizes loans, the distribution of inputs, and the purchase of the crop. A state bank provides loans to groups of cotton growers with a joint liability clause. The bank has an agreement with CMDT stating that a group's cotton revenue is directly transferred to the group's account. As a result, the joint liability clause is enforced and a group's revenue is first used to pay back its loan. If a group defaults, it faces exclusion from future loan.

While groups do not present collateral to the lender, they do internally collateralize loans, allowing compensation of good or lucky producers who effectively pay the debts of poor or unlucky producers. A window into the operation of this internal collateralization of loans is provided by the 2006 survey of Malian cotton farmers. That survey was conducted on the heels of a bad cotton season, and it shows that even if a group's cotton revenue is greater than its debt, individual farmers face adverse consequences when their production does not cover their individual loan.

Of the 240 farmers who grew cotton that year, 79 declared having difficulties with their loan repayment. More than a third

[4] The data were collected by the University of Namur's Centre de Recherche en Économie du Développement with funding from the Agence Française de Developpement. Of the 505 households, 301 were surveyed in 2006, and 204 were surveyed in 2007.

[5] In our sample, for example, the average cotton revenue was 138,000 FCFA/ha while farmers bought an input package amounting to approximately 70,000 FCFA/ha, or 51% of the average cotton revenue.

[6] The CMDT sets the cotton price at the beginning of the growing season. Therefore, farmers do not face risk from price movement.

Table 1
Credit rationing among cotton farmers in Mali

Loan access status	% Of all non borrowers
No access (Quantity rationing)	58%
Positive access	42%
Risk rationing	12%
No project	11%
Other*	19%

*This category includes all responses that could not be unambiguously classified into the previous two categories.

(38%) had to sell farm assets (most often an animal) to pay back their loan, three had sent one of their children to work in another farm in exchange for debt relief, and two pledged part of their farm land. Other farmers obtained refinancing of their loan through their group (the agreement was that they would compensate the group the following year). Farmers also see their credit line reduced when they have debt with the group and some face exclusion from the group.[7] These figures suggest that when the joint-liability clause is binding and a group member's debt is paid by other members' cotton production, the defaulter's debt is not forgiven: group members may enforce immediate repayment. In addition, farmers repeatedly mentioned the "tensions" that the joint liability created within villages. As an example, the survey recorded cases of children being mocked because their father could not honor his debt.

This collateral risk of loans appears to discourage many farmers from growing cotton altogether, leading to risk rationing in the credit market (Boucher et al., 2008). Risk rationing occurs when lenders, constrained by asymmetric information, shift so much contractual risk to the borrower that the borrower voluntarily withdraws from the credit market even when she has the collateral wealth needed to qualify for a loan contract. The 2006 survey yields an estimate of the extensive margin of risk rationing. Specifically, the questionnaire included a nonborrower module designed to elicit the reasons why they had no loans. Table 1 reports these reasons and indicates that, of all farmers who were not planting cotton (and thus not borrowing), 42% believed they could obtain a loan to grow cotton if they so wished.[8] Of the farmers who did not borrow, 12% (i.e., 28% of the farmers who has access to credit but chose not to borrow) declared that they were discouraged by the collateral risk of the loan. (The other leading explanation was that they did not have a profitable investment to make that required a loan.)

These figures give a lower bound estimate of risk-rationing, as they ignore the intensive margin: exposure to collateral risk also implies efficiency losses for borrowers who chose suboptimal loan sizes, and thus reduce cultivated areas under cotton. The survey does not allow quantifying this effect, but in-depth qualitative interviews conducted with a restricted number of farmers showed that some of them recently reduced their planted area as a result of being exposed to substantial collateral risk.

While the presence of joint liability enables lenders to overcome problems of information and to offer loans to individuals who have no formal collateral (Ghatak and Guinnane, 1999; Stiglitz, 1990) it effectively shifts risk on group members. Farmers not only dread the consequences of defaulting on their loan but also the bad outcomes of other group members. This specific feature of group loans may discourage *ex ante* investments, leading to a special type of risk rationing. In addition it opens the door to "strategic default." When a farmer expects his cotton production to pay other farmers' debt, he has little incentives to work hard. This type of behavior is all the more likely as the number of potential defaulters increases. In other words, joint liability makes the credit system very sensitive to covariate shocks (Kurosaki and Khan, 2012).

We found evidence of both problems in Southern Mali. First, semiopen interviews with 12 farmers who had high historical cotton yields revealed that the majority of farmers had significantly reduced their area cultivated under cotton over the last five years,[9] and those farmers all reported that joint liability was in part responsible for this trend. They claimed to be "tired" of seeing their production used to pay back other villagers' loan for several years in a row. One farmer even stopped planting cotton for four years.[10] Second, there is anecdotal evidence of strategic default, even if it is largely contained by the parastatal monopsony. Three of the twelve farmers admitted to having sold part of their production to producers from neighboring villages to avoid paying the debt of other members of their group, keeping just enough cotton to pay back their own loan.

In this context, index insurance contracts are expected to raise farmer welfare through three mechanisms. First, it would reduce farmers' year-to-year income variability and the associated (expected) utility cost. Second, by reducing the extent of risk rationing, insurance would encourage farmers to invest more in their most profitable activity, thereby raising their expected revenue. Finally, it would improve the sustainability of joint liability loan contracts by reducing the probability of group default and the probability that the debt of several group members is paid back by other members. However, and foreshadowing our subsequent analysis, index insurance can only increase welfare through these three channels if basis risk is low enough and the insurance contract solves the problems of collateral loss and strategic defaults.

[7] In the credit module applied to nonborrowers, we asked farmers with no access to loan, the reason of their exclusion. The first reason mentioned is that they have a bad credit history with their group.

[8] The remaining 58% believed they could not obtain a loan and the two main explanations were that their fields were not well suited for cotton production and that they had pending debt with their cooperative.

[9] These interviews were conducted in the summer of 2012 in the area of the original survey. Their content and analysis is reported in Schaus (2012).

[10] That farmer also said that he had decided to plant cotton again after other group members had agreed that he would get his entire cotton revenue even if some members were to default.

3. Sources of basis risk under index insurance

Agricultural index insurance does not insure a household directly against shortfalls in its own income or yields,[11] but instead insures it against an index that is correlated with its losses and thus predicts them. An index insurance contract can be represented as a schedule that maps the index of predicted losses into indemnity payments to the household. To avoid problems of moral hazard and adverse selection, the insured should not be able to influence the index, and the realization of the index should not depend on which individuals choose to purchase the insurance. At the same time, to fulfill its insurance function, the index needs to be well correlated with, and reliably predict, losses. If it does not, then there is little reason to expect that insurance will resolve the risk rationing and agricultural underperformance challenges described in Section 2. This section elaborates the forces and design features that determine the predictive reliability of index insurance contracts.

As a first step toward thinking about the factors that determine the predictive reliability of an index insurance contract, define the zone z as the geographic space that is covered by a single insurance index (z could be a valley, a municipality, or the area within, say, a 25-km radius of a meteorological station). Let y_{hzt} denote the realized agricultural yield of household h in zone z in year t, and let denote the average yields in year t across the households in the zone. Yields for household h can be written as:

$$y_{hzt} = \bar{y}_{zt} + \varepsilon_{hzt}, \tag{1}$$

where ε_{hzt} is an idiosyncratic shock to the cotton yield of household h, and where its expectation is equal to the difference in long-term yields between the household (μ_{hz}) and the zone (μ_z), that is, $E(\varepsilon_{hzt}) = (\mu_{hz} - \mu_z)$. To keep notation simple, we assume that this difference is zero, although nothing of substance would change were we to assume otherwise.

Consider now the case of an area yield index insurance contract in which $\bar{y}_{zt}$ is measured directly without error and serves as the insurance index. In this case, the normalized variance of the idiosyncratic component, $\tilde{V}(\varepsilon_{hzt}) = V(\varepsilon_{hzt})/V(y_{hzt})$, is an inverse measure of the quality of the insurance index. The magnitude of this term will in part reflect agro-ecological conditions. For example, $\tilde{V}(\varepsilon_{hzt})$ will be high in places with extreme localized variation in rainfall, like Mali. In addition, the magnitude of this idiosyncratic variation will also depend on the geographic scale of the insurance zone considered. As the geographic scale of the index shrinks from province, to village, to household, $\tilde{V}(\varepsilon_{hzt}) \to 0$.[12]

Figure 1 illustrates this basic idea. The total width of the diagram ($A + B + C$) represents the total yield variation faced by the farmer. The double vertical line marks the division of risk between idiosyncratic and correlated components. As the geographic scale of the insurance index shrinks, this line will shift leftwards, reflecting reduced idiosyncratic variation around the area yield insurance index.

While the geographic scale of the index is critical for the quality of the insurance, so is the type of the index itself. Rather than an area yield index, suppose that $\bar{y}_{zt}$ is not measured directly, but is instead predicted with an index signal θ_{zt}, such that

$$\bar{y}_{zt} = f(\theta_{zt}) + \upsilon_{zt}, \tag{2}$$

where υ_{zt} is an average yield prediction error.[13] For example, θ_{zt} could be a vector of weather variables. While weather information is related to average yields in the geographic domain of the weather station, it is unlikely to perfectly predict those yields. Note that this prediction error is not idiosyncratic variation, but is in fact a portion of the potentially insurable correlated risk.

Figure 1 illustrates this further decomposition of total variation under a weather or other predicted yield index. The width of the area B now reflects the relative magnitude of this prediction error. We refer to this element of variation as the contract design risk. Overall, the fraction of yield variation faced by the household that is not covered by the contract is simply the sum of the idiosyncratic plus the design risk. This basis risk measure is one possible (inverse) measure of the quality of an index insurance contract. A related, but distinct measure of contract quality is what we term the FNP. FNP is simply the probability that a household does not receive an insurance payout when its yields fall below the level at which it desires insurance coverage to begin. Denoting this level at which the household desires insurance protection as S_h, and letting S_z denote the contractual strike point at which the index insurance begins to pay off, we can express this term as:

$$FNP = \text{Prob}(f(\theta_{zt}) > S_z | y_{hzt} < S_h). \tag{3}$$

The magnitude of basis risk and the FNP are important for a number of reasons. Chief among those reasons is that increases in these measures make it less likely that index insurance will suffice to eliminate risk rationing and induce low-wealth farmers to take on additional production risk. In addition, as the next section will discuss, the magnitude of basis risk and the FNP directly impinges on the demand for insurance from a variety of behavioral perspectives.

[11] Trying to insure all sources of variation in agricultural outcomes for small farmers is beset by a host of problems rooted in the costs of obtaining information on small farm outcomes that renders such insurance infeasible (see Hazell, 1992).

[12] While a more localized contract might thus seem unambiguously desirable, a too localized scale (e.g., an area contract based on village level yields rather than district level area yields) makes it likely that moral hazard problems will increase as such a small number of farmer might collude to generate the poor yields that would generate an insurance payout.

[13] The type of index and the scale of the index are of course not independent. The scale of a weather index is dictated by the density of weather stations, whereas, say, satellite signals offer more options for more localized scales (Carter, 2012).

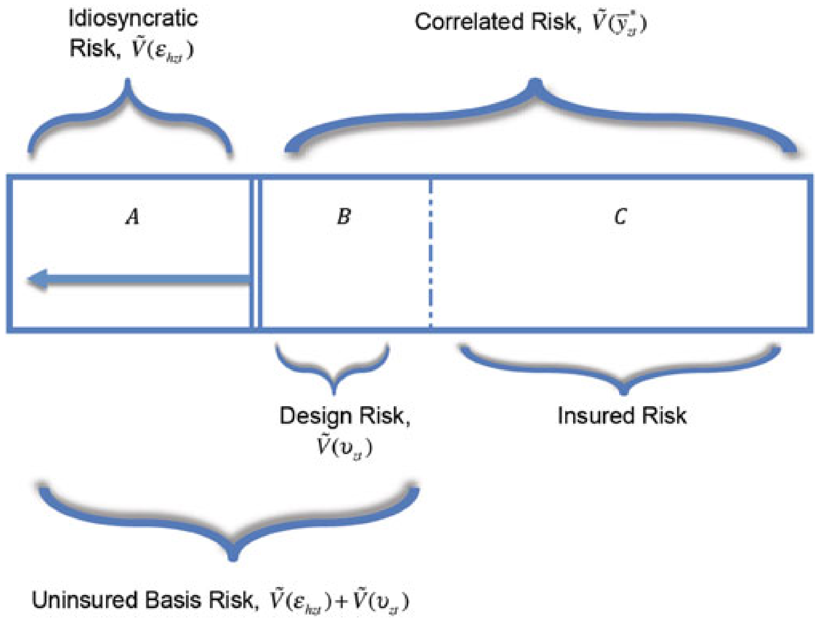

Fig. 1. Insured and uninsured risks under index insurance.

4. Conventional single-scale index contracts and the demand for insurance under risk and compound risk aversion

We now explore the impact of basis risk on the demand for a conventional index insurance contract under alternative models of decision making. We begin by examining the tradeoffs between basis risk and moral hazard under this type of contract. We then look into the demand for an actuarially unfair insurance under expected utility maximization.

In order to carry the demand analysis, we use the findings of framed field experiments that we implemented in Mali with 331 cotton farmers. These experiments elicited coefficients of risk aversion, and coefficients of compound risk aversion, which we define later in this section. Using the elicited coefficients of risk aversion, we first simulate the impact of the probability of false negative (FNP) on the demand for single-scale index insurance under expected utility theory. Next, we note that index insurance appears to the individual as a compound lottery, which creates something akin to ambiguity. We then explore the impact of that ambiguity, or compound risk aversion, on the demand for index insurance. Pursuing this further, we simulate the impact of FNP on the demand for single-scale index insurance under ambiguity or compound risk aversion, using the elicited coefficients of compound risk aversion.

4.1. Tradeoffs between basis risk and moral hazard under single-scale contracts

As we discussed in Section 2, the cotton sector in Mali is a monopsony. The parastatal CMDT purchases the entire cotton crop at a price that is fixed at the beginning of the season, and weighs and records the production of each individual producer, as well as the aggregate production of the village cooperative to which the individual belongs. Proceeds are placed in an account owned by the cooperative and must be used to retire the cooperative's joint production loan before any withdrawals can take place. Given this group credit arrangement, we focus here on the village cooperative as the insured party, ignoring yield variation between individuals within a cooperative (and the additional basis risk it creates) for the sake of simplicity. Whatever the demerits of Mali's monopsonistic cotton system, it does offer the option of designing reliable area yield index insurance contracts that require no additional (costly) data collection.[14]

Conventional index insurance contracts have one trigger: an event occurring at a higher scale activates insurance payments. For this reason, contracts of this type are called single-scale contracts. A single-scale area yield contract for a cooperative c in insurance zone z can be written as:

$$p_{czt} = \begin{cases} \pi(S_z - \bar{y}_{zt}) & \text{if } \bar{y}_{zt} < S_z \\ 0, \text{ otherwise} \end{cases},$$

where p_{czt} is the insurance indemnity to the cooperative in year t, $\bar{y}_{zt}$ are average yields in the insurance zone, S_z is the strike point for the insurance contract, and the payoff function, $\pi(S_z - \bar{y}_{zt})$, determines the indemnity paid. The payoff function can take a variety of forms, with a simple linear form being the most common. Discussion of the optimal form of this payoff function is beyond the scope of this article, and we will here focus on the contract that was offered in Mali, which relied on a fixed, lump sum payoff structure (i.e., $\pi[S_z - \bar{y}_{zt}] = L$ if $\bar{y}_{zt} < S_z$, where L is the per-hectare cotton loan liability).

[14] In addition to measuring production, CMDT also measures the area planted under cotton.

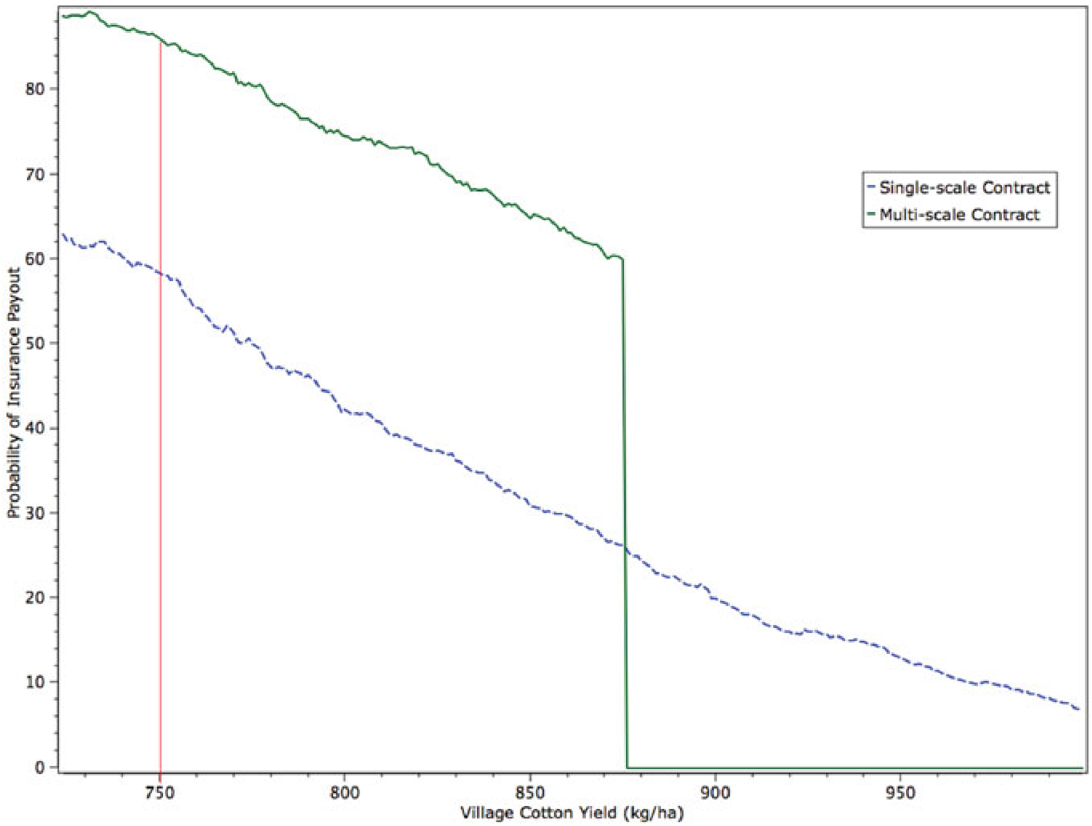

Fig. 2. Single versus multiscale index insurance contracts.

The scale of the insurance zone is a key determinant of basis risk under an index insurance contract. During the design phase for the Mali contract, this issue came to the fore when the research team presented leaders of cotton cooperatives a draft insurance contract at which yields would be based at the level of the *zone de production agricole* (or ZPA). A ZPA is a grouping of approximately 10 geographically proximate village cotton cooperatives. While there is no precise geographic definition, cooperatives within a ZPA are typically within 10 km of each other.

The leaders objected that yields in their individual villages could be quite poor (well below S_z) even when average ZPA yields were near normal. In brief, the cooperative leaders recognized that the high spatial variability in Sahelian rainfall patterns would result in large basis risk and FNP under a contract scaled at the ZPA level. To solve this basis risk problem, the leaders proposed reducing the scale of the index to the village cooperative level, such that $\bar{y}_{zt}$ would be replaced by yields measured at the village cooperative level, $\bar{y}_{czt}$. The research team noted that it was quite unlikely that an insurance company would offer a contract at that scale, given that the small size of village cooperatives (20 to 30 individuals with a variety of family and social interconnections) suggested severe moral hazard problems.

The solid line in Fig. 2 estimates the severity of the basis risk problem that would be confronted by village cooperatives under the higher scale, ZPA-level area yield insurance contract (the Appendix reports the estimation procedure, which was based on cooperative and ZPA level data from 2000 to 2010). For this contract, the strike point is defined as $S_z = 900$ kg/ha, or at about 80% of average yields in the village. This strike point gives a 10% payoff probability, meaning that on average the contract would pay off once ever 10 years.

The horizontal axis measures village cooperative yields, whereas the vertical axis measures the probability that the cooperative will receive an insurance payment given its realized yields (i.e., the vertical axis measures Prob $[\bar{y}_{zt} < S_z | y_{czt}]$). Benchmarking the performance of this standard contract against a village yield level of 875 kg/ha, we see that under the ZPA-level contract, cooperatives only have about a 30% probability of receiving an indemnity payment when their yields first fall below this critical level. That is, the contract gives a false negative signal 70% of the time when yields are just at this level. Overall, this contract will pay off 50% of the time when village yields are below 875 kg/ha[15] (i.e., $FNP\,[S_c = 875] = 50\%$).

An alternative way to benchmark this contract is to compare it to a critical yield level of 750 kg/ha, the level at which village cooperative leaders reported that repayment problems become

[15] Village cooperative leaders reported that repayment problems become severe when village yields fall below 750 kg/ha. At this level, the standard contract has a marginal false negative rate of 45%, and overall pays off 74% of the time when villlage yields are below 750.

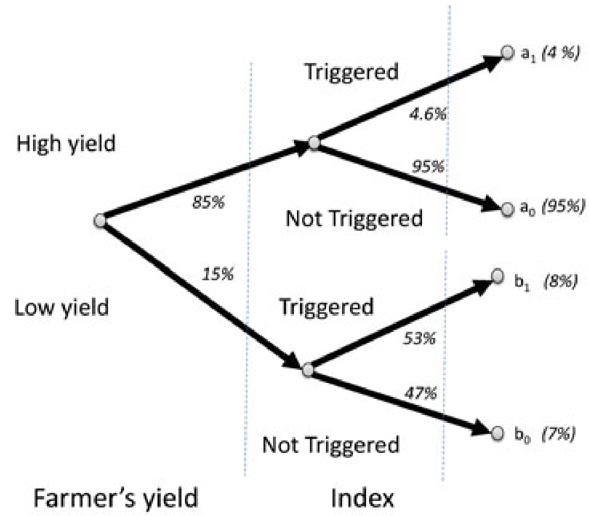

Fig. 3. Payoff structure under single-scale contract.

unmanageably severe. This level is marked by the dotted vertical line in Fig. 2. As can be seen, at this level, the standard contract has a marginal false negative rate of 45%, and has an FNP of 26%. While basis risk of this magnitude appears quite high, it is important to note that it is much less than that which would hold under rainfall contracts, which would have both estimation error and likely be at an even higher geographic scale given the paucity of terrestrial rainfall stations.

Under the standard contract, the flip side of a false negative signal is a false positive signal. As can be seen in Fig. 2, the ZPA contract has a nontrivial probability of paying off when village yields are above 875 kg/ha (because their ZPA neighbors have been less lucky than they have been). Such payoffs are of course not free, and 33% of the actuarially fair premium for this contract is driven by payoffs when villages do not actually need insurance protection relative to the 875 kg/ha benchmark.

In order to have an idea of what sort of demand would be generated by the single- scale contract, an *ex ante* demand analysis is necessary. We next present a conceptual framework for the study of this demand under expected utility theory and alternative decision-making processes.

4.2. *Ex ante demand for index insurance under expected utility*

The payoff structure of the single-scale contract, presented in Section 4.1, involves random variables with continuous probability distributions. In our effort to analyze the demand for this insurance contract, we discretize its payoff structure. This enables us to simplify the analysis without losing sight of those aspects of the single-scale contract that are most relevant to its demand.

Figure 3 shows the discretized payoff structure under the single-scale index insurance contract that Section 4.1 explains in detail. Under this structure, an individual farmer (or village cooperative) faces, for example, an 85% probability that yields are good, and a 15% probability that yields are bad. If individual yields are good, there is a 4.6% probability that the index will trigger a payoff, resulting in an income of a_1 (equal, say, to the net income under good yields less the insurance premium plus the value of the insurance indemnity payment). Most of the time, however, insurance payments are not made and the individual receives an income of a_0 (equal, say, to the net income under good yields less the insurance premium).

If the individual experiences poor yields, there is a 53% probability that the index insurance will trigger a payoff, resulting in an income of b_1 (equal to the net income under bad yields, less the insurance premium plus the value of the insurance indemnity payment). However, there is a FNP of 47% (for the reasons enumerated in Section 3). In this case, the individual receives a net income of b_0 (equal to the net income under bad yields minus the insurance premium and minus any collateral that must be forfeited to cover loan default). Note that $a_1 > a_0 > b_1 > b_0$.

While index insurance is effectively a compound lottery (a fact which we discuss in detail later), under the standard axioms of expected utility theory, the individual will reduce the compound lottery to a simple lottery, with payoff probabilities given by the figures in parentheses next to each payoff level.

Standard economic theory predicts that 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 under an index insurance contract), the expected utility maximizing agent will still purchase whatever partial insurance is available if priced at an actuarially fair level. In a more realistic setting, however, insurance companies impose loadings (i.e., amounts in excess of the actuarially fair premium) to cover transaction costs. In that case, standard economic theory predicts that a utility maximizer will leave part of the risk uninsured. Singe-scale index insurance contracts are an example of partial insurance, as they typically have a loading of at least 20%. Therefore, a risk-averse agent will purchase index insurance only if basis risk is small enough compared to the fraction of total risk he is exposed to.

In order to gauge the impact of basis risk on the uptake of single-strike index insurance, we first implemented a series of field experiments designed to reveal individual coefficients of relative risk aversion among 331 Malian cotton farmers. Details of these experiments are given in Elabed and Carter (2012). In the analysis that follows, we assume that the distribution of risk aversion among these farmers reflects the distribution in the overall population.

Using these estimates, we simulate the impact of basis risk on the demand for the single-scale contract. We do so by performing a symmetric increase in the normalized variance of the idiosyncratic component, $\tilde{V}(\varepsilon_{hzt})$, defined in Section 3. This symmetric increase is equivalent to a simultaneous increase in the probability of not triggering the index when the farmer's yield is low and an increase in the probability of triggering the index when his yield is high keeping the probability of triggering the index constant. Since the farmer receives a payment under the single-scale contract whenever the index is triggered, this symmetric increase is equivalent to an increase in the FNP and an increase in the probability of the false positive payout. Therefore, under this simulation, the price of the insurance contract remains constant.

Figure 4 illustrates the impact of FNP on the demand for index insurance assuming that:

i. Individuals are expected utility maximizers;
ii. Insurance costs 20% more than the actuarially fair price;
iii. The distribution of risk aversion in the population of farmers matches the distribution revealed by the experimental games played in Mali; and,
iv. The probability of insurance payout is constant and is equal to 12%.

The horizontal line in Fig. 4 represents the price of the single-scale insurance contract, which is 6480 CFA (13.22 USD) in this case. In addition, because of assumption (iv), the probability of false negative cannot be more than 20%.

As can be seen from the dashed curve in Fig. 4, increasing FNP in a single-scale index insurance contract will discourage demand (and the resolution of the costly risk-rationing problem) because it fails to sufficiently reduce the risk of collateral loss. For a contract with zero basis risk, that is, one that pays off for sure in case of a loss, moderately and highly risk averse farmers (67% of the population in the Mali experiment) demand index insurance. Since the probability of payout is constant under this simulation, increasing the FNP destabilizes the consumption by transferring income from the bad state of the world to the good state of the world, which explains the decreased demand. In addition, as the FNP increases, the farmers with the highest risk aversion coefficient are the first to stop demanding the contract.[16] The vertical line in Fig. 4 denotes the point where the contract carries an FNP equal to 47% (as under the single strike point contract presented in Section 4.1). In this case, we notice that only half of the population would demand the insurance contract.

4.3. Compound risk aversion and ex ante demand for index insurance

While basis risk and FNP matter to an extent when individuals are expected utility maximizers, there is ample evidence that people do not behave according to expected utility theory when they face a risky prospect. Because of the presence of basis risk and FNP, index insurance is a form of probabilistic insurance, a concept introduced by Kahneman and Tversky (1979). Contrary to the predictions of the expected utility theory, studies of the uptake of probabilistic insurance have found that consumers dislike this type of insurance contract, instead of preferring an insurance contract that has FNP of zero. Wakker et al. (1997) show that the respondents demand about a 30% reduction in the premium to compensate for a 1% probability of not getting a payment in case of a loss. 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% increase in the probability that the insurance contract fails.

While there are multiple explanations for this dislike of probabilistic insurance, we focus here on the interrelated concepts of ambiguity[17] and compound risk aversion.[18] Ambiguity aversion was first demonstrated by Ellsberg (1961). In his experiments, Ellsberg showed that individuals react much more cautiously when choosing among risks whose probabilities are uncertain (i.e., ambiguous risks) versus choosing among risks whose probabilities are known with certainty. While the individual probabilities under index insurance (and in probabilistic insurance experiments) are known, for individuals who cannot computationally reduce a compound to a single lottery, the final probabilities are unknown, as in the Ellsberg experiment, which thereby introduces something akin to ambiguity. Halevy (2007) corroborates this intuition by experimentally establishing a relationship between ambiguity aversion and compound risk aversion, showing that that those who are ambiguity averse are also compound risk averse.[19] We here explore the implications of this intuition for the demand for index insurance, and especially the sensitivity of that demand to increases in basis risk.

Elabed and Carter (2012) employ the Klibanoff et al. (2005) smooth model of ambiguity aversion. Under this model, the expected, compound risk averse utility associated with the index insurance contract illustrated in Fig. 1 can be written as:

$$\begin{aligned} 0.85 \times v\{0.046u(a_1) + 0.95u(a_0)\} + 0.15 \\ \times v\{0.53u(b_1) + 0.47u(b_0)\}, \end{aligned} \tag{4}$$

where u is a standard concave utility function and the function v is defined with $v' > 0$, $v'' \leq 0$.

In the compound risk neutral case, when v is linear, this expression will reduce to a standard expected utility problem. As the concavity of v increases, compound risk aversion increases and the penalty for a greater spread in the secondary lottery increases. The compound risk averse farmer is willing to pay an additional premium for reducing the compound index insurance lottery compared to his compound risk neutral counterpart, for

[16] The most risk-averse farmers drop out first because higher basis risk increases the probability of the worst outcome, b_0 in Fig. 1 (Clarke, 2011).

[17] 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 production function generating the yield. For example, the farmer does not know his yield outcome in case there is a drought. This assumption is unrealistic.

[18] Other candidate explanations include the probability weighting function of prospect theory (Kahneman and Tversky 1979; Wakker et al., 1997), and the rank-dependent utility function of cumulative prospect theory (Segal, 1988).

[19] Compound risk aversion was first defined in Abdellaoui et al. (2011), by comparing certainty equivalent between a compound lottery and the equivalent reduced lottery.

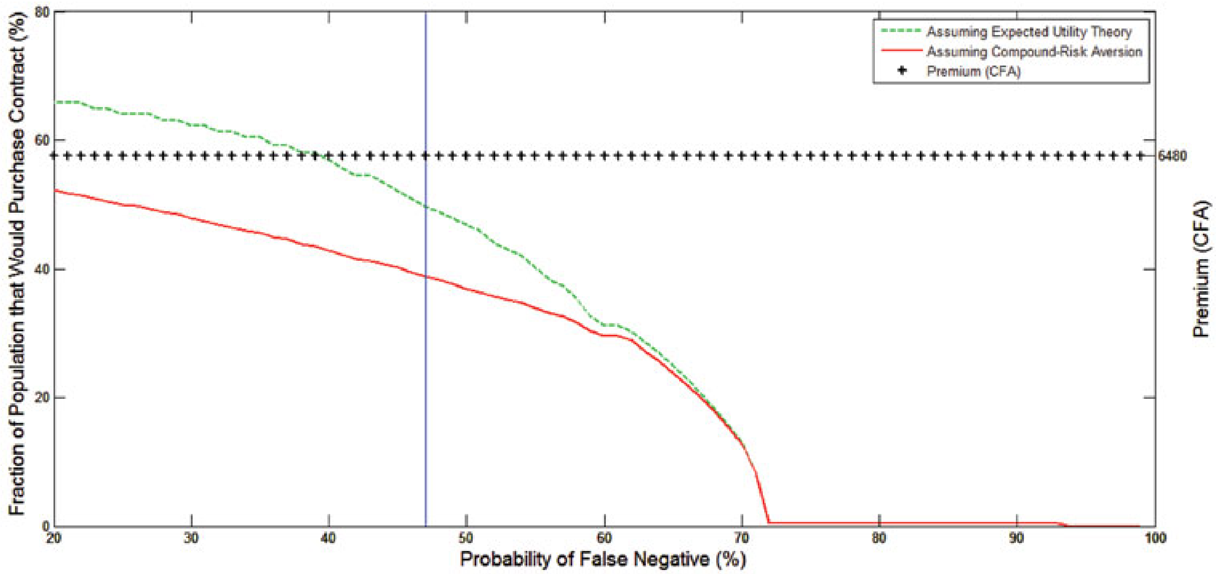

Fig. 4. Single-strike index insurance uptake as a function of the probability of false negative.

the same level of risk aversion as represented by the curvature of u.

As detailed in Elabed and Carter (2012), the field experiments conducted in Mali also allowed measurement of the coefficient of compound risk aversion. A full 57% of game participants revealed themselves to be compound risk averse of varying degrees. Using the distribution of compound risk aversion in this population, the solid line in Fig. 4 displays the impact of FNP on the 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. For example, if the probability of false negative was 30%, only 48% of the population would demand this contract as opposed to 65% under expected utility theory. Under the single-strike contract presented in Section 4.1, only 39% of the population would demand this insurance contract as opposed to the 52% demand that would be expected if individuals were simply expected utility maximizers.

This *ex ante* analysis highlights the importance of designing insurance contracts that minimize basis risk. In the following section, we show that multiscale contracts could reach this goal with the additional benefit of decreasing moral hazard.

5. Multiscale index insurance contract to minimize basis risk

As shown in Section 4, the need to moral hazard-proof the contract by selecting a higher level scale comes at a nontrivial cost in terms of increased basis risk and FNP and reduced insurance demand. This section presents an innovative multiscale insurance contract designed to mitigate this problem.

5.1. A Multiscale contract to reduce basis risk in Mali

Under a standard single-scale contract, the tradeoff between basis risk and moral hazard is a classic problem of one instrument being used to address two problems. Rather than try to mediate this problem with a single-scale contract, we instead equate the number of instruments to the number of goals and propose the following two-scale index insurance contract:

$$p_{czt} = \begin{cases} 0 & \text{if } \bar{y}_{zt} \geq S_z \quad \text{or} \quad y_{czt} \geq S_{cz} \\ L & \text{if } \bar{y}_{zt} < S_z \quad \text{and} \quad y_{czt} < S_{cz} \end{cases},$$

where the new term, S_{cz} is a second trigger set at the level of the village cooperative, with $S_{cz} < S_z$. Under this contract structure, the first trigger (set at the ZPA level) controls the moral hazard problem. It tells villagers that a low yield in their village will only be believed if yields in the ZPA are sufficiently low to make it likely that low village yields reflect misfortune and not malfeasance. The lower scale trigger at the village is then meant to offer protection to villages at the yield level for which they actually need insurance protection.

The dashed line in Fig. 4 displays the statistical properties of this multiscale contract using the same risk parameters employed to study the single-scale contract in Section 4. For this analysis, the strike points were set with $S_{cz} = 875$ and $S_z = 1{,}000$. Importantly, these strike points give exactly a 10% payoff probability under the two-scale contract, and hence this contract would carry the identical premium as the standard, single-scale contract.

As can be seen in Fig. 4, the two-scale contract has quite different statistical properties than the single-scale contract. First, it sharply reduces the incidence of false negatives, or situations wherein a cooperative whose yield is below the focal threshold of 875 kg/ha fails to get a payoff. The marginal false negative rate falls from 70% to 35%. In aggregate, this

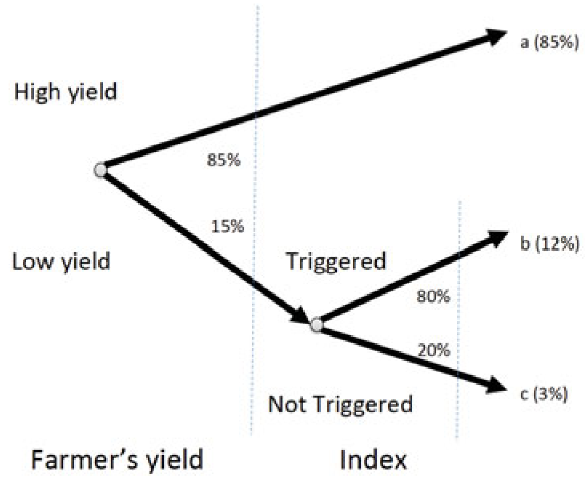

Fig. 5. Payoff structure under two-scale contract.

contract pays off 77% of the time when village yields are below 875 kg/ha (and 93% of the time when they are below a critical level of 750 kg/ha).

Second, the two-scale contract completely eliminates false positives, or situations when a cooperative whose yield is above the zone-specific threshold receives a payout. As the figure makes clear, premium dollars under the two-scale contract are being used entirely to fund payments when the cooperative has yields below the village trigger levels and needs financial assistance, and are not being dissipated to fund payments when none are needed (when $\bar{y}_{czt} > S_{cz}$)

5.2. *Ex ante demand for insurance under a multiscale index insurance under risk and compound risk aversion*

Because of the statistical properties discussed in the previous section, the multiscale contract would seem to be more desirable than the single strike contract. In order to verify this intuition, we use the modeling framework presented in Section 4 and perform an *ex ante* analysis of the demand of this type of contract under expected utility theory and compound risk aversion.

Figure 5 reveals the payoff structure under the two-scale index insurance contract. Under this structure, an individual farmer (or village cooperative) faces, as in the single-scale contract, an 85% probability that yields are good, and a 15% probability that yields are bad. Unlike the single-scale contract, if individual yields are good, insurance payments are not made and the individuals receive a payoff of a (the net income under good yields less the insurance premium). If the individual experiences poor yields, there is an 80% probability that the index insurance will trigger a payoff, resulting in an income of b (equal to the net income under bad yields, less the insurance premium plus the value of the insurance indemnity payment). However, there is a 20% of FNP. In this case, the individual receives a net income of c (equal to the net income under bad yields minus the insurance premium and minus any collateral that must be forfeited to cover loan default). Note that $a > b > c$.

Having represented the payoff structure under the two-scale index insurance contract, we investigate the impact of basis risk on the demand of this contract under expected utility theory and compound risk aversion. Using the coefficients of risk aversion elicited from the experiments in Mali, we use the methodology discussed in Section 4.2, which consists in a symmetric increase in $\tilde{V}(\varepsilon_{hzt})$. As in the simulation presented in Section 4.2, this increased idiosyncratic variance/basis risk implies an increased FNP. However, because of the village level trigger, this increased variance does not symmetrically increase the false positive probability (recall that under the two-scale contract, villages are not paid when their yields are adequate irrespective of what the level of yields at the higher scale/ZPA level). Because of this asymmetry, the overall probability of a payoff decreases and the price of the insurance declines. Under the two-scale contract, while increased basis risk lowers the insurance value of the contract, it is partially offset by a decrease in the price.

Figure 6 simulates the relationship between FNP and the demand for two-scale index insurance, under the assumptions (i), (ii), and (iii) of Section 4.2. The dotted line in Fig. 6 represents the premium paid for the two-scale contract. As the probability of false negative increases, demand for the partial insurance offered by this index insurance contract remains relatively robust assuming that individuals maximize expected utility.

Using the distribution of compound risk aversion elicited in the experiments, the solid line in Fig. 6 displays the impact of FNP on the demand for the two-scale index insurance. As expected, compound risk aversion worsens the impact of FNP (and basis risk) relative to under expected utility theory. The vertical line marks the point where the single-scale contract and the two-scale contract carry the same price. In this case, 55% of the population would demand the two-scale contract. The single-scale contract presented in Section 4 would have an expected demand of only 39%. Accordingly, the two-scale contract attracts 40% more farmers relative to the single-scale contract.

All things considered, by reducing the FNP and basis risk, multiscale contracts would face a higher demand from the farmers relative to single-scale contracts. With this in mind, the next section reports preliminary uptake results of an index insurance project that distributed the two-scale contract described in Section 5.1.

6. Demand for multiscale index insurance in the Mali insurance pilot

This section describes demand for a multiscale contract introduced as part of an index insurance pilot project launched in 2010 in the sector of Bougouni, in southern Mali. This contract was designed to pay off when two indexes are triggered: (i) a ZPA-level trigger of 900 kg/ha; and (ii) coop-specific triggers

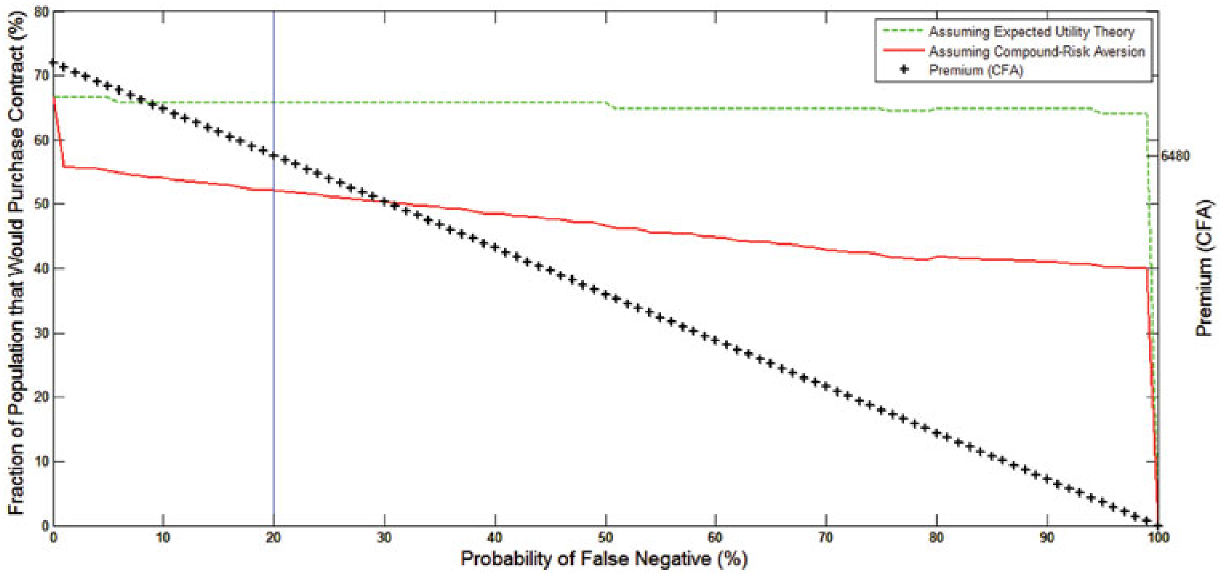

Fig. 6. Two-scale index insurance uptake as a function of the probability of false negative.

varying between 264 and 913 kg/ha. The level of the second trigger was adjusted to keep the price of the insurance constant across villages.

Recall that the cotton industry in Mali is a monopsony, and that production takes place in cooperatives. The pilot project was designed around this cooperative structure; out of the 86 cooperatives in the area, two thirds (58) of the cooperatives were allocated into treatment group and one third (28) of the cooperatives were maintained as a control group. The treatment cooperatives were then offered the option of purchasing the insurance contract. In order to increase the likelihood of substantial take-up, we adopted an encouragement design: treatment cooperatives randomly received randomly distributed discounts that reduced the price to 50%, 75%, or 100% of the actuarially fair premium. Throughout this process, our implementing partner emphasized that the discount was temporary, and that cooperatives should not expect such a discount in subsequent years.

In the first year of the program, 16 out of the 58 treatment cooperatives (30%) agreed to purchase the index insurance contract. This uptake rate is significantly below that predicted in the above-mentioned analysis, but well above up-take rates in some other pilot projects. For example, a similar project in Peru, which employed a single-trigger area-yield insurance contract, faced a demand as low as 5%.

In summary, designing index insurance contracts with minimal basis risk is important for their popularity. In addition, recall that insurance contracts are expected to reduce risk rationing in the credit market, which can have two consequences. First, the number of cotton farmers in insured cooperatives will increase. Second, insured households will increase their area planted to cotton. Future work will analyze these issues as well as more carefully examine the pattern of demand and its relation to measured risk and compound risk aversion.

7. Conclusion

Basis risk is an unavoidable element of agricultural insurance, but how important is it? This article has tried to shed light on this question in the context of small-scale cotton farmers in Mali who appear to avoid risky, but on average, profitable economic opportunities. Noting that index insurance appears to the farmer as an ambiguous compound lottery, we have explored the impact of both compound risk and risk aversion on the potential demand for index insurance as basis risk increases. We find that compound risk aversion lowers insurance demand by some 13 percentage points below what would be predicted for risk averse, but compound risk neutral farmers. In addition, demand under both kinds of aversion drops off sharply as basis risk increases.

These findings suggest that to be effective, index insurance contracts must be found that reduce levels of basis risk. Choosing the correct index is important in this regard, and area yield contracts in principal should strongly dominate weather-based contracts. Unfortunately, conventional area yield-based index insurance contracts face a severe tradeoff. Reducing the scale of the index to bring it closer to the farmer reduces basis risk, but increases the problem of moral hazard. We show that one solution to this conundrum is to design multiscale contracts. In the specific case of Mali, we show that a two-scale contract can, at the same actuarially fair premium, reduce the probability that a village is not paid when their yields are low from 45% under the conventional contract to only 7% under the multiscale contract. Demand simulations indicated that uptake of the multiscale contract would be 40% higher than under the equivalently priced single-scale contract.

While it is too soon to say that multiscale contracts can work in the real world, results from an initial pilot in Mali in 2011 are encouraging. Unfortunately, the March 2012 military coup in

Mali led to the near collapse of many institutions, cutting short this pilot effort. As of writing this article, the pilot project has moved our research project to neighboring Burkina Faso, where the cotton market structure and agro-ecological conditions are very similar to Mali's and a version 2 of the multiscale contract will be rolled out in 2013. Future data collection and analysis should allow us to better gauge the impact of improved contract design on the insurance demand, especially for compound risk averse individuals.

Acknowledgments

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Appendix: Simulation procedure used to generate the payoff probability under two different index insurance contracts

This appendix explains the simulation procedure used to estimate the payoff probabilities under the single-scale contract and the two-scale contract. The data used in the simulations consist of two time series of cooperative and ZPA level yield covering the period from 2000 to 2010 in the district of Bougouni, Southern Mali.

Step 1: Estimation of Weibull Probability Density Function

The first step is to estimate the probability density function f_z of ZPA yields, which is a Weibull probability density function:

$$f_z(y) = a_z b_z^{-a_z} y^{a_z-1} e^{-\left(\frac{y}{b_z}\right)^{a_z}}, \tag{A.1}$$

where a_z and b_z refer to the shape and scale parameters. We estimate a model in which we assumed that the shape and scale parameters of the Weibull to be functions of the long-term average yield of each ZPA:

$$\begin{cases} a_z = a_0 + a_1\overline{y_z} \\ b_z = b_0 + b_1\overline{y_z} \end{cases}, \tag{A.2}$$

where the subscript z refers to ZPA. We end up with a ZPA-specific Weibull function. We carried out the estimation of the parameters of the Weibull function using maximum likelihood methods. Here are the parameter values we used for the simulation:

Step 2: Estimation of Basis Risk

In order to design the preferred two strike point contract, we need an estimate of basis risk that is an estimate of the degree to which village co-op yields vary around ZPA yields. To do this, we estimated the following statistical model:

$$y^*_{czt} = \beta_0 + \beta_1 y^*_{zt} + \grave{O}_{czt}, \tag{A.3}$$

where y^*_{czt} is the "demeaned" cotton yield of village co-op c located in ZPA z in year t, and y^*_{zt} is the demeaned yield of ZPA z in year t, and $\grave{O}_{czt}$ is the basis risk term. "Demeaned" means that we subtracted from each observation its long-term average yield (e.g., $y^*_{czt} = y_{czt} - \bar{y}_{cz} = y_{czt} - \frac{1}{T}\sum_{t=1}^{T} y_{czt}$, where T is the number of years of data we have on village co-op c in ZPA z). We would expect the parameter β_0 to be close to 0 in value and we would expect to see β_1 close to 1 in value. Note that the residual basis risk term picks up the extent to which village co-op yields do not track ZPA yields.

We estimated the parameters of the basis risk model using two approaches. For both approaches, we estimated the model separately for each ZPA. The first estimation method was ordinary least squares. This estimation method assumes homoskedasticity, meaning that the variance of the basis risk term $\grave{O}_{czt}$ is always the same; in addition, because it seems likely that variance of basis risk decreases as ZPA yields decline. In a severe drought year, all village co-ops will have low yields (just like the ZPA), meaning that the variance of basis risk shrinks with ZPA yields. We thus also estimate the basis risk equation using generalized least-squares methods in which we specify the variance of basis risk to be of the following form:

$$\mathrm{E}\left[\sigma_\varepsilon^2\right] = [\gamma_0 + \gamma_1\overline{y^*}_{zt} + \gamma_2(\overline{y^*}_{zt})^2]^2, \tag{A.4}$$

where σ_ε^2 is the variance of the basis risk.

In general, we find evidence that basis risk shrinks as ZPA level yields decline. Finally, for purposes of the analysis and pricing of the contract, we took the simple average of the standard deviation of basis risk under the heteroscedastic model (A.5) when ZPA yields drop to 700 kg/ha and the homoscedastic estimate in order to calculate basis risk. It is this level of basis risk that we use to price the contract. The simulations we presented in the article use a standard deviation of basis risk equal to 134.

Finally, before pricing the contract, we decided to focus only on those ZPAs where basis risk was not too high. We then took these eligible ZPAs and divided them into high- and low-yield ZPAs. The simulations we present in the article focus on a high-yield district which has a long-term average yield of 1,142 kg/ha. As we will now explain in Step 3, we use the average for this high ZPAs to price the contract.

Step 3: Pricing of Contract

The first step is to calculate the Weibull parameters for the district. Once we did that, we used a standard algorithm for generating random numbers from a Weibull distribution with known parameters. We generated 8,000 random draws for ZPA yields.

For each simulated ZPA yield, we then drew a random draw from the appropriate distribution of basis risk. Consistent with our regression model, we assume that basis risk is normally distributed with mean zero and variance as estimated and explained in Step 2. Adding the simulated basis risk element to the simulated ZPA yield gives us a sequence of simulated village co-op yields. We then wrote an algorithm to locate the village co-op strike point that yields a contract that pays off exactly 10% of the time and hence has an actuarially fair price of 95,000 CFA/ha.

Table A1
Parameter values used for the simulations

a_0	a_1	b_0	b_1	$\overline{y_z}$	$\mathrm{E}\left[\sigma_\varepsilon^2\right]$
2.4645	4.3925	26.3448	1,040.4648	1,142	134

References

Abdellaoui, M., Klibanoff, P., Placido, L., 2011. Ambiguity and compound risk attitudes: An experiment. Working paper, Kellogg School of Management, Northwestern University. Accessed December 2012, available at http://www.kellogg.northwestern.edu/faculty/klibanof/ftp/workpap/AKP2011.pdf

Boucher, S., Carter, M.R., Guirkinger, C., 2008. Risk rationing and wealth effects in credit markets: Theory and implications for agricultural development. Am. J. Agric. Econ. 90(2), 409–423.

Bryan, G., 2010. Ambiguity and insurance. Yale Working paper. Accessed December 2012, available at http://www.econ.yale.edu/∼gtb3/Gharad_Bryan/Research_files/GharadBryanJMP2.pdf

Carter, M.R., 2012. Designed for development impact: Next generation approaches to index insurance for small farmers. In: Churchill, C., Matul, M. (Eds.), Microinsurance compendium, Vol II. International Labor Organization, Geneva.

Castillo, M.J., Boucher, S., Carter, M.R., 2012. Will I be paid after a loss? Evaluating conventional versus index insurance contracts in Ecuadorean Agriculture, working paper. UC Davis Working paper. Accessed December 2012, available at http://agecon.ucdavis.edu/people/faculty/michael-carter/docs/CastilloBoucherCarterNov2012.pdf

Clarke, D., 2011. A theory of rational demand for index insurance. Working paper, University of Oxford. Accessed December 2012, available at http://www.economics.ox.ac.uk/materials/working_papers/paper572.pdf

Ghatak, M., Guinnane, T.W., 1999. The economics of lending with joint liability: Theory and practice. J. Dev. Econ. 60(1), 195–228.

Elabed, G., Carter, M.R., 2012. Basis risk and compound-risk aversion: Evidence from a WTP experiment in Mali. UC Davis Working paper. Accessed December 2012, available at http://agecon.ucdavis.edu/people/faculty/michael-carter/docs/ElabedCarterJan2013.pdf

Ellsberg, D., 1961. Risk, ambiguity, and the Savage axioms. Q. J. Econ. 75(4), 643–669.

Halevy, Y., 2007. Ellsberg revisited: An experimental study. Econometrica. 75(2), 503–536.

Hazell, P., 1992. The appropriate role of agricultural insurance in developing countries. J. Int. Dev. 4, 567–581.

Kahneman, D., Tversky, A., 1979. Prospect theory: An analysis of decision under risk. Econometrica 47(2), 263–291.

Karlan, D., Osei, R.D., Osei-Akoto, I., Udry, C., 2012. Agricultural decisions after relaxing credit and risk constraints. NBER Working paper. Accessed February 2013, available at http://www.nber.org/papers/w18463.pdf?new_window=1

Klibanoff, P., Marinacci, M., Mukerji, S., 2005. A smooth model of decision making under ambiguity. Econometrica 73(6), 1849–1892.

Kurosaki, T., Khan, H.U, 2012. Vulnerability of microfinance to strategic default and covariate shocks: Evidence from Pakistan. Develop. Econ. 50(2), 81–115.

Schaus, C., 2012. Le fonctionnement des groupes de credit et du principe de caution solidaire en periode de crise: le cas des cooperatives de coton au Mali. Master Thesis in Economics, University of Namur.

Segal, U., 1988. Probabilistic insurance and anticipated utility. J. Risk Insurance 55(2), 287–297.

Stiglitz, J.E., 1990. Peer monitoring and credit markets. World Bank Econ. Rev. 4(3), 351–366.

Wakker, P., Thaler, R., Tversky, A., 1997. Probabilistic insurance. J. Risk Uncertainty 15(1), 7–28.