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The Impact of Index-Based Insurance on Informal Risk-Sharing Networks

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The impact of index-based insurance on informal risk-sharing networks

Steve Boucher*and Matthieu Delpierre†

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1 Introduction

The near absence of formal crop insurance markets implies that rural households in many developing countries depend primarily on their own, potentially costly, autarkic strategies for income and consumption smoothing and the strength of their informal risk sharing networks to mitigate the myriad sources of risk they face (Rosenzweig & Binswanger (1993); Townsend (1994); Morduch (1995); Ligon et al. (2002)). This bleak risk management landscape for agricultural households may be changing thanks to the recent re-discovery of index insurance by researchers and development institutions. The indemnity in index insurance contract is based on an external index, such as rainfall, directly measured average yield, or satellite-based predictions of average yield, which is correlated with the individual insured farmer's yield, but independent of his/her isolated action and behavior. As such, the contracts are relatively immune to both the moral hazard and adverse selection problems that plague conventional, named peril contracts. This conceptual promise has spurred a number of research initiatives that explore the optimal design of index contracts and put in place and evaluate pilot index insurance initiatives (Barnett et al. (2008); Miranda & Farrin (2012)). The jury is still out on index insurance as significant challenges – including high basis risk, low farmer financial literacy, and high coordination costs across insurers, re-insurers and regulators – remain unresolved. If, however, these pilot projects are deemed successful and scaled-up, rural households in developing countries may enjoy expanded access to formal insurance markets via index insurance.

This goal of this paper is to consider how this expansion of formal crop insurance may play out. Specifically, we develop a theoretical model that explores how the introduction of a formal index insurance market may affect farmers' risk taking behavior and the degree of risk sharing in existing informal risk sharing arrangements (IRSAs). At first glance, the separate risk domains of the two types of institutions suggest unambiguously positive efficiency and welfare impacts. IRSAs are information intensive and thus tend to be limited to spatially concentrated areas, such as a village. As such, IRSAs are best suited to mitigate idiosyncratic risks, such as those deriving from health or plot-specific pest problems that are relatively independent across households within the village. In contrast, index insurance contracts are aimed at mitigating covariate shocks, such as yield declines due to drought, that tend to simultaneously affect all households in a village.

By removing the covariate risk that IRSAs are unable to address, index insurance would appear to unambiguously increase households' risk bearing capacity, leading to greater investment and welfare. Indeed, one might expect that by providing protection from covariate risk, index insurance may "crowd-in" and strengthen idiosyncratic risk sharing in IRSAs.

Closer consideration of the incentives embedded in IRSAs, however, reveals that this win-win scenario need not obtain. We show that when risk-taking is not contractible by members of the IRSA, the introduction of formal index insurance to individuals will reduce informal risk sharing and can also, under conditions we lay out, reduce risk taking and welfare. The crowding out of idiosyncratic risk sharing and investment is reversed if the index insurance contract is instead offered at the group level.

To understand the intuition behind the crowding out result, we must turn to the tradeoff that exists between incentives and risk sharing within IRSAs of finite size in the presence of moral hazard. If IRSAs

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were infinitely large, then members would be able to completely eliminate idiosyncratic risk through full risk pooling, and no tradeoffs would exist. In the real world, however, IRSAs are finite; they are limited to the number of households in a village or the individuals in a household's extended family. As such, even if members fully pool their idiosyncratic risk, the average realization of the idiosyncratic shock across network members in a given year need not be zero. As a result, IRSA members confront "residual" idiosyncratic risk. If risk taking is not contractible among members of the IRSA, then this residual idiosyncratic risk becomes a vector of moral hazard; as I increase my risk taking, I increase the variance of this residual risk and impose a negative externality on others in the group. Mutual insurance thus creates reciprocal externalities of risk, and the Nash level of risk-taking is excessive. To mitigate the adverse consequences of moral hazard, the group finds it optimal to adopt an incomplete rate of risk-sharing. This rate is second best as there is a tradeoff between insurance against idiosyncratic risk and excessive risk-taking.

We now see how the introduction of index insurance may have unintended, adverse consequences as the reduction of covariate risk provides incentives for individuals to increase their risk taking. In order to mitigate the ensuing higher residual idiosyncratic risk, the IRSA may endogenously choose to reduce the amount of idiosyncratic risk pooling, thus providing a counter-incentive in order to decrease risk taking. Our model is thus similar in spirit to that of Arnott & Stiglitz (1991) who show that formal insurers will ration insurance in order to maintain agents' incentives and that the agents' welfare may be decreased by the introduction of informal risk sharing.

The paper proceeds as follows. Section 2 introduces our assumptions on technology, risk and risk preferences and characterizes the first best level of risk taking. Section 3 introduces the institutional setup of the IRSA, in which members set the fraction of their idiosyncratic risk that they pool with others. We assume that the level of risk sharing is costlessly enforceable and characterize its equilibrium value. In contrast, we assume individual risk taking behavior is not contractible within the IRSA and, as described above, this will be the source of moral hazard. We show that for any given level of risk pooling, the equilibrium level of risk taking will be too high relative to the cooperative level. The second main result of Section 3 immediately follows; namely that in order to address the negative risk taking externality, the group will optimally choose incomplete sharing of idiosyncratic risk. Section 4 introduces a stylized index insurance contract in which the farmer chooses the level of coverage. The coverage level, in turn, is calibrated relative to the farmer's level of risk taking so that full coverage, i.e., coverage equal to risk taking, provides full insurance against covariate risk. Section 4 concludes by characterizing index insurance demand. Section 5 delivers the main results of the paper, namely the impact of the introduction of index insurance on informal risk sharing, individual risk taking and welfare under individual versus group subscription to index insurance. Section 6 concludes with a discussion of limitations to and potential extensions of the model and some reflections on the optimal design of index insurance contracts in developing countries.

2 Technology, risk and preferences

We consider a group of farmers belonging to the same community or cooperative, $N = \{1, ...n\}$. For the time being, we assume that group members are homogeneous, in terms of technology, endowment and preferences. Let us start by describing the technology and the risk environment. An individual farmer's income is stochastic and is supposed to have the following form:

$$Y(\sigma_i) = \mu(\sigma_i) + \sigma_i \Theta_i, \forall i \in N, \tag{1}$$

where Θ_i is a zero mean random variable with unit variance. Therefore, in the absence of insurance or risk-sharing, the mean and variance of income are simply given by

$$E(Y_i; \sigma_i) = \mu(\sigma_i); Var(Y_i; \sigma_i) = \sigma_i^2.$$

The function μ is twice continuously differentiable and has the following characteristics: $\mu'(\sigma) \geq 0$, for $\sigma \in [0, \sigma^{**}]$; $\mu'(\sigma) < 0$, for $\sigma \in (\sigma^{**}, +\infty)$ and $\mu''(\sigma) < 0$, where $\sigma \in R_+$ is a decision variable.[1] This specification is intended to represent the basic tradeoff between risk and return, which is inherent to agricultural production choices in uncertain environments. There will be such a tradeoff if the farmer's expected income can only increase at the cost of a higher variance, that is when μ is increasing in σ. One may argue that some technologies, such as irrigation facilities, allow to increase returns and reduce risk at the same time. This possibility is incorporated to our framework by the existence of a downward sloping portion of μ. Nevertheless, we do not expect any equilibrium value of σ to be situated in that portion. Indeed, the farmer will reduce his/her exposure to risk until the cost of doing so outweighs its benefits, which requires that the latter be positive, at least. Notice also that σ^{**} is the production strategy that would adopt a risk neutral farmer, who simply maximizes his/her expected income. Under imperfect or inexistent insurance markets, risk averse farmers' optimal choice will fall somewhere in the interval $[0, \sigma^{**}]$, that is precisely where there is tradeoff between risk and return: $\mu'(\sigma) \geq 0$. The variable σ is therefore intended to represent the farmer's risk-taking behavior.

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[1] We assume that shocks and expected income are additively separable. In theoretical papers, multiplicative risks are often encountered. We argue that our specification adds degrees of freedom to the multiplicative version. Our specification actually encompasses the multiplicative form as a special case: suppose Θ is a standardized random variable. The multiplicative form

Agricultural production is subject to a series of shocks of different natures, from drought and pests to illnesses undermining the farmer's ability to work. Turning to the risk environment of this model, a fundamental distinction needs to be drawn between to main classes of risks: on the one hand, let us call *covariate* the shocks that tend to affect the whole group at the same time, such as a rainfall deficit, or market prices. On the other hand, the term *idiosyncratic* pertains to risks that are orthogonal between individuals, such as very localized meteorological events or non-epidemic illnesses. From a statistical point of view, it is always possible to decompose a given risk between a common, or covariate, component, which is perfectly correlated within the group, and a idiosyncratic component. This is precisely how our risk structure is framed. We further specify the stochastic term as the sum of two independent random variables: $\Theta_i = \theta_c + \theta_i$. The covariate risk is embodied by $\theta_c \sim G$. This variable is common to everyone in the sense that there is a single draw and hence a unique value of θ_c at the group level. Besides, there are n i.i.d. random variables $\theta_i \sim F$. The latter therefore denote the farmer's idiosyncratic risk. The aggregate income shock is then the sum of a covariate shock $\sigma_i\theta_c$ and a idiosyncratic shock $\sigma_i\theta_i$. To be consistent with our assumptions on Θ_i, we have

$$E(\theta_c) = E(\theta_i) = 0,$$

$$Var(\theta_c) = (1-b)\,; Var(\theta_i) = b,$$

so that, indeed, $E(\theta_c + \theta_i) = 0$ and $Var(\theta_c + \theta_i) = 1$, by independence between θ_c and θ_i. The parameter b measures the - constant - idiosyncratic fraction of aggregate risk. When index-insurance will be introduced, this parameter will usefully approach the notion of basis risk. Intuitively, indeed, $(1-b)$ will be the fraction of risk that index-insurance may be able to capture, while b defines the scope for risk-sharing at the group level. At first sight, a constant b may appear restrictive. It requires that production choices, which we consider as endogenous, are allowed to impact on aggregate risk, but not on their type. While a choice between different types of seeds, or a decision on the intensity of chemicals application, seem to meet this requirement, the allocation of land or changes in the crop portfolio, may intuitively violate it. This is not necessarily true. Consider the following example. Suppose an initial situation where farmers allocate half of their land parcels to subsistence crops and the remaining to export crops. What are then the consequences on the risk structure of an increase in the fraction of land devoted to cash crops? Aggregate risk may certainly increase as the farmer's exposure to a single random price is higher and his/her diversification level is reduced. As regards the impact on b, the question is whether the scope for risk-sharing will be modified or, put differently, whether the correlation between their respective incomes will be affected. Therefore, the other farmers' choices will matter. If everyone modifies her allocation the same way, correlations remain unchanged. Correlations will be impacted provided changes are heterogeneous or different activities are available. b can indeed be higher if farmers specialize on uncorrelated activities. This is actually a coordination issue. Since our focus is on moral hazard, we only need to define risk-taking as a unidimensional concept.

We now turn to agents' preferences. The utility function $u(Y)$ is increasing and concave and characterized by constant absolute risk aversion (CARA). Making use of Pratt's approximation, the certainty equivalent of income can be written as

$$u^{-1}(Eu(Y)) \approx \tilde{Y} = \mu(\sigma) - \frac{1}{2}\eta Var(Y),$$

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would be

$$Y(\sigma) = (1+\Theta) f(\sigma).$$

Hence $E(Y) = f(\sigma)$ and $Var(Y) = f(\sigma)^2$. The function $f(\sigma)$ can then be normalized as $f(\sigma) = \sigma$, without loss of generality. It is now straightforward to show that this is strictly identical to our specification for $\mu(\sigma) = \sigma$. This is therefore more restrictive than the additive version.

where η is the - constant - coefficient of absolute risk aversion. Our results are not qualitatively affected by this choice of a particular class of utility functions, however. In our setting, the main implication of this choice is the following. When there is a tradeoff between risk and return, risk-taking σ increases both the expected income and its variance. Under CARA, those two effects can be readily identified. Under decreasing absolute risk aversion (DARA), a third positive effect would appear, namely a change in the farmer's subjective perception of risk. The latter effect would decrease the marginal cost of risk taking.[2] For the sake of readability, we simply want to get rid of this second order effect, which is clearly dominated by the increase in objective risk in any optimal decision on σ.[3]

To conclude this section, let us mention here a first benchmark case. Under perfect insurance markets, farmers can get protected against uncertainty at actuarially fair prices. In the first best, they then behave as risk neutral decision makers, in which case, optimal risk-taking simply maximizes expected income:

$$\mu'\left(\sigma^{FB}\right) = 0 \iff \sigma^{FB} = \sigma^{**}.$$

For this result to hold, it is nevertheless needed to assume that the covariate shock θ_c vanishes at the market level. In other words, the market needs to be sufficiently large so that groups of farmers with different and potentially independent θ_c's are themselves atomistic in the insurance market. Under this condition, by the Law of Large Numbers, the average shock will converge to zero.

3 Informal risk-sharing with moral hazard

Let us now move to a more realistic market environment. Due to information asymmetries and high levels of transaction costs, traditional insurance products are unavailable to most farmers in developing countries. Assume then, from now on, that insurance markets are completely missing. Since some fraction b of the farmers' income variability is uncorrelated between them at the local level, they have an incentive to pool their risks in order to smooth income. As amply documented, however, informal risk-sharing is subject to several enforceability constraints and is generally incomplete (Townsend (1994); Jalan & Ravallion (1999); Hoogeveen (2002); Murgai et al. (2002); Morduch (1995)), be it measured at the community or even at the household level (Duflo & Udry (2003)). In this section, we provide microfoundations for this incompleteness in a model with moral hazard in production choices. In the next section, index-insurance will be introduced to assess its impact on the, initially imperfect, functioning of informal risk-sharing.

3.1 The informal insurance setup

We assume, first, that group composition is exogenous. The examples we have in mind are therefore the cases of a producers' cooperative, an extended family or a rural community with stable membership. This is a rather mild assumption if group members are homogeneous. Indeed, endogenous changes in group composition are mostly expected to take place if agents differ in some respect. In our framework, this assumption simply amounts to saying that the size of the group n is exogenously given.

Second, as regards enforcement issues, we suppose that the group members can fully commit to make transfers to others ex post. It follows that we rule out limited commitment as a source of incomplete risk-sharing. We rather focus on moral hazard. The implications of this choice are discussed below. On the contrary, we suppose that the group is unable to prevent its members from adopting their preferred production plans. In other words, risk-taking σ is assumed to be unenforceable by the group. This will generate moral hazard as we make clear in what follows.

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[2] In autarky, for instance, the impact of a marginal change in risk-taking would be

$$\frac{\partial \tilde{Y}}{\partial \sigma} = \mu'(\sigma)\left(1 - \frac{1}{2}\eta'\sigma^2\right) - \eta\sigma,$$

under DARA, while it is simply given by

$$\frac{\partial \tilde{Y}}{\partial \sigma} = \mu'(\sigma) - \eta\sigma,$$

under CARA.

[3] Moreover, as shown by Clarke (2011), the shape of demand for index-insurance as a function of risk aversion is pretty similar in the two cases, namely CARA and DARA. In the former case, it does not seem abusive to think of the potential heterogeneity in the degree of absolute risk aversion as a good proxy for wealth inequalities.

Third, notice that the covariate shock being perfectly correlated among group members, it is not tradable. Let then α denote the share of his/her idiosyncratic shock that each farmer commits to pool at the group level. In practice, risk-pooling will translate into decentralized income transfers between group members. But, rather than writing bilateral transfers explicitly, let us consolidate those transfers at the group level. Let T_i stand for the net transfer received by farmer i. The group budget constraint therefore imposes that $\sum_{j \in N} T_j = 0$. If farmers pool a fraction α of their idiosyncratic shock, the budget constraint will be satisfied if and only if

$$T_i = \alpha \left(-\sigma_i \theta_i + \frac{1}{n} \sum_{j \in N} \sigma_j \theta_j \right). \tag{2}$$

To avoid any ambiguity, recall that a positive shock actually increases income. Then, as can be seen from this equation, the net transfer received by farmer i will be positive provided his/her idiosyncratic shock is lower than the average shock at the group level. Hence, a farmer facing a negative shock cannot always benefit from a transfer. The others' outcome obviously matter. Notice, also, that, as the size of the group increases, the average realization of idiosyncratic shocks converges to zero. It results that the capacity to absorb idiosyncratic risk is increasing in group size. Intuitively, this is simple due to a diversification effect. For a given level of risk-sharing α and making use of equations (1) and (2), farmer i's after transfer income writes

$$\begin{aligned} Y_i \left(\alpha, \sigma_1 ... \sigma_n \right) &= \mu \left(\sigma_i \right) + \sigma_i \left(\theta_c + \left(1 - \alpha \right) \theta_i \right) + \alpha \frac{1}{n} \sum_{j \in N} \sigma_j \theta_j \\ &= \mu \left(\sigma_i \right) + \sigma_i \theta_c + \sigma_i \left[\left(1 - \alpha \right) + \alpha \frac{1}{n} \right] \theta_i + \alpha \frac{1}{n} \sum_{j \in N \setminus \{i\}} \sigma_j \theta_j . \end{aligned} \tag{3}$$

By independence between the different random variables that appear in (3), we can write the variance of income as

$$Var \left(Y_i ; \alpha, \sigma_1 ... \sigma_n \right) = \sigma_i^2 \left(1 - b \right) + \sigma_i^2 \left[\left(1 - \alpha \right) + \alpha \frac{1}{n} \right]^2 b + \left(\alpha \frac{1}{n} \right)^2 \sum_{j \in N \setminus \{i\}} \sigma_j^2 b. \tag{4}$$

Recall that, in autarky, the income variance is simply σ_i^2. A careful inspection of expression (4) allows to highlight the following: the distinction between covariate and idiosyncratic risks becomes important. The former remains unchanged, while the latter is shared and then reduced. The second term illustrates this effect. The higher the level of risk-sharing α, the lower this term. The third term shows, however, that farmer i's income variability is now affected by the others' risk-taking behavior. Risk-sharing therefore entails risk spillovers. This will result in moral hazard.

3.2 Moral hazard

In order to highlight the impact of moral hazard in this setup, let us characterize the second best, which we define as the vector of risk-sharing and risk-taking $(\alpha, \sigma_1, ... \sigma_n)$ that maximizes welfare in the absence of formal insurance markets.

Proposition 1 ***Second best:*** *In the absence of formal insurance markets and if risk-taking σ is enforceable by the group, then risk-sharing is complete $\alpha^{SB} = 1$ and the level of risk-taking is homogeneous $\sigma_i = \sigma^{SB}, \forall i \in N$ and satisfies*

$$\mu' \left(\sigma^{SB} \right) - \sigma^{SB} \eta \left[\left(1 - b \right) + \frac{1}{n} b \right] = 0.$$

Proof. Given that farmers are homogeneous in technology, endowment and preferences, optimal risk-taking is constant across agents. If the same σ is adopted by every group member, the objective function writes

$$\tilde{Y} \left(\alpha, \sigma \right) = \mu \left(\sigma \right) - \frac{1}{2} \eta \sigma^2 \left[\left(1 - b \right) + \left[\left(1 - \alpha \right) + \alpha \frac{1}{n} \right]^2 b + \left(\alpha \frac{1}{n} \right)^2 \left(n - 1 \right) b \right]. \tag{5}$$

It is straightforward to show that the first order condition with respect to α gives

$$\frac{\partial \tilde{Y}}{\partial \alpha} = 0 \iff \frac{\partial Var\left(Y\right)}{\partial \alpha} = 0 \iff \alpha^{SB} = 1.$$

Taking the partial derivative of (5) with respect to σ and substituting for optimal risk-sharing gives the result in terms of risk-taking. ■

The second best can be reached if the level of risk-taking σ is enforceable. The group is then able to internalize the risk spillovers highlighted in equation (4). In the absence of moral hazard and of other potential source of imperfection, there is complete risk-sharing. Yet, even under complete risk-sharing, the idiosyncratic variance amounts to $\frac{\sigma^2}{n}b$, remaining strictly positive and vanishing only asymptotically with group size. By the latter effect, risk-taking is increasing in group size n and in b, which denotes the extent of the tradable risk. Insurance remains imperfect for two reasons: (1) the finite size on the group and (2) the existence of some non-tradable risk $\sigma^2\left(1-b\right)$. As expected in this context, risk-taking is still negatively related to the coefficient of absolute risk aversion η.

Assume now that σ is unenforceable. To analyze this case, we define the timing of the game as follows:

1. The group members agree on a rate of risk-sharing α.[4]
2. They simultaneously and non-cooperatively decide on their risk-taking level σ_i.

The impact of non-cooperative risk-taking is illustrated in the following Lemma.

Lemma 2 ***Moral hazard:*** *For any given level of risk-sharing α, the non-cooperative level of risk-taking is larger than the cooperative level and is therefore always inefficiently high: $\sigma^C\left(\alpha\right) < \sigma^N\left(\alpha\right), \forall \alpha \in [0,1]$.*

Proof. The cooperative level of risk-taking $\sigma^C\left(\alpha\right)$ maximizes (5) so as to internalize risk spillovers. $\sigma^C\left(\alpha\right)$ is hence implicitly defined by

$$\frac{\partial \tilde{Y}\left(\alpha,\sigma\right)}{\partial \sigma} = 0 \iff \mu'\left(\sigma^C\right) = \eta\sigma^C\left[\left(1-b\right) + \left[\left(1-\alpha\right)+\alpha\frac{1}{n}\right]^2 b + \left(\alpha\frac{1}{n}\right)^2\left(n-1\right)b\right]. \tag{6}$$

If risk-taking is unenforceable, agents have an incentive to deviate from this level. Indeed, taking the others' behavior as given, individuals maximize

$$\tilde{Y}_i\left(\alpha,\sigma_1...\sigma_n\right) = \mu\left(\sigma_i\right) - \frac{1}{2}\eta\left[\sigma_i^2\left(1-b\right) + \sigma_i^2\left[\left(1-\alpha\right)+\alpha\frac{1}{n}\right]^2 b + \left(\alpha\frac{1}{n}\right)^2\sum_{j\in N\setminus\{i\}}\sigma_j^2 b\right]. \tag{7}$$

The first order condition of this problem is

$$\frac{\partial \tilde{Y}_i\left(\alpha,\sigma_1...\sigma_n\right)}{\partial \sigma_i} = 0 \iff \mu'\left(\sigma^N\right) = \eta\sigma^N\left[\left(1-b\right) + \left[\left(1-\alpha\right)+\alpha\frac{1}{n}\right]^2 b\right]. \tag{8}$$

Since the other farmers' behaviors do not appear in farmer i's optimality condition (8), we have an equilibrium in dominant strategies (A fortiori a Nash equilibrium). It follows that equation (8) directly defines the Nash (non-cooperative) level of risk-taking σ^N. A simple comparison of conditions (6) and (8) shows that

$$\sigma^C\left(\alpha\right) < \sigma^N\left(\alpha\right) \iff \left(\alpha\frac{1}{n}\right)^2\left(n-1\right)b > 0.$$

Indeed, on the left hand side of both equations, we have the same decreasing function of σ ($\mu'' < 0$), while the right hand side is linearly increasing in σ, with a higher slope in the case of equation (6). ■

The intuition behind this result is simply that risk spillovers are not internalized by the individual. The individual marginal cost of risk-taking is therefore lower that the social marginal cost. This results in excessive risk-taking.

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[4] As group members are homogeneous, the choice of the equilibrium concept does not have an impact on the equilibrium value of α. For instance, a vote will be unanimous and its outcome will coincide with the choice of a dictator, arbitrarily selected within the group, or with a bargaining solution.

3.3 Incomplete risk-sharing

Lemma 2 provides us with the equilibrium risk-taking level for any given level of risk-sharing α. Let us now solve the first stage of the game where farmers get to agree on the rate of risk-sharing itself. As stated in the following proposition, moral hazard will be the source of incomplete risk-sharing.

Proposition 3 *In the absence of formal insurance markets and if risk-taking σ is unenforceable by the group, then risk-sharing is incomplete $\alpha^* < 1$ and the level of risk-taking is homogeneous $\sigma_i = \sigma^*, \forall i \in N$ and satisfies*

$$\mu'(\sigma^*) - \eta\sigma^* \left[(1-b) + \left[(1-\alpha^*) + \alpha^* \frac{1}{n} \right]^2 b \right] = 0.$$

Proof. The objective function is again given by expression (5), evaluated at $\sigma = \sigma^N(\alpha)$, namely the non-cooperative value of risk-taking (equation 8). The first order condition of this problem has the following form:

$$\frac{d\tilde{Y}}{d\alpha} = \frac{\partial \tilde{Y}}{\partial \alpha} + \frac{\partial \tilde{Y}(\sigma^N)}{\partial \sigma} \frac{\partial \sigma^N}{\partial \alpha} = 0, \tag{9}$$

where

$$\begin{aligned} \frac{\partial \tilde{Y}}{\partial \alpha} &= \eta \sigma^{N2} (1-\alpha) \frac{n-1}{n} b > 0 \iff \alpha < 1, \\ \frac{\partial \tilde{Y}(\sigma^N)}{\partial \sigma} &= -\eta \sigma^N \alpha^2 \frac{n-1}{n^2} b < 0. \end{aligned}$$

Those expressions are obtained by taking the first partial derivative of (5) with respect to α and σ, respectively. The latter derivative is then evaluated at $\sigma = \sigma^N(\alpha)$. To this end, we have made use of condition (8). Finally, applying the implicit function theorem on equation (8), we find that

$$\frac{\partial \sigma^N}{\partial \alpha} = -\frac{2\eta\sigma^N \left[(1-\alpha) + \alpha \frac{1}{n} \right] \frac{n-1}{n} b}{\mu''(\sigma) - \eta \left[(1-b) + \left[(1-\alpha) + \alpha \frac{1}{n} \right]^2 b \right]} > 0.$$

The second term on the right hand side of (9) is therefore always strictly positive. This implies that the first term has to be strictly negative for (9) to be satisfied, which is only possible if α is strictly lower than one. ■

As highlighted in Lemma 2, at every given rate of risk-sharing, moral hazard results in excessive risk-taking. The main intuition is then that incomplete risk-sharing helps to mitigate this effect. More precisely, the optimal rate of risk-sharing solves the tradeoff between a reduction in idiosyncratic risk and the resulting increase in risk spillovers that excessive risk-taking generates. This is precisely what condition (9) tells us: the first term on the right hand side gives the direct partial effect of risk-sharing on $\tilde{Y}$ and is positive as long as the former is incomplete. In other words, holding behaviors constant, the expected marginal utility of risk-sharing is positive as it reduces risk. However, the non-cooperative level of risk-taking consequently increases. As the initial level was already too high, this indirect partial effect of risk-sharing is detrimental to welfare. In this regard, a parallel can be drawn between our setup and the Arnott & Stiglitz (1991)'s model. Indeed, the impact of moral hazard is very similar as it generates insurance incompleteness in both settings. While incomplete risk-sharing arises in our informal environment, quantity rationing emerges on Arnott & Stiglitz (1991)'s formal market. In both cases, the partial insurance provides the agents with minimal incentives to behave cautiously.

A last point pertaining to the equilibrium level of risk-taking deserves a brief discussion here. An argument based on excessive risk-taking might appear at odds with empirical observations. Indeed, farmers in developing countries do not seem to behave as risk-neutral expected profit maximizers. Put differently, on may want to increase their level of risk-taking, not the contrary. In fact, we only assert that risk-taking may be excessive relative to the existing level of coverage. Background risk remains important. On the one hand, the covariate risk remains uninsured. On the other hand, the equilibrium level of risk-taking with moral hazard $\sigma^N(\alpha^*)$ may be inferior to the second best level of risk-taking $\sigma^{SB} = \sigma^C(1)$. Indeed, for a common rate of risk-sharing, $\sigma^N(\alpha) > \sigma^C(\alpha)$. But $\alpha^* < 1$ makes the sign of the difference between $\sigma^N(\alpha^*)$ and σ^{SB} ambiguous and thus fully compatible with the observation that farmers' production choices remain heavily affected by risk.

4 A formal insurance against covariate risk

This section is devoted to a description of the index-insurance contract. In practice, index-insurance contracts may essentially differ along two dimensions: on the one hand, the way the index is constructed and, on the other hand, the function that maps the index into the payout eventually received by farmers. We adopt here a very stylized contract, with the intention to capture its main property or purpose, which is to offer a coverage against covariate risk. We argue that the interaction between index-insurance and informal risk-sharing highlighted in this paper entirely relies on the ability of formal insurance to reduce covariate risk, not on the particular form taken by the contract. For the sake of legibility of the argument, we therefore define, in what follows, the simplest and most efficient way of reducing the covariate variance. More precisely, we make the two following simplifications.

4.1 The index

First, we assume that the formal insurance provider can observe the realization of θ_c, which will therefore be the index. The main simplification that this assumption implies consists in ruling out basis risk at the group level. In other words, the index perfectly coincides with the realization of the covariate shock of the group. To fix ideas, one can imagine that θ_c is simply rainfall, that rainfall is uniformly distributed across space, at least within the area where the group is located, and that there is a weather station in this area.[5] Due to the existence of the idiosyncratic risk θ_i, there is basis risk at the individual level, since individual yields are only imperfectly correlated with θ_c, but not at the group level. To make our framework more general and closer to reality, we should have assumed the existence of a third source of risk. Let us briefly describe this alternative setting. Suppose that the index is measured at a larger geographical scale. Maintaining the assumption that the index perfectly matches the variable θ_c, we need a new random variable to capture the divergence between the covariate shock of the group and the index. To this end, a random variable θ_g, independent to the $(n+1)$ others, could have denoted a group specific shock. With our assumption, we then abstract from this - realistic - third source of risk. The latter only increases the level of background risk. Neglecting it does not affect our results. Indeed, perfect income smoothing cannot be achieved, even in our simplified setting. Complete coverage against covariate risk is technically feasible, but the finite size of the group will prevent farmers from getting rid of their idiosyncratic risk.

4.2 The payout function

Second, the payout function is supposed to have the following form:

$$P_i\left(\theta_c\right) = -c_i\theta_c, \tag{10}$$

where $c_i \in R_+$ represents the rate of coverage. In the following sections, we will explore two alternative cases: (1) the case of individual subscription, where c is a farmer's choice variable and (2) the case of group subscription, where the decision on c is taken by the group. As shown by equation (10), the payout, or indemnity, P is positive in case of an adverse shock ($\theta_c < 0$) and negative otherwise. Full coverage is then obtained for $c_i = \sigma_i$, in which case the payout perfectly offsets the covariate shock $\sigma_i\theta_c$. In addition, we assume that a linear tariff πc_i is paid is every state of the world. It is easy to see that the expected payout is zero: $E\left(P\right) = 0$. It follows that the contract will be actuarially fair if and only if $\pi = 0$. While such a contractual form is the most efficient in terms of variance reduction, it is not observed in practice. Index-insurance practitioners are, instead, more familiar with a payout function such as

$$\begin{aligned} P_i\left(\theta_c\right) &= c_i\left(\tilde{\theta}_c - \theta_c\right), \text{ if } \theta_c \leq \tilde{\theta}_c, \\ &= 0, \text{ otherwise,} \end{aligned}$$

where $\tilde{\theta}_c$ is a strike point, generally negative (an adverse shock is required), below which a payment intervenes. A premium is then paid independently of θ_c. For this scheme, the actuarially fair premium is equal to the expected payout:

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[5] This is just an example as we can show that this setting also adequately represents the case of indexes based on average yields.

$$E(P_i) = c_i \int_{-\infty}^{\tilde{\theta}_c} \left(\tilde{\theta}_c - \theta_c\right) dG(\theta_c) = c_i G\left(\tilde{\theta}_c\right) \left[\tilde{\theta}_c - E\left(\theta_c \mid \theta_c < \tilde{\theta}_c\right)\right].$$

What our specification does is to assume that the strike point $\tilde{\theta}_c$ is equal to zero and that the premium is paid in cases of positive shocks and is proportional to the extent of this shock (the premium is $c_i\theta_c$). Our specification therefore flattens the income over both negative and positive values of θ_c. This is more efficient in terms of variance reduction. There is a couple of reasons why this simple scheme may be difficult to implement in practice: (1) transaction costs and (2) enforceability issues. The former argument simply says that if there is some fixed cost associated to the payment, then there is an interest to reduce the frequency of interventions by restricting them to cases of relatively large adverse shocks $\left(\tilde{\theta}_c < 0\right)$. The latter point pertains to the timing of the payment of premiums and indemnities. In our scheme, the value of the premium paid by the farmer (cases where $\theta_c > 0$) depends on the realization of the index. Its payment can therefore only take place ex post. While ex ante, before uncertainty is realized, everyone should be willing to pay the premium; ex post, the payment will be subject to commitment problems (ex post moral hazard). This is a fortiori true if the payout received by the farmer is, at this stage, zero with probability one. This second argument definitely goes against the enforceability of our scheme. Let us nevertheless concentrate on covariate variance reduction, what index-insurance is supposed to do, and assume that the payout function defined by equation (10) is enforceable.

Taken together, our two assumptions, on the index and the payout function, tend to overestimate the performance of index-insurance as a protection against risk at the group level. The interaction effects highlighted in this paper are therefore, themselves, overestimated as compared to real-life situations.

4.3 Demand for index-insurance

To conclude this section, let us explore what the demand for such a product will be.

While analyzing demand, the following points allow us to show that our representation of index-insurance is not over-simplified. The idea is that, with our contract, we are able to replicate important results that are generally admitted in the literature.

As a preamble, let us examine how a farmer's income is affected by the introduction of this contract. For a given level of coverage $c = \tilde{c}$ and for a given vector of risk-sharing and risk-taking behaviors $(\alpha, \sigma_1 ... \sigma_n)$, farmer i's income becomes

$$\begin{aligned} Y_i^{II} &= Y_i + (P - \pi\tilde{c}) \\ &= \mu(\sigma_i) - \pi\tilde{c} + (\sigma_i - \tilde{c})\theta_c + \sigma_i(1-\alpha)\theta_i + \alpha\frac{1}{n}\sum_{j\in N}\sigma_j\theta_j, \end{aligned}$$

where the superscript II stands for *Index-Insurance* and has the following mean and variance:

$$E\left(Y_i^{II}\right) = \mu(\sigma_i) - \pi\tilde{c}, \tag{11}$$

$$Var\left(Y_i^{II}\right) = (\sigma_i - \tilde{c})^2(1-b) + \sigma_i^2\left[(1-\alpha) + \alpha\frac{1}{n}\right]^2 b + \left(\alpha\frac{1}{n}\right)^2 \sum_{j\in N\setminus\{i\}} \sigma_j^2 b. \tag{12}$$

In the absence of index-insurance, the covariate variance was simply $\sigma_i^2(1-b)$. It is then worth calculating the reduction in variance that index-insurance allows to obtain:[6]

$$\Delta(\sigma_i) = Var(Y_i) - Var\left(Y_i^{II}\right) > 0 \iff \sigma_i > \frac{\tilde{c}}{2}.$$

This condition states that index-insurance will indeed reduce the farmer's income variance provided his/her level of risk is sufficiently high. This is consistent with the work of Miranda (1991) on area-yield crop insurance. To understand this condition, it is useful to re-write (12) as

$$Var\left(Y_i^{II}\right) = Var(Y_i) + Var(P) + 2Cov(Y_i, P).$$

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[6] See Appendix 1.

This implies that

$$\Delta\left(\sigma_i\right) = -\left[Var\left(P\right) + 2Cov\left(Y_i, P\right)\right],$$

where[7]

$$\begin{aligned} Var\left(P\right) &= \tilde{c}^2\left(1-b\right), \\ Cov\left(Y_i, P\right) &= -\sigma_i \tilde{c}\left(1-b\right). \end{aligned}$$

This decomposition shows that purchasing index-insurance amounts to participating in a lottery. The payout is itself stochastic and its correlation with income is imperfectly negative. The more negative the covariance between the farmer's income and the payout, the higher the benefit. It happens that this covariance is linearly increasing in σ_i. The demand for index-insurance will therefore be increasing in own risk σ_i.

Consider now c as a decision variable. The following proposition describes the shape of demand in the case of individual subscription, with and without moral hazard (and in the case of group subscription, but in the absence of moral hazard only. See the next section).

Lemma 4 *Individual subscription to index-insurance is given by*

$$c_i^* = Max\left\{0, \sigma^* - \frac{\pi}{\eta\left(1-b\right)}\right\}, \forall i \in N, \tag{13}$$

where σ^* *satisfies*

$$\mu'\left(\sigma^*\right) - \pi - \sigma^*\eta\lambda b = 0, \tag{14}$$

where

$$\begin{aligned} \lambda &= \frac{1}{n}, \text{ under cooperative risk-taking (no moral hazard),} \\ &= \left[\left(1-\alpha\right) + \alpha\frac{1}{n}\right]^2, \text{ under non-cooperative risk-taking.} \end{aligned}$$

Proof. Provided in Appendix 2. ■

Proposition 5 *Individual subscription to index insurance* c_i^*

1. *is decreasing in the premium* π : $dc_i^*/d\pi \leq 0$,
2. *is decreasing in the fraction of idiosyncratic risk over total risk* b : $dc_i^*/db \leq 0$,
3. *is hump-shaped in the coefficient of absolute risk-aversion* η*, with*

$$\lim_{\eta \longrightarrow 0^+} c^*\left(\eta\right) = \lim_{\eta \longrightarrow +\infty} c^*\left(\eta\right) = 0, \forall \pi > 0.$$

Proof. Those results derive from Lemma 4 and the application of the implicit function theorem on equation (14). ■

As expected, demand for index-insurance decreases with the premium π charged by the provider. Two other features that are generally admitted in the literature (see Clarke (2011)) appear in our framework: (1) demand decreases with basis risk b. The latter parameter describes indeed the share of total risk that the index fails to capture. (2) Demand is hump-shaped in the coefficient of absolute risk aversion η, which is fully consistent with the work of Clarke (2011). Moreover, we observe that risk-neutral and infinitely risk-averse agents do not purchase any index coverage. The intuition behind this result is given by the two following effects of risk-aversion:

$$\frac{dc^*}{d\eta} = \frac{\partial c^*}{\partial \eta} + \frac{\partial c^*}{\partial \sigma}\frac{\partial \sigma^*}{\partial \eta},$$

where

$$\frac{\partial c^*}{\partial \eta} > 0; \frac{\partial c^*}{\partial \sigma} = 1; \frac{\partial \sigma^*}{\partial \eta} < 0.$$

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[7] See Appendix 1.

On the one hand, the direct partial effect of risk-aversion on demand for index-insurance is positive, as intuition would suggest. Indeed, other things being equal, willingness to pay for insurance increases with risk-aversion. On the other hand, as noted above (see also Miranda (1991)), the benefits of index-insurance are increasing in the agent's initial level of variance. As it happens, risk-taking is itself decreasing in risk-aversion and, at the limit, infinitely risk-averse individuals have no risk to be protected against. With exogenous risk-taking, demand would have been monotonically increasing in risk-aversion. This shows the importance of considering production choices as endogenous.

5 The interaction between index-insurance and informal risk-sharing

We are now set to explore the effects that the introduction of a formal index-insurance contract might have on a pre-existing risk-sharing network. Our focus will be twofold. On the one hand, we will analyze whether index-insurance may crowd in or crowd out informal risk-sharing. In terms of our framework, where the network composition is exogenous, we will be interesting in a potential impact on the equilibrium rate of risk-sharing α^*. On the other hand, we will examine welfare implications.

5.1 The impact of index-insurance without moral hazard

Before turning to the case of moral hazard, let us briefly present the case of enforceable (cooperative) risk-taking as a benchmark. The following proposition characterizes the impact of index-insurance on risk-sharing, risk-taking and welfare in the absence of moral hazard. The initial situation (absence of index insurance) is therefore given by Proposition 1. Notice also that Proposition 6 is common to both individual and group subscription cases.

Proposition 6 ***The impact of index-insurance without moral hazard:*** *If risk-taking σ is enforceable by the group, then*

1. *The rate of risk-sharing is unaffected by the presence of index-insurance: $\alpha^* = \alpha^{SB} = 1$.*
2. *Individual demand for index-insurance is given by Lemma 4, which implies that*
3. *If the premium charged by the insurer is too high: $\pi > \sigma^{SB}\eta(1-b)$, then demand for index-insurance is zero and the initial level of risk-taking σ^{SB} remains unchanged, where σ^{SB} is defined in Proposition 1.*
4. *As index-insurance becomes affordable: $\pi \leq \sigma^{SB}\eta(1-b)$, demand for index-insurance is interior and the equilibrium level of risk-taking σ^* (defined by equation (14) with $\lambda = 1/n$), increases following any reduction in the premium: $\partial\sigma^*/\partial\pi < 0$.*
5. *Following the introduction of index-insurance, welfare increases; farmers' level of expected utility is a decreasing function of the premium: $\partial\tilde{Y}(\alpha^*, \sigma^*, c^*)/\partial\pi < 0$.*

Proof. Provided in Appendix 3. ■

This proposition first points out that, if risk-sharing is perfect, it is unaffected by index-insurance. Moral hazard is therefore the source of the crowding out effect that we highlight in the case of individual subscription.

Second, point 5 states that, in the absence of moral hazard, index-insurance cannot reduce welfare. Moreover, the impact on welfare is strictly positive, provided index-insurance is not too expensive. This is actually the best case scenario. This benchmark case can be directly linked with Arnott & Stiglitz (1991)'s paper. If group members can perfectly monitor each other to enforce the cooperative level of risk-taking, then they show that informal risk-sharing improves welfare. This statement simply needs to be reversed in this paper. In other words, this is, in our case, the introduction of formal insurance that increases welfare.

The remaining of this section is devoted to moral hazard cases. It is divided into two parts. The following subsection tackles the case of individual subscription to index-insurance, while the subsequent one explores the case of group subscription. This parameter of the "contract design" will prove crucial in determining interactions and welfare effects.

5.2 The impact of index-insurance with moral hazard: the case of individual subscription

Let us now analyze the impact of the introduction of index-insurance under non-cooperative risk-taking. Assume that an index-insurance contract is offered to farmers on an individual basis. Our attention is restricted here to the homogeneous case. While farmers are already homogeneous in terms of technology, endowment and risk preferences, we also want that all of them get access to the newly available contract. There may be reasons why this requirement might not be met in practice. For instance, index-insurance contract are often linked to a specific crop. If farmers are heterogeneous with respect to their crop portfolio, or if there are barriers to entry to this crop, then farmers may not have an equal access to the contract. This creates ex post heterogeneity and may alter our results. The impact of ex post heterogeneity is discussed below. The situation that is then best represented by this model is the case of a farmers' cooperative, potentially organized around a specific crop production, such as cotton, for example. In this case, the assumption of equal access is reasonable. Moreover, a producers' cooperative is a relevant social unit for risk-sharing as well.

In order to highlight the main effect of this model, we assume from now on that $\mu'''(\sigma) = 0$. Recall that the function μ describes the technology. Assuming that $\mu'''(\sigma) = 0$ amounts to making a second order approximation of the relationship between risk and return. This allows to get rid of higher order effects and to focus on the main result of this paper. The interested reader can refer to Appendix 5, where this assumption is relaxed.

Since we are dealing with the moral hazard case, the initial equilibrium, in the absence of index insurance, is described by Proposition 3. Recall, in particular, that equilibrium risk-sharing is, in this case, incomplete: $\alpha^* < 1$, which is a more realistic starting point. The timing of the game is as follows:

1. The group members agree on a rate of risk-sharing α.
2. They simultaneously and non-cooperatively decide on their risk-taking level σ_i and on their subscription to index-insurance c_i.

Proposition 7 ***The impact of index-insurance on risk-sharing under individual subscription: Crowding out.*** *If risk-taking σ is unenforceable by the group, then index-insurance crowds out informal risk-sharing if and only if subscription c^* is interior, more precisely,*

$$\begin{aligned}\alpha &= \alpha^* < 1, \text{ if } \pi > \tilde{\pi} = \tilde{\sigma}\eta(1-b), \\ &= \alpha^*_{II} < \alpha^* < 1, \text{ if } \pi \leq \tilde{\pi},\end{aligned}$$

where α^* is defined in Proposition 3 and where $\tilde{\sigma} = \sigma^{NC}(\alpha^*_{II})$, iff $\tilde{\sigma}$ satisfies

$$\mu'(\tilde{\sigma}) - \eta\tilde{\sigma}\left[(1-b) + \left[(1-\alpha^*_{II}) + \alpha^*_{II}\frac{1}{n}\right]^2 b\right] = 0.$$

Moreover, $\partial\alpha^*_{II}/\partial\pi = 0$.

Proof. Provided in Appendix 4. ■

This proposition states that the rate of informal risk-sharing is negatively impacted by the introduction of an index-insurance contract if the letter is offered at the individual level. More precisely, we highlight a drop in idiosyncratic risk-sharing as soon as individual demand for index-insurance becomes slightly positive. To describe this effect with more precision, let us draw a distinction between *discrete* and *marginal* crowding out effects. The former, which we observe in this model, pertains to the discontinuity in the rate of risk-sharing as a function of the premium π. In contrast, we would define the latter as an impact of π, and hence of the level of index-insurance coverage, on α at the margin. Surprisingly enough, this effect is not present in this model: $\partial\alpha^*_{II}/\partial\pi = 0$.[8] In other words, the negative impact on risk-sharing is a binary event, which is due to the very existence of index-insurance coverage and not due to the extent of this coverage.

In order to give additional insights into this discrete crowding out result, let us develop here an outline of the formal proof, which is available in Appendix 4.

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[8] Except if $\mu''' \neq 0$, see Appendix 5.

Understanding the first part of the proposition should be straightforward. It simply states that if the index-insurance coverage is too expensive, then demand is zero and everything happens as if it did not exist.

When the premium is lower than the threshold $\tilde{\pi}$, demand is positive. A new technology to deal with risk is then available to farmers and the second stage of the game, where risk-taking decisions σ are non-cooperatively made, gets affected by this change in the technological environment. In Appendix 4, we show that, in cases of interior demand for index-insurance, in equilibrium, non-cooperative risk-taking satisfies

$$\frac{\partial \tilde{Y}_i\left(\alpha, c^*, \sigma_1 ... \sigma_n\right)}{\partial \sigma_i} = 0 \iff \mu'\left(\sigma_{II}^N\right) - \pi = \eta \sigma_{II}^N \left[(1-\alpha) + \alpha \frac{1}{n}\right]^2 b. \tag{15}$$

Recalling that, in the absence of (or with corner) index-insurance, the condition was

$$\frac{\partial \tilde{Y}_i\left(\alpha, 0, \sigma_1 ... \sigma_n\right)}{\partial \sigma_i} = 0 \iff \mu'\left(\sigma^N\right) = \eta \sigma^N \left[(1-b) + \left[(1-\alpha) + \alpha \frac{1}{n}\right]^2 b\right].$$

Equation (15) incorporates the optimal index-insurance coverage c^*, given by Lemma 4. By comparing the right hand sides of those two conditions, we can see that this is the structure of the marginal cost of risk-taking that is essentially impacted by index-insurance. In particular, the marginal cost in terms of an increase in covariate risk which is $\eta \sigma (1-b)$, without index-insurance, simply disappears with index-insurance.[9] The reason is that the optimal coverage c^* increases by one unit for each additional unit of σ (see equation (13)). The *marginal* increase in covariate risk is therefore perfectly insured, but at the cost of a reduction in expected income by π units (the marginal benefit of risk-taking is now $\mu'(\sigma) - \pi$) . The role of the variable c is actually quite similar to the role of σ as both of them allow the farmer to exchange variability against expected income. In the absence of index-insurance, σ was used to deal with the tradeoff between expected return and both types of risk, covariate and idiosyncratic. With index-insurance, the index coverage c is a new instrument to reach a balance between expected return and covariate risk. It follows that σ concentrates on the balance between expected return and idiosyncratic risk. Solving backward, we then turn to stage 1, where the rate of rate-sharing α is selected, while incorporating the adverse effects of excessive risk-taking due to moral hazard. The form of the optimality condition remains similar as it writes

$$\frac{d\tilde{Y}}{d\alpha} = \frac{\partial \tilde{Y}}{\partial \alpha} + \frac{\partial \tilde{Y}\left(\sigma_{II}^N\right)}{\partial \sigma} \frac{\partial \sigma_{II}^N}{\partial \alpha} = 0,$$

where the terms $\partial \tilde{Y} / \partial \alpha$ and $\partial \tilde{Y}\left(\sigma_{II}^N\right) / \partial \sigma$ are identical to the corresponding expressions without index-insurance (see Proposition 3), except that they are now evaluated at the new equilibrium σ_{II}^N. However, the remaining term is strictly higher with index-insurance:

$$\frac{\partial \sigma_{II}^N}{\partial \alpha} > \frac{\partial \sigma^N}{\partial \alpha}.$$

In other words, following an increase in risk-sharing, risk-taking increases more with index-insurance than without. This is entirely imputable to the above-mentioned mechanism, namely the fact the marginal cost of risk-taking is reduced to the idiosyncratic risk. As α decreases this cost, the reaction of σ is of a higher extent. The moral hazard issue, in the sense of Lemma 2, therefore worsens. It results a reduction in the rate of risk-sharing. To understand this point, it might help to compare the social (SMC) and private (PMC) marginal costs of risk-taking[10] with index-insurance to the corresponding expressions without index-insurance:

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[9] This does not mean that the covariate risk disappears since the level of coverage is incomplete if $\pi > 0$. This is the marginal cost that is zero.

$$\begin{aligned}
SMC_{II} &= \eta\sigma\left[\left[(1-\alpha)+\alpha\frac{1}{n}\right]^2 b+\left(\alpha\frac{1}{n}\right)^2(n-1)\,b\right], \\
PMC_{II} &= \eta\sigma\left[(1-\alpha)+\alpha\frac{1}{n}\right]^2 b, \\
SMC &= \eta\sigma\left[(1-b)+\left[(1-\alpha)+\alpha\frac{1}{n}\right]^2 b+\left(\alpha\frac{1}{n}\right)^2(n-1)\,b\right], \\
PMC &= \eta\sigma\left[(1-b)+\left[(1-\alpha)+\alpha\frac{1}{n}\right]^2 b\right].
\end{aligned}$$

What should be noted in this comparison is that the ratio of the PMC over the SMC is lower with index-insurance. This is simply because the increase in covariate risk $\eta\sigma(1-b)$ has disappeared from the marginal costs. In other words, what the farmer internalizes of the SMC is proportionally lower. In simpler terms, the externality is proportionally higher with index-insurance. Risk-sharing consequently decreases.

Let us insist on the fact that this crowding out effect is totally independent of the extent of index coverage. This is because the marginal cost of risk-taking does not longer incorporate $\eta\sigma(1-b)$, even if c^* is arbitrarily close to zero. The effect is due to a radical change in the technological environment. The reduction in α is therefore not due to higher risk-taking. By the way, as attested by the following proposition, we cannot exclude that risk-taking decreases after the introduction of index-insurance.

It should also be noted that, as a corollary of Proposition 7, if π is strictly lower than, but arbitrarily close to $\tilde{\pi}$, then the index coverage is almost zero and α drops. The overall level of protection against risk is, in this case, unambiguously lower. Implications for welfare are analyzed below.

Proposition 8 ***The impact of index-insurance on risk-taking under individual subscription:*** *If risk-taking σ is unenforceable by the group, then*

1. *Its equilibrium level with index-insurance is given by*

$$\begin{aligned}
\sigma &= \sigma^*,\ \text{if } \pi>\tilde{\pi}, \\
&= \sigma^*_{II}(\pi),\ \text{if } \pi\leq\tilde{\pi},
\end{aligned}$$

where σ^* and $\sigma^*_{II}(\pi)$ satisfy the following conditions

$$\mu'(\sigma^*) = \eta\sigma^*\left[(1-b)+\left[(1-\alpha^*)+\alpha^*\frac{1}{n}\right]^2 b\right], \tag{16}$$

$$\mu'(\sigma^*_{II})-\pi = \eta\sigma^*_{II}\left[(1-\alpha^*_{II})+\alpha^*_{II}\frac{1}{n}\right]^2 b. \tag{17}$$

2. *Risk-taking drops if index-insurance is adopted but the coverage level is small: $\sigma^*_{II}(\tilde{\pi})=\tilde{\sigma}<\sigma^*$,*
3. *Risk-taking increases following any reduction in the premium: $\partial\sigma^*_{II}(\pi)/\partial\pi<0$.*

Proof. First, if $\pi>\tilde{\pi}$, then the coverage level is at a corner and the initial equilibrium is unaffected by index-insurance.

Second, if $\pi\leq\tilde{\pi}$, the demand for index-insurance becomes interior. By Proposition 7, the rate of risk-sharing drops to $\alpha^*_{II}<\alpha^*$ and the non-cooperative level of risk-taking now satisfies (15). Besides, recall that $\tilde{\pi}=\tilde{\sigma}\eta(1-b)$, with $\tilde{\sigma}$ such that[11]

$$\mu'(\tilde{\sigma})-\eta\tilde{\sigma}\left[(1-b)+\left[(1-\alpha^*_{II})+\alpha^*_{II}\frac{1}{n}\right]^2 b\right]=0.$$

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[10] The social marginal cost of risk-taking is the right hand side of equation (6),

[11] See Proposition 7 and its associated proof.

Therefore, one can see that the two conditions (16 and 17) coincide for $\pi = \tilde{\pi}$, except that the latter is evaluated at α^*_{II}. It follows that $\tilde{\sigma} < \sigma^*$.

Finally, applying the implicit function theorem on (17), it is immediate to see that $\partial \sigma^*_{II} / \partial \pi < 0$. ■

This proposition tells us that index-insurance has indeed the potential to increase risk-taking, but only provided the coverage level is sufficiently high. The intuition behind this result is that the reduction in covariate risk has to be high enough, so as to outwheigh the increase in idiosyncratic risk generating by the discrete crowding out effect. The overall effect on risk will then be negative if the premium is too high and demand negligible, thereby causing a reduction in σ. Welfare effects follow the same logic as the next proposition shows.

Proposition 9 ***The impact of index-insurance on welfare under individual subscription:*** *If risk-taking σ is unenforceable by the group, then the introduction of index-insurance decreases welfare if the premium π is too high, while the equilibrium coverage c^* is interior:*

$$\tilde{Y}^*_{II} \leq \tilde{Y}^* \iff \pi \in [\pi_0, \tilde{\pi}],$$

where

$$\begin{aligned} \tilde{Y}^* &= \tilde{Y}(\alpha^*, 0, \sigma^*), \\ \tilde{Y}^*_{II} &= \tilde{Y}(\alpha^*_{II}, c^*(\pi), \sigma^*_{II}(\pi)). \end{aligned}$$

Proof. Provided in Appendix 6. ■

The introduction of index-insurance might reduce welfare. We highlight two simple conditions for this unintended outcome to occur. On the one hand, the product has to be offered on an individual basis; on the other hand, the premium must be high enough. To illustrate this point, consider a situation in which the index coverage c^* is initially interior, but just equal to zero ($\pi = \tilde{\pi}$). We then show that a marginal decrease in π reduces expected utility. The marginal impact of π on expected utility (the certainty equivalent of income $\tilde{Y}$) is actually twofold, as the following equation illustrates

$$\frac{d\tilde{Y}^*}{d\pi} = \frac{\partial \tilde{Y}^*}{\partial \pi} + \frac{\partial \tilde{Y}^*}{\partial \sigma} \frac{\partial \sigma^*_{II}}{\partial \pi},$$

where

$$\frac{\partial \tilde{Y}^*}{\partial \pi} = -c^*; \frac{\partial \tilde{Y}^*}{\partial \sigma} < 0; \frac{\partial \sigma^*_{II}}{\partial \pi} < 0.$$

On the one hand, the direct partial effect of π on $\tilde{Y}$ is negative (positive) and simply corresponds to the increase (decrease) in the price paid for each unit of coverage puchased. On the other hand, the Nash level of risk-taking gets affected by a change in the premium[12]. An inspection of equation (17) shows that, as the marginal benefit of risk-taking decreases with π, σ^*_{II} is a decreasing function of π. Besides, since we are dealing with the case of unenfoceable σ, we know that risk-taking is excessive in equilibrium. It follows that the increase in σ^*_{II} that the reduction in the premium generates is detrimental to welfare. If π decreases at the margin, then the direct effect is positive and the indirect effect (through σ^*_{II}) negative. On can immediatly see that the former will be dominated by the latter if c^* is small.

Before concluding this subsection, an additional point is worth raising. The rate of risk-sharing is a social parameter in this model and one may argue that a social norm cannot adapt easily to changes in the institutional or market environment. If we follow this line of reasoning and assume that α is somewhat rigid, it becomes difficult to claim that index-insurance crowds out risk-sharing under the circumstances highlighted in this paper. Is this good news for welfare? Actually not. Indeed, recall that technically speaking, α maximizes welfare in any given context. Therefore, if the context changes and, more specifically, if the moral hazard issue get stronger with index-insurance, then the situation may be even worse under a constant α. In other words, the discrete crowding out effect is a good thing. It helps to temper the incentives to take excessive risk, but, as always, at the cost of a higher idiosyncratic risk.

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[12] By the envelop theorem, there is no indirect effect through a change in the optimal coverage c^*.

5.3 The impact of index-insurance with moral hazard: the case of group subscription

(*This section is still incomplete.)*

Let us turn to the group subscription case. If the index-insurance contract is offered to the group, the timing of the game should be adapted. Indeed, the coverage level c becomes a joint decision, whose status is then similar to the rate of risk-sharing α. The timing becomes:

1. The group members agree on a rate of risk-sharing α and on a coverage level c.
2. They simultaneously and non-cooperatively decide on their risk-taking level σ_i.

Proposition 10 *Unless offered at actuarially favorable prices, group subscription to index-insurance is always incomplete in equilibrium:*

$$c^* \in \left[0, \sigma^N\left(\alpha^*, c^*\right)\right), \forall \pi \geq 0.$$

Proposition 11 *The introduction of index-insurance is always welfare improving under group subscription.*

The intuition behind those two key results proceeds as follows: in the case of group subscription, the moral hazard effect of index-insurance is internalized by the group. In order to mitigate this effect, the group adopts a lower coverage level as compared to what an individual would have chosen, for any given level of the premium. In particular, if the contract is actuarially fair, group subscription remains incomplete. This outcome may contribute to explaining the low take-ups that are generally observed empirically. With group subscription, index-insurance is then welfare-enhancing, whatever the level of the premium. To understand the latter result, one should simply notice that, since the coverage level is a social parameter, it is chosen so as to maximize social welfare. Let us have a look at the first order conditions on risk-sharing α and subscription to index-insurance c. They are given by

$$\begin{aligned}
\frac{d\tilde{Y}}{d\alpha} &= \frac{\partial\tilde{Y}}{\partial\alpha} + \frac{\partial\tilde{Y}\left(\sigma^N\right)}{\partial\sigma}\frac{\partial\sigma^N}{\partial\alpha} = 0, \\
\frac{d\tilde{Y}}{dc} &= \frac{\partial\tilde{Y}}{\partial c} + \frac{\partial\tilde{Y}\left(\sigma^N\right)}{\partial\sigma}\frac{\partial\sigma^N}{\partial c} = 0,
\end{aligned}$$

with

$$\frac{\partial\tilde{Y}\left(\sigma^N\right)}{\partial\sigma} < 0; \frac{\partial\sigma^N}{\partial\alpha} > 0; \frac{\partial\sigma^N}{\partial c}.$$

This information implies that $\partial\tilde{Y}/\partial c > 0$ in equilibrium. In particular, if we assume that $\pi = 0$, it results that $c^* < \sigma^N\left(\alpha^*, c^*\right)$. As explained above, by opting for incomplete subscription, the group takes into account the moral hazard effect of insurance. The optimization on c follows therefore the same logic than the choice of risk-sharing α.

6 Concluding Remarks

Farmers in developing countries are exposed to a series of shocks of different natures. With missing credit and insurance markets, rural households mainly rely on informal risk-sharing arrangements to smooth consumption. However, on the one hand, those institutions are themselves subject to important information and commitment constraints, on the other hand, they do not offer any protection against common shocks. In this context, the development of index-insurance programs, whose primary target is precisely the covariate fraction of risk, was expected to enhance farmers' welfare. Besides, since the types of shocks that informal risk-sharing and index-insurance are supposed to protect against are orthogonal, interactions between both schemes were unexpected to occur. In this paper, we have shown that if informal risk-sharing suffers from moral hazard, then the introduction of index-insurance contracts at the individual level may crowd out informal risk-sharing. The reason thereof is that index-insurance reduces the marginal cost of risk-taking, thereby worsening the moral hazard issue, which has adverse consequences on welfare possibilities. This moral hazard effect is essentially a binary effect and will therefore be offset if index-insurance proves sufficiently beneficial in terms of coverage. This will be the case if the premium charged by the provider is low enough. Fortunately, adverse effects on welfare are not entirely robust to changes in the contractual form. In particular, if index-insurance is offered at the group level, then its impact on risk-taking is properly internalized by the group and welfare effects are always positive.

Let us point out some final considerations.

First, it should be mentioned that the crowding out result critically depends on the presence of moral hazard. If the imperfection of informal risk-sharing rather originates from commitment constraints, contrasting predictions can be derived. Suppose that risk-taking is contractible (no moral hazard) but that informal insurance transfers are subject to commitment constraints. Suppose also that the sanction the group can inflict on defaulters is exclusion. Then group members evaluate the cost from the transfer they are supposed to make against the benefit they draw from group membership. In the case of a cooperative, this benefit not only includes infomal insurance but also other benefits associated to membership such as access to credit and other commercial facilities. Assume now that index-insurance is offered at the group level. In such a context, index-insurance may crowd in informal risk-sharing as the value of group membership is enhanced, which tends to relax the incentive compatibility condition and may increase the rate of informal risk-sharing. However, risk-taking seems difficult to enforce in practice and moral hazard may still prove relevant, even if combined with limited commitment in reality.

Second, the moral hazard effect of index-insurance that our model highlights is actually attributable to the fact that agents are allowed to choose their subscription level at the margin. This is indeed what generates the effect on the marginal cost of risk-taking. Therefore, a take it or leave it insurance offer would solve the issue. However, information asymmetries may prevent policy-makers from finding the appropriate rate of coverage. The solution would then be to delegate this task to agents that are better informed, such as the group itself. This observation offers another interpretation of our recommendation that group subscription should be favored.

Third and finally, an important limitation of our framework is that only homogeneous groups are considered. While we do not expect important changes to occur in the case of individual subscription, the impact of group heterogeneity under group subscription deserves attention. Indeed, if a single subscription level is adopted at the group level, it is unlikely to be optimal for every member. Welfare effects should then be carefully analyzed. A final issue that our paper does not address is: what if the two groups, namely the informal risk-sharing network and the set of agents to whom index insurance is offered, do not coincide? Those two considerations should be tackled in future research.

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