Formal Insurance and Informal Risk-sharing

Experimental Evidence from Insurance Decisions by Ethiopian Farmers

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Abstract

Aggregate weather risk remains an important source of vulnerability for low-income households in developing countries. Insurance is becoming an important financial instrument to mitigate the impact of this risk. This paper contributes to existing theoretical and empirical knowledge on the interaction of insurance with informal risk-sharing in two ways. Firstly, we present a simple and highly generalisable model predicting complementarity of risk-sharing with insurance against aggregate shocks, and substitution between risk-sharing and insurance against idiosyncratic losses. Secondly, we present the first empirical evidence that investigates these relationships directly, by exogenously varying the extent of risk-sharing in an artefactual field experiment with low-income farmers in Ethiopia. We find that, indeed, index insurance and risk-sharing are complements, while indemnity insurance and risk-sharing are substitutes.

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1 Introduction

Aggregate weather risk remains an important source of vulnerability for low-income households in developing countries. The 2014 drought in Kenya reduced food availability and livestock productivity for 1.6 million Kenyans (IFRC, 2014). The 2016 drought in Ethiopia affected more than 10 million Ethiopians; and humanitarian aid agencies estimated that $1.4 billion in humanitarian aid and donations would be needed to address the humanitarian crisis (WFP, 2016). That these aggregate weather shocks lead to major human disasters is, in part, caused by the fact that, aside from the immediate impact on consumption and food availability, they negatively affect future-oriented strategies of farming communities. Empirical evidence shows that the threat of aggregate weather shocks cause households to engage in costly risk management activities and refrain from adopting improved agricultural technologies because they are reluctant to invest savings and take out loans (Rosenzweig and Binswanger, 1993; Morduch, 1995; Carter et al., 2007). The investment in low return production activities implies that households, when confronted with repeated asset losses and income shocks, do not build up resilience but rather remain at a low-level equilibrium, potentially trapping them in poverty (Barnett, Barrett and Skees 2008). On top of this, weather risk poses a portfolio problem for lenders, increasing the cost of credit to low-income farmers (Carter, Cheng, and Sarris, 2016). Agricultural risk may also negatively affect low-income farmers development out of poverty by affecting supply and take up of credit. And things may get worse as climate change is likely to increase the frequency of extreme weather events that cause these disasters.

Increasingly local and national governments, UN agencies, and national and international NGOs are using financial instruments such as insurance to protect themselves and their population against these natural disasters. Dercon and Clarke (2016) describe how the governments of India, Kenya, Mexico, and Ethiopia have all engaged in these methods of disaster protection. Since the 1990's index insurance pilot projects have been undertaken and financially supported by organizations as diverse as the World Bank, the International Finance Corporation (IFC), the United States Agency for International Development (USAID), Asian Development Bank (ADB), Inter-American Development Bank (IADB), International Livestock Research Institute (ILRI), the United Kingdom Department for International Development (DfiD), and United Nations World Food Program (UNWFP), among many others (Miranda and Farrin, 2012).

The theoretical proposition of insurance is that it provides claim payments to cover losses in bad years in exchange for regular premium payments in good years. As such it prepares households to smooth consumption levels (Townsend, 1994) and encourages the use of strategies that build future resilience (Elabed and Carter, 2014; Karlan et al., 2014). Insurance against losses (indemnity insurance) leads to obvious incentive problems in agricultural production. Index insurance, however, provides protection against aggregate weather risk, and as such is correlated with losses, but imperfectly so. Indices on which these insurances are based include (any combination of) rainfall, moisture, and temperature data, flood and wind speed measures, and area-average yield statistics and measures of vegetation conditions.

Despite the theoretical proposition of index insurance, its potential as a tool for smoothing the consumption of vulnerable, low-income households is challenged by basis risk. Basis risk stems from the imperfect correlation of actual losses with the index, which implies that there exists a probability that a low-income household purchases insurance against the insurance premium, suffers a loss, but does not get a payout because the index has not been triggered. As such, it potentially decreases wealth in states where policy holders are already vulnerable. Index insurance is therefore better viewed as a financial derivative, which may be interesting for wealthy consumers, but may simply be too risky for many of the rural poor when it is offered as an individual product (Clarke, 2016). However, the above-mentioned exposition on the utility of index insurance is not based on a recognition of the fact that many of the potential low-income consumers of index insurance are not operating in autarky but are already engaged in the sharing of risk through informal risk-sharing arrangements (IRSAs). Even though these ISRAs do not protect against aggregate shocks, they do allow for consumption-smoothing of idiosyncratic shocks (Townsend, 1994; Udry, 1994; Dercon and Krishnan, 2000; Duflo and Udry, 2003). Insofar as basis risk is not perfectly correlated amongst different individuals in the IRSAs it has the potential to be smoothed through the IRSAs.

In this paper we present a simple model with clear closed form solutions based on a parameter for the level of group risk-sharing, demonstrating that index insurance against aggregate shocks is a complement to informal risk-sharing, whilst indemnity insurance acts as a substitute. While it is not the first model investigating this relationship, it is significantly more general than other models. More importantly though, we present the first empirical evidence that investigates these relationships directly by conducting an artefactual field experiment with low-income farmers in Ethiopia, where we exogenously vary the extent of risk-sharing, and demonstrate that, indeed, index insurance and risk-sharing are complements, while indemnity insurance and risk-sharing are substitutes. The latter empirical evidence is especially important because even though two other studies have investigated these relationships, they have only done so by either making risk-sharing more salient through framing (Dercon et al., 2014) or by making assumptions about the strength of a social network, and therefore implicitly about informal risk-sharing, based on membership of an ethnic group (Mobarak and Rosenzweig, 2012).

As such this paper first of all fits within a literature on offering insurance against aggregate shocks, such as weather shocks, to groups versus individuals. De Janvry, Dequiedt, and Sadoulet (2013) analyse the demand for such insurance when farmers belong to communities with shared interests. They demonstrate that when these contracts are offered to individuals free-rider problems may occur where the sum of individual willingness to pay may be lower than the willingness to pay if the contract were only introduced at the group level. Furthermore, individuals from a group may fail to coordinate on the Pareto dominant outcome in which they all choose to take insurance. Offering insurance to groups would then increase demand relative to individual insurance offers. Boucher and Delpierre (2014) develop a theoretical model of index insurance purchase and investment with moral hazard and suggest that the inability of IRSAs to fully insure against all idiosyncratic risk (as they are constrained in their size), creates incentives to increase risk-taking, which, if individuals can not contract risk-taking, reduces incentives to share risk with others. As such index insurance may thus crowd-out informal risk-sharing. These two papers specifically focus on strategic interactions between members of informal risk-sharing groups in a context of constrained coordination or limited contracting, which, as they demonstrate, can be overcome by adequate design of contracts. In this paper we are interested in the complementarity of formal insurance and informal risk-sharing when these coordination problems do not exist and, in the experiments in this paper, deliberately extract from this problem by exogenously varying the extent of risk-sharing and not including insurance payouts in risk-sharing.

This paper is therefore most closely related to a literature on the complementarity of formal insurance and informal risk-sharing. It is well understood that individual indemnity insurance can reduce informal risk-sharing, and that the introduction of informal risk-sharing can crowd out demand for individual indemnity insurance (e.g. Arnott and Stiglitz, 1991; Attanasio and Ros-Rull, 2000). Our framework improves upon the framework of Mobarak and Rosenzweig (2012) and Dercon et al. (2014), which generate similar central results, in three key ways. Firstly, we derive much simpler and clearer closed form solutions for both index and indemnity insurance purchases than in these other models, by introducing a specific parameter for the level of group risk-sharing. These closed form solutions clearly show that index (indemnity) insurance purchase is increasing (decreasing) with the level of group risk-sharing. Secondly, we use an intuitively appealing conditional probability structure to model losses, making loss probabilities conditional on the state of the index, which allows us to extend the model to more than two risk-sharers. This conditional probability structure offers a simple, intuitive, and highly tractable way to understand index insurance. Indeed in our experiment, the index insurance product is explained in terms of conditional probabilities.

Thirdly, and most importantly, our theoretical results are significantly more general than Mobarak and Rosenzweig (2012) and Dercon et al. (2014). Mobarak and Rosenzweig (2012) generate the result that informal risk-sharing *may* increase demand for index insurance, and their framework does not extend to include the result that indemnity insurance and informal risk-sharing are substitutes. Dercon et al. (2014) generate the same central theoretical results as this paper, namely that informal risk-sharing is a complement to index insurance but a substitute for indemnity insurance, but require far greater restrictions on the utility function. Indeed Dercon et al. (2014) must assume, on top of non-satiation and risk-aversion, that agents have utility functions' whose third and fourth derivatives satisfy both temperance and prudence. We only need to assume non-satiation and risk-aversion to generate our theoretical results. That we do not require such further restrictions on the utility function is particularly important in the light of evidence from the experimental literature (Deck and Schlesinger, 2009) that, even if there is some evidence for prudence, the behavior of agents appears more consistent with intemperance than temperance. Thus our framework builds on previous models in important ways, adding generality and simplicity to previous theoretical findings.

In terms of the empirical contributions to this literature this paper builds on Dercon et al. (2014) and Mobarak and Rosenzweig (2012). Dercon et al. (2014), as part of a marketing campaign for index insurance carried out training sessions for leaders and members of IRSAs where they randomized the content of the training. In some treatment arms risk-sharing of idiosyncratic basis risk was emphasized. They find that the effect of training on the benefits of sharing basis risk increased demand for index insurance. Mobarak and ROsenzweig (2012) conduct a randomized control trial where they randomize index insurance offers and the locations of rainfall gauges (as a measure of basis risk). To investigate the effect of risk-sharing they use survey data on endogenous measures of the strength of a social network to make assumptions about the extent of risk-sharing. This paper adds to this literature by providing the first direct empirical evidence investigating the relationship between index insurance and risk-sharing, but also indemnity insurance and risk-sharing, directly by conducting an artefactual field experiment with low-income farmers in Ethiopia, where we exogenously vary the extent of risk-sharing and investigate actual insurance purchases. In this paper we therefore do not have to rely on framing of risk-sharing or on endogenous risk-sharing measures.

The rest of the paper is organised as follows. In Section 2 the Conceptual Framework with the theoretical model and the predictions is presented. Section 3 describes the experimental design. Section 4 explains the Estimation Strategy. Section 5 presents the results and

Section 6 concludes.

2 Conceptual framework

The central result of our theoretical framework is that index insurance is a complement to informal risk-sharing agreements, whilst indemnity insurance acts as a substitute. We show this theoretically by using a highly stylised model to highlight the central intuition, before embedding the result in a full theoretical framework of index and indemnity insurance decisions with binary index and loss states.

2.1 Skeletal Model

Our central theoretical intuition can be usefully illustrated using a skeletal model as follows. An infinite number of risk-averse farmers have uncertain incomes y_i. Expected income is the same for all farmers, denoted x, and is itself random, depending for example on common weather shocks. An index is able to track x perfectly, and thus underpin an index insurance product against common shocks to x.

The farmers implement a costless risk-sharing mechanism, whereby a proportion θ of each farmer's income is paid into a common kitty, which is then evenly divided among them. Since the number of farmers is infinite, each receives an amount $E(\theta y_i) = \theta x$ from the kitty. So after risk-sharing, farmer i's income is

$$\theta x + (1 - \theta) y_i.$$

Farmers have access to index and indemnity insurance, which compensate for variation in x and y_i, respectively. Then, if both insurance types are actuarially fairly priced, each risk-averse farmer will choose to fully insure their post risk-sharing income. This full insurance is achieved as follows.

Theorem 1: In the skeletal model, each farmer purchases a portfolio of insurance that has a proportion θ of index insurance, and proportion $1 - \theta$ of indemnity insurance.

That is, the proportion of index insurance in the optimal insurance portfolio is equal to the risk-sharing parameter. *In other words, the greater the level of risk-sharing in the community, the greater the demand for index insurance and the lower the demand for indemnity insurance.*

It is important to note that this result does not impose conditions on the utility function, beyond the standard assumptions of non-satiation and risk aversion. Furthermore, the result does not depend on whether or farmers' incomes are correlated, or on any assumptions over the distributions of x and y_i.

Moreover, the central result appears robust to adding further complexities such as premia which are not actuarially fair, costly risk-sharing, and expected income x as a function of the index rather than equal to it.

2.2 Full Theoretical Framework

Our central intuition can be embedded into a richer insurance framework with binary index and loss states. Consider an infinite number of risk-averse farmers. Each farmer has endowment y and faces a possible loss L. With probability q a drought occurs. If there is a drought, each farmer incurs the loss with conditional probability P. If the drought does not occur, the conditional probability of incurring the loss is $p < P$. Thus, the expression $P - p$ can be interpreted as a measure of how informative the index is on actual losses.

For simplicity, we assume that farmer losses are independent conditional on drought outcome, but unconditionally losses are positively correlated since they all depend on whether or not there is a drought.

This loss and index structure is more in line with Clarke and Kalani (2011), Dercon et al. (2014), and Clarke (2016) than with Mobarak and Rosenzweig (2012) and Boucher and Delpierre (2014). This is because there is either a loss or no loss for each participant, and the aggregate shock does not affect wealth directly, but rather increases the probability of loss. However, we depart from previous models in two significant ways. Firstly, unlike Mobarak and Rosenzweig (2012) and Dercon et al. (2014), we assume that the index correlates perfectly with common shocks. This is similar to how Boucher and Delpierre (2014) model index insurance, as fully covering aggregate shocks but not covering idiosyncratic basis risk, except that we do not assume, as they do, that aggregate and idiosyncratic shocks both affect wealth directly; we rather assume that aggregate shocks make individuals losses more likely. This means that all basis risk must be interpreted in terms of idiosyncratic shocks, rather than as the result of the inability of the index to track common shocks. Thus, for example, local rainfall events such that the rainfall on a farmer's field doesn't match that of the index must be interpreted as idiosyncratic shocks. Secondly, we assume that, conditional on the common shocks picked up by the index, agents losses are independent. Whilst this assumption is theoretically convenient, it is likely this would be violated in practice, for example if two farmers live close to one another and thus face similar risks (eg fire or theft) aside from the common shock.

The farmers engage in costless risk-sharing: irrespective of individual outcomes, they all pay a proportion θ of their assets into a common kitty which is then divided equally among them. Hence each farmer pays either θy or $\theta(y - L)$, depending on individual outcome, into the kitty, and receives $\theta(y - PL)$ from the kitty if there is a drought and $\theta(y - pL)$ if there is not.

There are thus four possible outcomes for each farmer:

Table 1: Outcomes after risk-sharing, without insurance

Drought	Loss	Probability	Outcome after risk-sharing
Yes	Yes	qP	$\theta(y - PL) + (1 - \theta)(y - L)$
Yes	No	$q(1 - P)$	$\theta(y - PL) + (1 - \theta)y$
No	Yes	$(1 - q)p$	$\theta(y - pL) + (1 - \theta)(y - L)$
No	No	$(1 - q)(1 - p)$	$\theta(y - pL) + (1 - \theta)y$

Each farmer has access to two forms of insurance: indemnity insurance and index insurance. Let α be the number of units of indemnity insurance purchased by a farmer. Each unit of indemnity insurance pays out L if and only if the farmer suffers an individual loss, irrespective of whether or not there is a drought. And let β be the number of units of index insurance taken out. Each unit of index insurance pays out L if and only if there is a drought, irrespective of whether the farmer suffers a loss.

Assuming both types of insurance are actuarially fair, premia equal expected losses. Hence the cost per unit of cover is $(qP + (1 - q)p)L$ for indemnity insurance and qL for index insurance.

With insurance, the outcome for a farmer in each state of the world is as follows (the probabilities are unchanged and omitted to save space):

Table 2: Outcomes after risk-sharing and insurance

Drought	Loss	Outcome after risk-sharing and insurance
Yes	Yes	$\theta(y - PL) + (1 - \theta)(y - L) - \alpha(qP + (1 - q)p)L - \beta qL + \alpha L + \beta L$
Yes	No	$\theta(y - PL) + (1 - \theta)y - \alpha(qP + (1 - q)p)L - \beta qL + \beta L$
No	Yes	$\theta(y - pL) + (1 - \theta)(y - L) - \alpha(qP + (1 - q)p)L - \beta qL + \alpha L$
No	No	$\theta(y - pL) + (1 - \theta)y - \alpha(qP + (1 - q)p)L - \beta qL$

The farmer's problem is to maximise expected utility over these four outcomes with respect to insurance decisions α and β. At the optimum, risk-averse farmers choose α and β to ensure full consumption smoothing such that in each of the four states of the world, the farmer gets their autarchic expected income $y - (qP + (1 - q)p)L$.

Simple algebraic rearrangement shows that this full consumption smoothing can be achieved by farmers purchasing index and indemnity insurance coverage as follows.

Theorem 2: In our full theoretical framework, optimal indemnity and index insurance purchases are given by:

$$\alpha = 1 - \theta \qquad \text{and}$$
$$\beta = \theta(P - p),$$

Since full consumption smoothing is achieved costlessly, this is an optimal solution for all utility functions satisfying non-satiation and risk aversion.

These expressions show how index insurance and indemnity insurance are, respectively, a complement and a substitute to group risk-sharing. Furthermore, the expression for β nests the familiar result from Clarke (2016) that demand for index insurance is decreasing in basis risk. This is because as $(P - p)$ becomes smaller, this corresponds intuitively to an index which is less informative on losses. Indeed, when $P = 1$ and $p = 0$, so $(P - p) = 1$, the index is perfectly informative on individual losses so index insurance effectively becomes indemnity insurance. As the expressions for α and β shows, in this case one unit of effective indemnity insurance is bought.

It is worth noting that these results rely on the assumption that both types of insurance are actuarially fair. With marked up premia (as indeed is the case in our experiment), expected income becomes lower when one purchases insurance, and agents will only be willing to make this tradeoff depending on their risk-aversion. Thus insurance purchases with marked up premia may depend on the agent's risk-aversion. However, we retain the assumption of actuarially fair premia in our model for the sake of simplicity and clarity of exposition, and because it does not change the fundamental intuition underlying the predictions of the model.

2.3 Predictions

In both models, it is immediately clear from the closed form solutions for index and indemnity insurance purchases that the models generate two clear predictions.

1. Optimal indemnity insurance cover decreases with the level of risk-sharing.
2. Optimal index insurance cover increases with the level of risk-sharing.

3 Experimental design

We conducted an artefactual field experiment in rural Ethiopia. The experiment was conducted over ten sessions, in ten different villages, with 40 invited local farmers in each.

Participants had been contacted and invited in advance, through their iddir (local risk-sharing group). Therefore, all participants in a session belonged to the same iddir. Each session lasted a maximum of three hours and was conducted in a classroom with desks, chairs and cardboard dividers. The same eight enumerators were present at all the sessions, each enumerator in charge of training and collecting the responses for five subjects.

The ten sessions were randomly assigned to one of four treatment arms, as shown in Table 3: indemnity insurance with and without risk-sharing, and indemnity insurance with and without risk-sharing.

Table 3: Number of Sessions by Treatment Arm

	Indemnity insurance	Index insurance
No risk-sharing	3	2
Risk-sharing	3	2

Note: Allocation of sessions to the four treatment arms. In all, ten sessions were held, and each participant in a session received the same treatment. All participants in a session belong to the same iddir.

Data were collected in several steps. First, participants were asked to play a gamble choice game to elicit risk preferences, and a risk-pooling game, before being fielded a survey on background characteristics. Next they played a game which aimed to teach them the mechanics of how aggregate and individual shocks would be realised in the lab setting. They were then asked about the working of their iddir and details of their personal formal insurance cover, if any. Next was a practice game aimed at imparting understanding of the insurance product (index or indemnity, according to treatment arm). Finally, two rounds of the main insurance game was played according to the assigned treatment arm. Only the last two components, the practice games and the insurance games, differed by treatment arm.

Farmers were provided with comprehensive training on the insurance products through group education, instructions and help from the enumerators, and practice games to increase and check understanding. Since many of the subjects were illiterate, each game was explained orally with the help of visual aids, and physical randomization devices (colored tokens and dice). Subjects were informed that they would be given 200 birr (USD 3.33)[1] in an envelope at the start of the session, and that during the experiment, they would be exposed to the risk of losing 100 birr. They were also told that they could purchase insurance to mitigate the risk of losing 100 birr. If they decided to do so the premium would be deducted from their final payoffs. The payoffs were substantial for rural Ethiopian farmers, given that the daily wage for unskilled labour was in the range 50–150 birr at the time. Table 4 provides an overview of the structure and order of session component.

[1]The exchange rate at the time of the experiment was 1 USD to 60 birr

Table 4: Session structure

EXPLANATION AND PRACTICE	
	Group explanation: aggregate shock and idiosyncratic losses
	Group explanation: tokens and dice
	Play training round: shocks and losses; enumerators check understanding
	Group explanation: indemnity insurance OR index insurance
	Play training round: insurance; enumerators check understanding
	Group explanation: sharing of losses
	Practice round 1
	Practice round 2
EXPERIMENT	
	Subjects given 200 birr endowment
	Subjects buy insurance (0, 1 or 2 units) and pay premium
	Aggregate shock determined by draw of token at group level
	Subjects roll dice to determine losses
	Subjects pay 100 birr to enumerator in case of loss
	Subjects informed about partner's loss outcome
	Any loss is shared (receive 50, send 50 or no adjustment)
	Insurance pay-outs

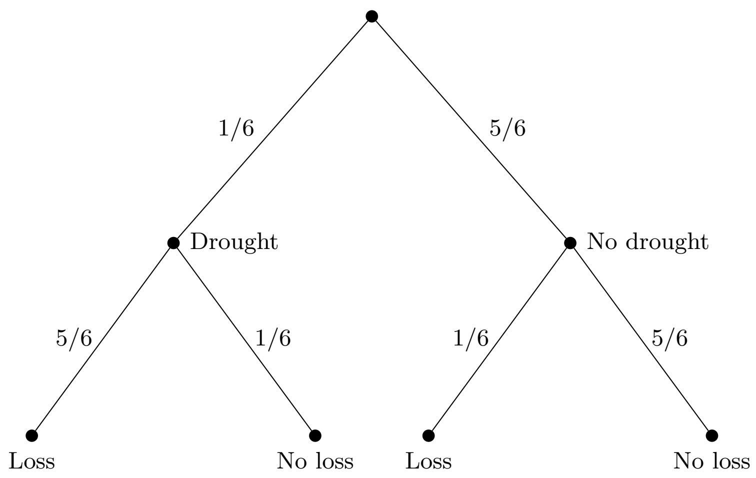
Note: Italicised items only apply to treatment arms with risk-sharing.

3.1 Aggregate and idiosyncratic shocks

Subjects were introduced to the concepts of aggregate and idiosyncratic shocks. The aggregate shock was introduced as a possible region-wide drought, the occurrence of which depended on the color of a token drawn from an envelope. There were 6 tokens, 5 blue and 1 yellow. If a yellow token was drawn, the drought occurred, and if a blue token was drawn, it did not. Depending on the color of the token, participants rolled different dice, and the color of their die roll determined whether they experienced a loss or not. For each game, the aggregate shock was drawn in front of the room so that all participants could see. If there was a drought, participant would roll dice with 5 yellow sides and 1 blue side. If there was no drought, they all rolled rolled dice with 1 yellow side and 5 blue sides. If the die showed yellow, the subjects suffered a loss of 100 birr.

As in the theory section, the aggregate shock (drought or not) was informative of the probability of suffering individual losses. Each participant's die throw was independent, but because the choice of die depended on the aggregate shock, farmer losses were unconditionally correlated. The probabilities and the states are presented in Figure 1. The unconditional expected net payoff without insurance was 172.22 birr.

Figure 1: Aggregate shock and idiosyncratic losses



Note: Extensive-form game. Probabilities are presented next to the branches of the tree. The states are presented at the nodes of the tree representing drought, no drought, loss and no loss. The drought occurs with probability 1/6. The loss occurs with probability 5/6 if there is a drought and with probability 1/6 if not.

3.2 Risk-sharing

All participants in each session belonged to the same risk-sharing group (iddir). However, in the experiment, decisions about risk-sharing were not left to the participants but varied exogenously. In the treatment arms without risk-sharing, participants could not share risk with each other during the session.[2] In the risk-sharing treatment arms, participants were randomly and anonymously paired with another participant in the same session. The identity of the partners was not revealed to the participants. They were informed that, irrespective of the aggregate shock, insurance decisions and payouts, they would be sharing losses with their partner such that if one suffered the 100 birr loss but the other didn't, then the latter would compensate the former with 50 birr.

That the experiment 'forced' farmers to share risk is important when identifying the effect of risk-sharing on index insurance demand, because it mitigates concerns that, if risk-sharing were optional, farmers might not actually share risk with one another in a one-shot game. The procedures for the insurance and insurance with risk-sharing treatments are presented in Table 4.

It is also worth noting that only losses, not insurance costs or payouts, were shared. This means that the participants did not have an incentive to free-ride on their partner's insurance, which might otherwise depress demand for insurance and confound the mechanism

[2]It is still possible that the shared risk after the session, but it is not clear that someone who had done well in the games would choose to reveal this after the end of the session.

studied here.

3.3 Insurance

Next, subjects were informed about either indemnity insurance or index insurance, depending on the treatment arm. In the indemnity insurance treatments, subjects were told that they could purchase insurance that would pay out if they incurred the loss, irrespective of whether or not the drought occurred. In the index insurance treatments, subjects were told that they could purchase insurance which would pay out in the case of drought, irrespective of whether or not they suffered a loss.

In both cases, participants could purchase 0, 1 or 2 units of insurance. Each unit of insurance was associated with a payout of 50 birr. The premium per unit of cover was 20 birr for indemnity insurance and 10 birr for index insurance. Table 5 presents unconditional probabilities, expected payouts and premia for the two insurance types. Note that neither insurance product was priced at the actuarially fair rate. In line with the literature and commercial insurance pricing, indemnity insurance was priced with a higher loading (mark-up above the actuarially fair rate) than index insurance.[3] Lower verification costs and reduced potential for moral hazard are two main reasons why index insurance can be expected to be sustainable at a lower mark-up than indemnity insurance.

Table 5: Characteristics of Insurance Products Offered

	Indemnity insurance	Index insurance
Payout per unit of cover	50	50
Unconditional probability of payout	5/18	1/6
Expected payout (=actuarially fair premium)	$125/9 \approx 13.9$	$25/3 \approx 8.3$
Premium charged per unit of cover	20	10
Implied loading / mark-up above fair premium	44%	20%

Note: Each participant was offered either indemnity or index insurance, but not both, and could choose between 0, 1 or 2 units of cover. The premia were set so as to make the loadings roughly in line with the literature.

Table 6 shows net payoffs for a participant for each state of the world and each possible insurance decision. Net payoffs are calculated as the endowment (200), minus any insurance premia, minus the loss (100) if incurred, plus any insurance payoffs. From the table it is clear that participants in the index insurance treatments were exposed to downside basis risk with a probability of 5/36.

The expected outcome of the risk with one unit of index insurance, $\mu_{\alpha=1}^{Index}$, is 171 birr and the expected variance of outcomes, $(\sigma^2)_{\alpha=1}^{Index}$, is 1427 birr. The expected outcome of the

[3] Clarke and Kalani (2011) use loadings of 60% for indemnity insurance and 20% for index insurance. Reported commercial loadings range from 70% to 430% for rainfall index insurance (Cole et al. 2009, Table 1) and from 140% to 470% for indemnity insurance (Hazell 1992, Table 1).

risk with two units of insurance, $\mu_{\alpha=2}^{Index}$, is 169 birr and the expected variance of outcomes, $(\sigma^2)_{\alpha=2}^{Index}$, is 1543 birr.

The expected outcome of the risk with one unit of insurance, $\mu_{\alpha=1}^{Indem}$, is 166 birr and the expected variance of outcomes, $(\sigma^2)_{\alpha=1}^{Indem}$, is 501 birr. The expected outcome of the risk with two units of insurance, $\mu_{\alpha=2}^{Indem}$, is 160 birr and the expected variance of outcomes, $(\sigma^2)_{\alpha=2}^{Indem}$, is 0 birr.

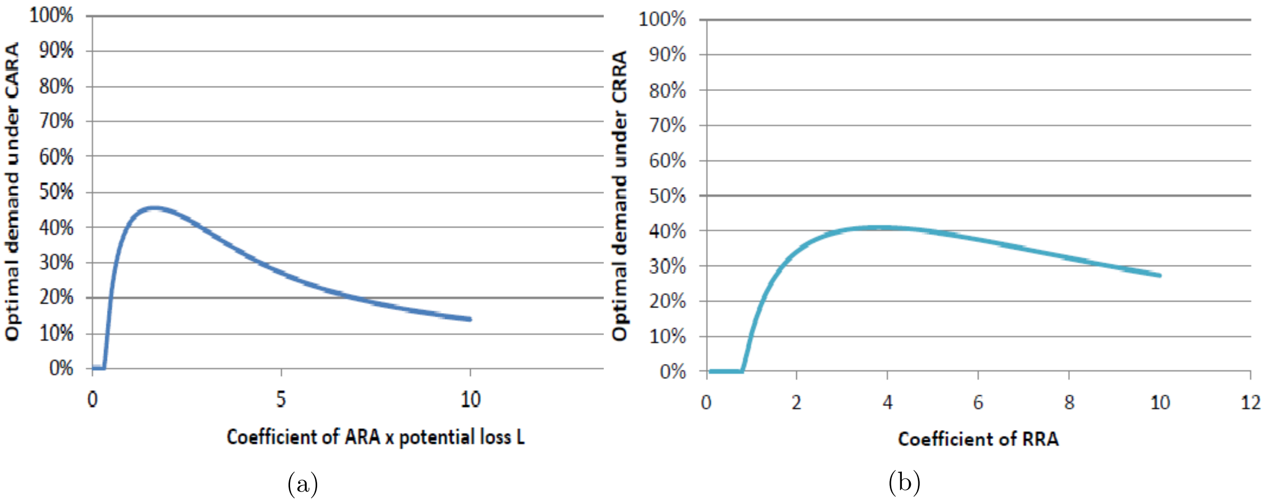
Table 6: States and payoffs

			Payoff with indemnity insurance		Payoff with index insurance	
Prob	State	Units	Calculation	Net	Calculation	Net
5/36	Drought, loss	0	$200 - 100$	100	$200 - 100$	100
		1	$200 - 20 - 100 + 50$	130	$200 - 10 - 100 + 50$	140
		2	$200 - 2 \cdot 20 - 100 + 2 \cdot 50$	160	$200 - 2 \cdot 10 - 100 + 2 \cdot 50$	180
1/36	Drought, no loss	0	200	200	200	200
		1	$200 - 20$	180	$200 - 10 + 50$	240
		2	$200 - 2 \cdot 20$	160	$200 - 2 \cdot 10 + 2 \cdot 50$	280
5/36	No drought, loss	0	$200 - 100$	100	$200 - 100$	100
		1	$200 - 20 - 100 + 50$	130	$200 - 10 - 100$	90
		2	$200 - 2 \cdot 20 - 100 + 2 \cdot 50$	160	$200 - 2 \cdot 10 - 100$	80
25/36	No drought, no loss	0	200	200	200	200
		1	$200 - 20$	180	$200 - 10$	190
		2	$200 - 2 \cdot 20$	160	$200 - 2 \cdot 10$	180

Note: Payoffs in birr for each combination of drought, loss, type of insurance and units of insurance purchased. The (no drought, loss) state is where index insurance leads to downside basis risk.

Optimal demand as a function of risk preferences is presented in Figure 2. Graph (a) presents optimal demand by CARA preferences and Graph (b) represents optimal demand by CRRA preferences. The upper bound for optimal demand when assuming DARA preferences is 48.3% as per Clarke (2016).

Figure 2: Optimal demand for index insurance by risk preferences



Note: The graphs represent optimal demand for the index insurance product under assumption of CARA in graph (a) and CRRA in graph (b).

3.4 Risk preference elicitation

All subjects participated in a Binswanger lottery. Subjects chose between the six lotteries in order to elicit their risk-preferences. These choices are presented in Table 7 and are used to calculate risk preferences by taking the geometric mean of the interval for the coefficient of relative risk aversion implied by a subject's lottery choice, assuming CRRA preferences.

Table 7: Binswanger Lottery and Choices of Experimental Participants

Lottery option	Implied CRRA interval
25 birr with certainty	7.51 – ∞
Equal chance of 48 or 23 birr	1.74 – 7.51
Equal chance of 60 or 20 birr	0.81 – 1.74
Equal chance of 75 or 15 birr	0.32 – 0.81
Equal chance of 95 or 5 birr	0.00 – 0.32
Equal chance of 100 or 0 birr	0.00

4 Estimation strategy

To estimate the overall effect of the treatments on insurance purchase first a probit regression will be estimated where the binary dependent variable, Y is 0 if the subject, i, purchased 0 units of insurance and 1 if the subject purchased 1 or 2 units of insurance:

$$Pr(Y_{i,k} = 1) = \beta_1 Tr_{i,k} + \beta_2 Enum_k + \epsilon_{i,k} \quad \epsilon_{i,k} \sim N(0,1), \forall i = 1, ..., N \tag{1}$$

$Tr_{i,k}$ is the treatment variable which is 1 for the treatment condition where risk-sharing occurs. $Enum_k$ is a vector of dummy variables controlling for enumerator fixed effects. $\epsilon_{i,k}$ is the error term.

An ordered probit regression will be estimated through MLE where the probability of observing outcome $Y_i^* = n$ is estimated as a lineair function of the independent variables plus the error term:

$$Y_i^* = \beta_1 Tr_{i,k} + \beta_2 Enum_k + \epsilon_{i,k}, \quad \epsilon_{i,k} \sim N(0,1), \forall i = 1, ..., N \tag{2}$$

Y_i takes on values 0 through 2 according to the following scheme:

$$Y_i = n\mu_{n-1} < Y*_i \leq \mu_n, \tag{3}$$

where n=0, 1, or, 2, and $\mu_{-1} = -\infty$, and $\mu_m = +\infty$ An indicator variable $Z_{i,n}$ is defined which equals 1 if $Y_i = n$ and 0 otherwise. The log-likelihood can be written as:

$$ln(L) = \sum_{i=1}^{N} \sum_{n=0}^{n=2} Z_{i,n} ln[\Phi_{i,n} - \Phi_{i,n-1}], \tag{4}$$

where $\Phi_{i,n} = \Phi[\mu_n - (\beta_1 Tr_{i,k} + \beta_2 Enum_k)]$ and $\Phi_{i,n-1} = \Phi[\mu_{n-1} - (\beta_1 Tr_{i,k} + \beta_2 Enum_k)]$

To allow for the possibility that the data have been generated through a process whereby subjects separately decide to purchase zero or a positive amount and then decide the number of units to purchase (Mullahy, 1986; Cameron and Trivedi, 1998; Botelho et al., 2009) a hurdle model of a probit and a truncated-at-zero beta interval regression is used for the structural estimation of the insurance decisions (Cribari-Neto and Zeileis, 2010)[4].

The likelihood function for the hurdle model is constructed as the product of two likelihoods. The first component is the likelihood that the subject purchased zero or a positive amount of units of insurance and uses a probit specification. The second component is the likelihood based on the positive transfers and uses a truncated-at-zero beta-interval regression.

Let $\Phi_1(\alpha_1, Y_{i,k})$ represent the probability that the contribution is positive, let $f_2(Y_{i,k}, \alpha_2, \beta_2) = \{\Gamma(\alpha_2 + \beta_2)/[\Gamma(\alpha_2)\Gamma(\beta_2)]\} Y_{i,k}^{\alpha_2 - 1}(1-y)^{\beta_2 - 1}$ be the conditional distribution of the number of insurance units purchased, where $\alpha_2 > 0$ and 0< y ≤1, following Ferrari and Cribari-

[4]A typical way to perform a regression analysis in which the dependent variable assumes values in the standard unit interval (0, 1) is to use a logit or probit transformation and then perform a standard lineair regression. However, this approach has shortcomings. First, regression parameters will be interpretable in terms of the transformation and not in terms of the original dependent variable. Second, regressions involving data from the unit interval such as rates and proportions are typically heteroskedastic: they display more variation around the mean and less variation as we approach the lower and upper limits of the standard unit interval. Finally, the distributions of rates and proportions are typically asymmetric, and thus Gaussian-based approximations for interval estimation and hypothesis testing can be quite inaccurate in small samples.

Neto (2004). Let $\Phi_2(Y_{i,k}, \alpha_2, \beta_2)$ and denote the cumulative beta distribution. This re-parametrization of the beta distribution implies, for $f_2(Y_{i,k}, \alpha_2, \beta_2)$, parameters μ_2 and φ_2 where $\mu_2 = \alpha_2/(\alpha_2 + \beta_2)$ and $\varphi_2 = \alpha_2 + \beta_2$, so that $\alpha_2 = \mu_2\varphi_2$ and $\beta_2 = (1 - \mu_2)\varphi_2$. The advantage of this re-parametrization is that we can directly specify the mean and variance of the dependent variable $Y_{i,k}$ as $E(Y_{i,k}) = \mu_2$ and $Var(Y_{i,k}) = \mu_2$ and $Var(Y_{i,k}) = \mu_2(1\mu_2)/(1 + \varphi_2)$. The general form of the hurdle model likelihood function is then

$$
\begin{aligned}
L = \prod_{i\in\Omega_0} \{1 - \Phi_1(\alpha_1 + \beta_1 x)\} \quad \cdot \prod_{i\in\Omega_1} \{\Phi_1(\alpha_1 + \beta_1 x)\} \\
\cdot \prod_{i\in\Omega_1} \{f_2\{\Gamma(\alpha_2 + \beta_2)/[\Gamma(\alpha_2)\Gamma(\beta_2)]\} y^{\alpha_2 - 1}(1 - y)^{\beta_2 - 1}\}
\end{aligned} \tag{5}
$$

where $\Omega_0 = \{i|Y_{i,k} = 0\}$ denotes the zero contributions and $\Omega_1 = \{i|Y_{i,k} \neq 0\}$ denotes the positive contribution, and $\Omega_0 \cup \Omega_1 = \{1, 2, ..., N\}$. Taking the natural logarithm and rearranging terms, we see that the log likelihood can be written as

$$
\begin{aligned}
ln(L) = \sum_{i\in\Omega_0} ln\{1 - \Phi_1(\alpha_1 + \beta_1 Y_{i,k})\} + \sum_{i\in\Omega_1} ln\{\Phi_1(\alpha_1 + \beta_1 Y_{i,k})\} \\
+ \sum_{i\in\Omega_1} lnf_2\{\Gamma(\alpha_2 + \beta_2)/[\Gamma(\alpha_2)\Gamma(\beta_2)]\} Y_{i,k}^{\alpha_2 - 1}(1 - Y_{i,k})^{\beta_2 - 1}\}
\end{aligned} \tag{6}
$$

Since the likelihood function is separable with respect to the parameter vectors the log likelihood function can always be written as the sum of the log likelihoods from two separate models: a binomial probability model and a truncated-at-zero beta interval regression for $Y_{i,k}$.

5 Results

400 subjects participated in 10 sessions. Out of these 400 subjects three were unable to complete the experiment due to unanticipated family or work engagements. These individuals were excused from the experiment and received their participation fee. 80 individuals participated in the index insurance and risk-sharing treatment; 120 individuals in the indemnity insurance and risk-sharing treatment; 80 individuals in the index only treatment and 120 individuals in the indemnity only treatment. Table 8 presents the One Way Anova test for equality of means and variances for these four treatment groups and demonstrates that the sample is balanced.

Table 9 shows the mean units of insurance purchased and the proportion of individuals purchasing 0, 1, or 2 units of insurance per treatment. As we can see the proportion of individuals purchasing indemnity insurance decreases from 0.95 for the indemnity insurance only treatment to 0.83 for the indemnity insurance and risk-sharing treatment. The proportion

Table 8: Covariate balance test - One Way Anova

Covariates	F	chi2 equal variances
Gender	0.69(0.56)	0.13(0.99)
Household size	1.29(0.28)	5.44(0.14)
Marital status	0.23(0.88)	9.55(0.02)
Literacy	0.90(0.44)	0.03(0.99)
Education	0.24(0.87)	0.02(0.99)
Land size (Tsem)	1.11(0.35)	5.14(0.16)
TLU	0.81(0.49)	23.16(0.00)
Irrigation	1.21(0.31)	1.58(0.66)

of individuals purchasing index insurance increases from 0.47 for index insurance only to 0.92 for index insurance and risk-sharing. The mean units of insurance purchased decreases slightly for the indemnity insurance treatments when risk-sharing occurs, and more than doubles for the index insurance treatments when risk-sharing occurs.

Table 9: Descriptives insurance purchases per treatment

	Indemnity	Indemnity + Risk-sharing	Index	Index + Risk-sharing
Proportion who purchase				
No insurance (0 units)	0.05	0.17	0.53	0.08
Partial insurance (1 unit)	0.59	0.44	0.32	0.50
Full insurance (2 units)	0.36	0.39	0.15	0.42
Mean units purchased	1.31	1.23	0.61	1.33

Table 10 shows the ordered probit regression results for the units of insurance purchased where Column 3 and 5 include enumerator fixed effects. The estimates in the row 'Treatment' refer to the estimate for the odds of the combined MLE estimator while the row 'Margins' provides the effect on the predicted probability the number of units of insurance purchased. The overall effect is positive, large and significant for index insurance implying that risk-sharing increases index insurance purchase. The effect is driven by a significant reduction in the probability that individuals purchase 0 units of insurance and a significant increase in the probability that subjects purchase 2 units of insurance. The overall effect is negative but not significant for indemnity insurance. Table 11 present the result for the probit regression for a decision to purchase zero units of insurance versus a positive number of units of insurance. The row 'Treatment' presents the odds while the row 'Margins' present the estimated probability of purchasing a positive number of units of insurance. The occurence of risk-sharing significantly increases the probability of purchasing index insurance by 40% while it significantly reduces the probability of purchasing indemnity insurance by 11%.

Table 10: Ordered probit regressions of units of insurance purchased

	Indemnity insurance		Index insurance	
	(1)	(2)	(1)	(2)
Treatment	-0.14(0.15)	-0.13(0.15)	1.12(0.20)***	1.19(0.20)***
Margins				
$Pr(Y_i = 0)$	0.03(0.03)	0.02(0.03)	-0.34(0.05)***	-0.34(0.05)***
$Pr(Y_i = 1)$	0.03(0.03)	0.03(0.03)	0.02(0.03)	0.01(0.03)
$Pr(Y_i = 2)$	-0.05(0.06)	-0.05(0.06)	0.32(0.05)***	0.32(0.05)***
N	239	239	158	158
Enumerator FE		x		x
Pseudoll	-216.29	-215.05	-142.42	-136.16

Note: Ordered probit regression of the number of units of insurance purchased. Column 2 and 3 compare the indemnity insurance treatment to the indemnity insurance + risk-sharing treatment. Column 4 and 5 compare the index insurance treatment to the index insurance + risk-sharing treatment

Table 11: Probit regressions of binary insurance purchase decision

	Indemnity insurance		Index insurance	
	(1)	(2)	(1)	(2)
Treatment	-0.67(0.24)***	-0.67(0.25)***	1.43(0.26)***	1.52(0.28)***
Margins $Pr(Y_i = 1)$	-0.12(0.04)***	-0.11(0.04)***	0.40(0.05)***	0.40(0.05)***
N	239	239	158	158
Enumerator FE		x		x
Pseudoll	-216.29	-215.05	-72.58	-69.64

Note: Probit regressions of purchasing 0 units of insurance versus purchasing any number of units of insurance. Column 2 and 3 compare the indemnity insurance treatment to the indemnity insurance + risk-sharing treatment. Column 4 and 5 compare the index insurance treatment to the index insurance + risk-sharing treatment

Table 12 shows the MLE estimates for the hurdle model. In this joint estimation of both the probit of purchasing zero versus a positive number of units of insurance as well as the beta-interval regression for the number of insurance units we observe that the treatment of risk-sharing occurence predominantly has its effect through the estimate of Y_i^α. The odds estimate for the occurence of risk-sharing for index insurance is 1.46 and significant at the 1% level. This corresponds to an increase of .53 in the likelihood of purchasing any number of units of insurance (versus purchasing no insurance). The odds estimate for the occurence of risk-sharing for indemnity insurance is -0.66 and significant at the 1% level. This corresponds to a decrease of .06 in the likelihood of purchasing any number of units of insurance (versus purchasing no insurance).

Table 12: Hurdle model of probit and beta-interval regressions of insurance purchase

	Indemnity insurance		Index insurance	
	(1)	(2)	(1)	(2)
Y_i^α	1.23(0.10)***	1.62(0.18)***	0.48(0.09)***	-0.08(0.08)***
Treatment		-0.66(0.22)***		1.46(0.27)***
Y_i^μ	0.71(0.02)***	0.69(0.02)	0.70(0.04)***	0.65(0.05)***
Treatment		0.05(0.03)		0.07(0.04)*
Y_i^ϕ	0.25(0.01)***	0.24(0.01)***	0.25(0.01)***	0.23(0.02)***
Treatment		0.01(0.01)		0.02(0.02)
N	239	239	149	149
Pseudoll	-83.39	-78.38	-94.21	-73.97
H_0:$Y_i^\alpha = 0$	.00		.00	
H_0:$Y_i^\mu = 0$	.00		.00	
H_0:$Y_i^\phi = 0$	.00		.00	

Note: MLE estimation of hurdle model. Y_i^α is the parameter for the probit estimation. Y_i^μ and Y_i^ϕ are the parameters for the truncated-at-zero beta interval regression. The parameter estimates in (1) present the constants without treatment variable. (2) adds the treatment variable where treatment=1 for the treatments where risk-sharing occurs. Standard errors are clustered at the enumerator level.

6 Conclusion

In this paper we present a simple and highly generalisable model which gives clear closed form solutions, demonstrating that index insurance against aggregate shocks is a complement to informal risk-sharing, whilst indemnity insurance acts as a substitute. We also present the first empirical evidence that investigates these relationships directly by conducting an artefactual field experiment with low-income farmers in Ethiopia. Our experiment exogenously varies the extent of risk-sharing, and finds that, indeed, index insurance and risk-sharing are complements, while indemnity insurance and risk-sharing are substitutes.

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