# THE IMPACT OF INTERLINKED INDEX INSURANCE AND CREDIT CONTRACTS ON FINANCIAL MARKET DEEPENING AND SMALL FARM PRODUCTIVITY

Michael R. Carter†
University of California, Davis

Lan Cheng††
University of California, Davis

Alexander Sarris† † †
University of Athens

March 16th, 2011

ABSTRACT. This paper explores the relationship between credit and index insurance market development using a theoretical model in which small farm households have the option to either (i) adopt a capital-intensive technology that is risky but high-yielding, or (ii) self-insure by adopting a traditional low-input technology. We show that neither market is likely to develop in isolation from the other, and that uptake of improved technology will be low absent efforts to link credit and insurance. The failure of index insurance markets to independently develop is not per se due to the existence of basis risk or to its expense as self-insurance strategies are similarly characterized by basis risk and are costly to the household as they reduce mean incomes. However, we show that the interlinkage of credit and index insurance contracts can allow both markets to develop because the interlinked contract is more likely to stochastically dominate self-insurance. The analysis also shows that the way interlinkage will work depends fundamentally on the nature of the agricultural credit market and the degree to which lenders are able to demand and seize collateral in the event of loan default. This interplay between collateral and the nature of credit-insurance interlinkage has direct and important implications for the design of programs to simultaneously boost small farm productivity and deepen rural financial markets.

**Keywords:** Index insurance, Credit rationing, Interlinkage, Technology adoption

† Department of Agricultural and Resource Economics, mrcarter@ucdavis.edu.

†† Department of Agricultural and Resource Economics, lancheng@ucdavis.edu.

† † † Department of Economics, alekosar@otenet.gr.

# 1. Introduction

The correlated risks and information asymmetries that typify many low income smallholder agricultural economies can keep rural financial markets (for credit and insurance) thin or even absent.[1] The costs of these thin markets are obvious (and well documented), but the solution is far less clear. An earlier generation of efforts to employ conventional agricultural insurance to address the risk needs of the small farm sector failed under the weight of transactions costs, adverse selection and moral hazard (Hazell, 1992) .While it is tempting to declare the problem unsolvable, the pernicious role that risk plays in the construction and perpetuation of rural poverty demands further efforts in this area.

Enabled by technological advances in remote sensing and meteorological data, novel forms of agricultural index insurance (which indemnifies insured farmers based on an index that is correlated with individual outcomes, but is not influenced by individual behavior) would appear to offer a solution to this problem of thin financial markets twinned with low small farm productivity. And yet, despite their compelling logic, agricultural index insurance contracts have met with sometimes indifferent demand and low uptake by the intended beneficiary populations. While there can be multiple explanations for low uptake rates, this paper argues on theoretical grounds that uptake and impacts will be higher when index insurance is interlinked with credit contracts. Put simply, our argument is that either market, credit or insurance, in isolation is likely to be thin or slow to develop in smallholder agriculture. But when contracts are interlinked, the gains in market deepening and productivity growth are likely to be higher. Among other things, we will show that impacts of interlinkage are somewhat subtle, and differ across different types of economic environments.

Tendency to try to explain by inappropriate analogy to developed country experience, or by general statements/unadorned observations that basis risk too high or costs/loadings too high.[2] However, the reality is that the self-insurance strategies employed by small farmers expose farmers to significant basis risk and are actuarially unfair, with high implicit loadings and premia. The question is thus not whether or not there is basis risk under index insurance, but whether index insurance can stochastically dominate self-insurance.

Asking the question this way motivates the search for ways to combine index insurance with adoption of higher-yielding, but riskier technologies. That is, index insurance will more likely

---

[1]See Binswanger and Rosenzweig (1986)for a persuasive, if somewhat informal discussion of these points.

[2]See Smith and Watts (2009) for an analysis of the relevance of developed country experience for developing country index insurance schemes.

stochastically dominate self-insurance if it is a non-zero sum proposition that simultaneously allows an increase in expected income even as it reduces risk exposure. We here explore ways in which this might happen through the interlinkage of index insurance with credit contracts.

To do this, Section 2 reviews related theoretical studies and empirical evidence from developing countries. Section 3 presents a stylized model/representation of the technology and contracts potentially available to producer-consumer households in a low income agricultural economy. We show that index insurance contracts can be represented as a mean preserving squeeze of the stochastic distribution determining output, and the agricultural credit supply is determined by lenders' exposure to covariant default risks. Section 4 then explores households' demand for technology and financial products (credit and insurance) under three insurance schemes: 1) no insurance available, 2) stand-alone/non-interlinked index insurance, 3) interlinked index insurance with credit. We analyze each schemes in two stylized environments: one characterized by high levels of collateral ("Latin America") and another characterized by low levels of collateral ("Africa"). The analysis shows that while it substantially improves the demand for high-yielding technology and financial products when collateral level is high, the introduction of non-interlinked insurance has small positive or even negative impacts on households' demand when collateral level decreases. In contrast, the interlinked index insurance sustantially boosts households' demand for high-yielding technology in a low collateral environment. Section 5 analyzes the impacts of different insurance schemes when the credit market reaches an market equilibrium by endogenizing the quantity of agricultural loans. We show that the demand for new technology and financial products under no insurance and non-interlinked insurance schemes discussed in Section 4, will be choked off by the increased price of credit. However, when insurance is interlinked with credit, the lender is willing to provide any amount of agriculturl loans at a fixed low price so that any expansion of the demand will not be choked off. The performance of the interlinked contract also depends on basis risk and loading costs of index insurance and household heterogeneity of risk preference and wealth. The last part of this section explores the sustainablity of government subsidy program that subsidizes insurance premium. Section 6 concludes.

## 2. LITERATURE REVIEW

A very recent theoretical paper by Miranda and Gonzalez-Vega (2010) is the most related to our study. Miranda and Gonzalez-Vega focus on the impact of index insurance on lenders' profitability

when both basis risk and loading costs are extremely high. They argue that the lender's mandatory requirement that borrowers have to purchase index insurance to renew loans, would induce borrowers to default the existing loan contracts and thus lowers the lender' profits since the high basis risk and high insurance loading costs make the bundled loan contract less valuable and costly for borrowers. Although the heavily subsidized insurance could reduce default rates and increase lenders' profits, profit-maximizing lenders would increase interest rates so that the benefit of insurance could not accure to borrowers. They propose that instead of borrowers purchasing insurance, lenders' direct purchase of unsubsidized index insurance can stablize lenders' equity growth rate, because lenders can diversity the idiosycratic risks and have small basis risk.

However, Miranda and Gonzalez-Vega neglect the positive impact of index insurrance when basis risk and loading costs are in a reasonably moderate range. Second, they overestimate the negative impact of mandatory index insurance on lenders' profitability when basis risks and loading costs are extremely high by assuming that 1) lenders use dynamic incentive to reduce intentional default; 2) the lender reinforces the purchase of index insurance with future loans before the borrower repays the existing loan. These assumptions indicate that if index insurance lowers the expected utility of future borrowing, the borrower would not only refuse to borrow in the future but also default the existing loan. This exaggerates the negative influence of mandatory indxe insurance policy on default rates when basis risk and loading costs are high. If lenders either employ current losses such as collateral requirement instead of future loss such as dynamic incentive, or use dynamic incentive but introduce index insurance after borrowers fulfill their existing liability[3] , mandatory index insurance would mainly affect households' demand for loans but have small impact on default rates and lenders' profits. In other words, households would not borrow at all in the first place if the bundled insurance and loan contract does not peform well. Third, they do not show why systematic risk matters for lenders. Although they argue that systematic risk increases the variance of rate of return on equity, there is no structure to show that lenders' profitability depends on the variance of equity growth. Therefore, it is not convincing to conclude that lenders lose from borrowers' purchase of index insurance or benefit from their direct purchase. Finally, while arguing that expected-profit maximizing lenders will not allow their benefit from borrowers' purchasing insurance to accrue to borrowers. they do not show whether lenders allow the benefit from their own purchase of insurance

---

[3]If insurance does increase default rate, lenders are very likely to choose to introduce insurance after borrower repay the loan rather than before the repayment.

to accure to borrowers. Therefore, we cannot draw the conclusion that borrowers benefit more from lenders' being directly insured than lenders being indirectly insured through borrowers.

Our study contributes to the deeper understanding of the effect of borrowers' purchase of index insurance on lenders' ( and other firms) profitability. First, we analyze both "good" index insurane program (with moderate basis risk and loading costs) and "bad" index insurance program (with extremely high basis risk and loading cost as specified in Miranda and Gonzalez-Vega (2010)). Second, in our model farmers endogenously choose to borrow or not (which is exogenous in Miranda's model), knowing that if they choose to borrow they have to follow an exogenous repayment rule. We explicitly show how index insurance contract alters the risk structure and how covariant shocks influence lenders' expected profits given difference collateral environment. The results show that with "good" index insurance, mandatory insurance would reduce default rates and increase lenders' expected profits substantially in a low collateral environment. With "bad" index insurance as shown in Section 5.3 , mandatory insurance would lower lender's profits by raising default rates as predicted by Miranda's model, but by a very small shift. Third, we analyze how the interlinked insurance and credit contract can transfer lenders' benefits from index insurance to borrowers by endogenizing interest rates. Given a competitive credit market with a fixed level of expected profits, lenders are willing to lower interest rates when borrowers' purchase of insurance raises their profits. This interlinked contract is the key to make the lenders' profit level exogenously fixed. Since the interlinked contract enforces the insurance and credit contracts to be agreed upon simultaneously, borrowers can use their bargaining power to control lenders' profit level. In contrast, if lenders directly purchase insurance, they are likely to be profit-maximing and withold the benefit as shown in Miranda and Gonzalez-Vega (2010).

To the best of our knowledge, our paper is the first theoretical study to systematically analyze the impact of index insurance through the synergy with credit and production-enhancing technology on the financial market deepening, technology adoption and farmers' welfare. Specifically it is the first one to 1) endogenize credit supply when lenders' profitability depends on covariant shocks; 2) construct the market equilibrium of the credit market by endogenizing the quantity of agricultural loans; 3) analyze the impact of collateral environment, representing the implicit insurance provided by the loan contract, on the performance of formal index insurance, 4) analyze the impact of the interlinkage on a heterogeneous population instead of a typical representative. Our results shows

4

that index insurance is valuable to individual farmers when insurance is associated with production-enhancing activities. Index insurance is also valuable to lenders when borrowers purchases index insurance. Index insurance beomces even more valuable to households when insurance is interlinked with credit that transfers the benefit of insurance from lenders to borrowers.

There is one related empirical study by Giné and Yang (2009) who try to test the effect of bundled index insurance and loan contract on the demand of credit for the purpose of adopting new technology in Malawi. They use randomized field experiment where farmers in the treatment group have to purchase index insurance contracts in order to obtain loans and farmers in control group are offered loan contracts only. Note that the loan contract terms for the treament group are the same as that for the control group, which means the bundled contract in their experiment is essentially a non-interlinked index insurance and credit contract. Their result shows that the take-up rate of the bundled loan contract was 13% lower than that of uninsured loan, because the limited liability clause provides implicit insurance crownding out the demand for formal insurance. This result coinsides with the prediction of our model that the non-interlinked contract has a lower demand than stand-alone loan contract when the collateral level is low. More importantly, our model proposes an innovation of the interlinked index insurance and credit contract to solve this puzzle. Our model sugguests that the interlinked contract outperforms the non-interlinked and the stand-alone loan contract, especailly in a low collateral ( limited liability) environment, by inducing a higher take-up rate of credit and new technology.

## 3. Environment, Technology and Financial Contracts

This section lays out a stylized model of the risk-averse and small farm household. While highly simplified, the model captures the key elements of the small farm problem that are relevant to the problem at hand, including the self-insurance options available to the household. Agricultural production is influenced by both covariant and idiosyncratic shocks. Against this backdrop we define the set of potential financial contracts that could be offered by competitive lenders and insurance firms.

3.1. **Risk and Household Production and Consumption.** Small farm households are assumed to have access to two technologies, a traditional technology with low, but stable returns, and a higher yielding, but riskier technology that requires substantial use of purchased inputs. Both technologies are subject to idiosyncratic (or specific) shocks, $\theta_s$ and covariant shocks, $\theta_c$. We assume

a multiplicative structure and write the output of low-yielding technology as:

$$(3.1) \qquad y_\ell = \theta g_\ell$$

where $\theta = (\theta_c + \theta_s)$ with support $[0, \bar{\bar{\theta}}]$ , probability distribution function denoted $f(\theta)$, cumulative distribution function denoted $F(\theta)$ and $E(\theta) = 1$. From now on utill Section 5.3 we assume covariant risk dominates idiosyncratic risk. [4] The net income from low yielding technology is denoted as $\rho_l = y_\ell$ . Similarly, we write the output of the high-yielding technology as

$$(3.2) \qquad y_h = \theta g_h(K)$$

where $K$ is the amount of purchased inputs required. The superiority of high-yielding technology is the higher expected net return, $g_h(K) - K > g_\ell$. We further assume capital $K$ can only be financed by borrowing from the rural credit market. Denote the loan contract as $\ell < K, r, \chi >$, where $r$ is the contractual interest rate and $\chi$ is the collateral required (Section 3.3 gives details on the determination of contract terms). Net returns to the household under this loan contract are as follows:

$$(3.3) \qquad \rho_h = \begin{cases} \theta g_h(K) - (1+r)K, \text{ if } \theta > \tilde{\theta} \\ -\chi, \text{ otherwise} \end{cases}$$

where $\tilde{\theta} = \frac{(1+r)K - \chi}{g_h(K)}$ is the level of the shock such that the value of the collateral plus the output produced just equals the value required for full loan repayment. Note that this specification sharply assumes that the household retains no income (or collateral assets) until after the loan is repaid.

Assuming the separability between household's consumption and production, household consumption is given by $c_t = \rho_t + W + B, t = h, \ell$, where $W$ is the household's consumable and collateralizable wealth and $B$ is the risk-free income from off-farming activities. The lowest consumption can be under the high-yielding technology is $\underline{c} = W + B - \chi$. Figure 3.1 shows household consumption as a function of the stochastic factor under the two technologies in high and low technology environments. The dashed line represents consumption as a function of the stochastic factor under the low technology, whereas the solid curve represents consumption under the high technology when collateral is high and $\tilde{\theta}$ is low. As collateral requirements decreases, the consumption floor rises

---

[4] The simulation uses 75% of covariant risk over the total risk.

under the high technology illustrated by the dotted line, as more of the down-side risk is borne by the lender.

Assume the household is risk-averse and has a conventional concave utility function, $u(c)$. For purposes of later numerical analysis that we will use to illustrate various propositions, we assume that the utility function exhibit Constant Relative Risk Aversion (CRRA). Households choose technologies and contracts to maximize expected utility. The population of the economy is distributed following the joint probability distribution function $h(\psi, W)$, where $\psi$ is the Arrow-Pratt measure of relative risk aversion.

Figure 3.1 allows further exploration of risk under the high technology and the effectiveness of self-insurance. Using the numerical specification detailed in Appendix A, the solid line in Figure 3.1shows the CDF of household consumption under the self-financed high technology, while the dash dotted line shows the CDF of consumption under the low technology. Under this specification, the low technology substantially reduces the probability of low outcomes. However, this self-insurance strategy is far from perfect. First, it is actuarially unfair, reducing expected household income (and consumption) by the difference in expected incomes between the high and low technologies (23% of expected income reduction in the numerical parameters used to generate the figure). Second, compared to an idealized contract that shielded the household against any consumption losses any time the high yielding technology resulted in production less than its expected value (illustrated in Figure 3.1by the dashed line),[5] self-insurance exposes the household to residual or basis risk as there is still a substantial probability of consumption well below the expected level. As can be seen, this idealized contract stochastically dominates self-insurance. While the index insurance contracts discussed in the next section are clearly not going to dominate this type of idealized contract either, the relevant question is whether they can dominate self-insurance given the basis risk and implicit loadings associated with it.

3.2. **Index Insurance Contracts.** Unlike conventional agricultural insurance that pays off based on individual outcomes ($y_t$ in our notation), an index insurance contract contract pays off based on direct observation of the covariant shock ($\theta_c$) or on average yields ($\theta_c g_t$).[6] To keep matters simple,

---

[5]The contract illustrated in Figure 3.1is emulates a multi-peril contract that restores farm income to its average level any time an idiosyncratic or covariant shock occurs. Subtracted from consumption is the actuarially fair premium for such coverage. Such contracts typically do not exist for the small farm sector because of moral hazard, adverse selection and high transaction costs.

[6]As discussed by many authors, index insurance avoids the moral hazard, transactions costs and adverse selection problems that render conventional agricultural insurance unsustainable.
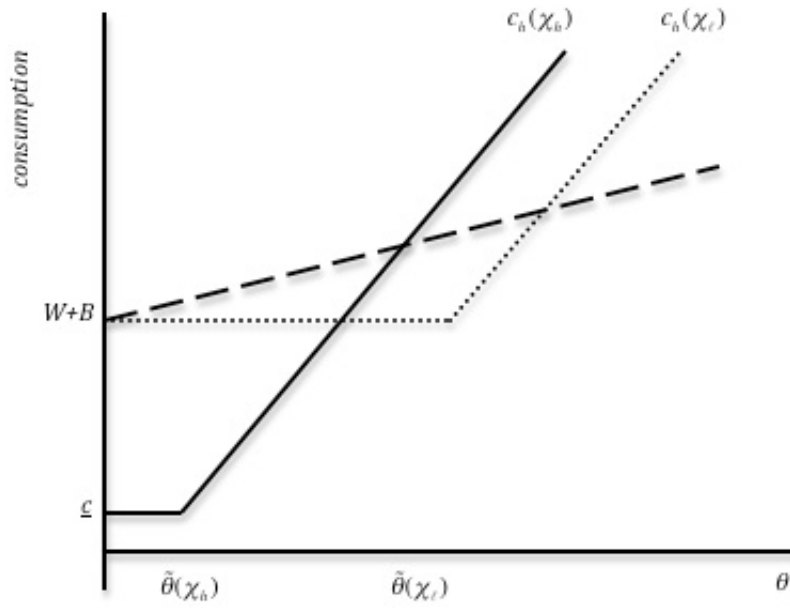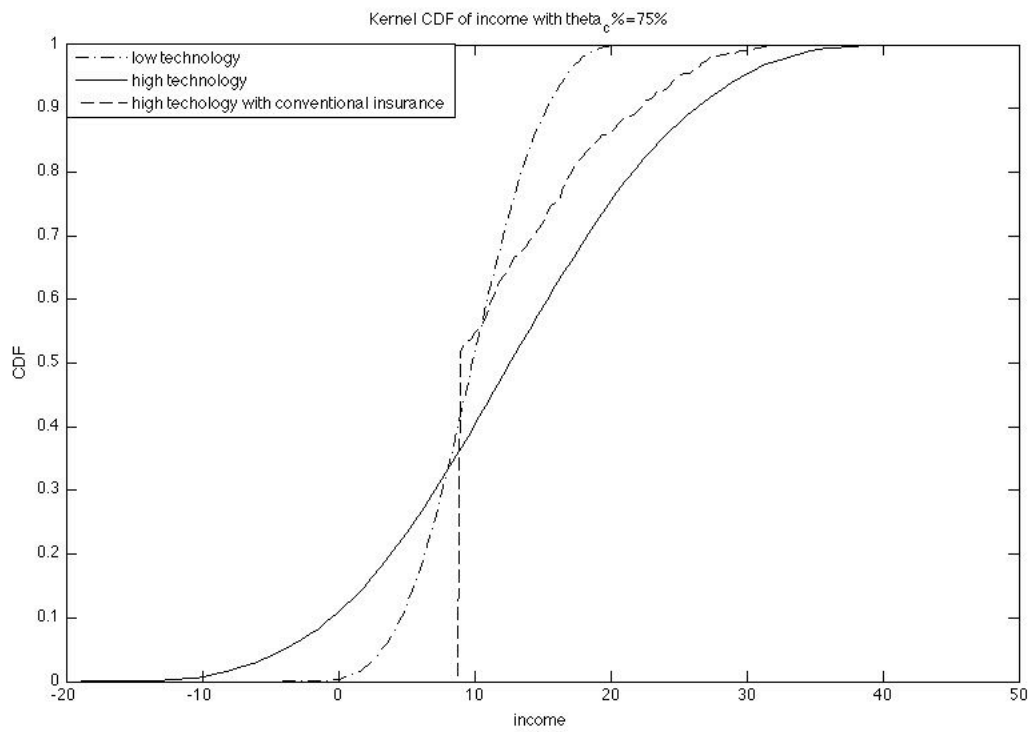
FIGURE 3.1. Technologies



FIGURE 3.2. CDF of high tech, low tech and high tech with conventional insurance

we will assume that the index insurance contract is based directly on $\theta_c$. We denote the insurance contract for technology $t$ as $I_t < \hat{\theta}_c, h_t, z_t, \beta_t >$, where $\hat{\theta}_c$ is the strike point for the contract, $h_t$ is indemnity normalized by $g_t$, $z_t$ is the normalized actuarially fair premium and $\beta_t$ is the normalized loading or markup of the insurance as a percentage of $z_t$. To simplify the mathmatical analysis the following theoretical strcuture assumes the insurance contract is actuarially fair, but the simulation uses a 30% of loading costs. The indemnity is defined by $h_t(\theta_c) = 1(\hat{\theta}_c > \theta_c)(\hat{\theta}_c - \theta_c)^7$. Under the actuarially fair insurance contract, gross returns to the farm household are given by:

$$(3.4) \qquad y_t^I = \begin{cases} (\theta_c + \theta_s)g_t + (\hat{\theta}_c - \theta_c)g_t - z_t g_t = (\hat{\theta}_c + \theta_s - z_t)g_t, \text{ if } \hat{\theta}_c > \theta_c \\ (\theta_c + \theta_s)g_t - z_t g_t, = (\theta_c + \theta_s - z_t)g_t \quad \text{otherwise} \end{cases} .$$

where $z_t = E[1(\hat{\theta}_c > \theta_c)(\hat{\theta}_c - \theta_c)]$. Note that this specifications assumes that the household first receives indemnity and pays insurance preimum, then applies the net income to repaying outstanding debt before bolstering its consumption.

As a prelude to later analysis, define $\theta^I = \theta + s(\theta)$, where $s(\theta) = 1(\hat{\theta}_c > \theta_c)(\hat{\theta}_c - \theta_c) - z_t$. Note that index insurance contract transforms the multiplicative shock that determines output such that the net output shock under insurance is equal to $\theta^I$. Because $z_t$ is the actuarially fair premium, $E[\theta^I] = E[\theta] = 1$ and the probability function describing the distribution of the net output shock are a "mean preserving squeeze" of the original distribution function. Denote the PDF and CDF of $\theta$ as $f(\theta)$ and $F(\theta)$ and that of $\theta^I$ as $f^I(\theta)$ and $F^I(\theta)$. We can express the original distribution of $\theta$ as a mean preserving spread of the insured distribution and show that the following properties hold (see mathematical proof in Appendix B):

$$(3.5) \qquad \int_0^{\bar{\bar{\theta}}} [F(\theta) - F^I(\theta)]d\theta = 0$$

$$(3.6) \qquad \int_0^y [F(\theta) - F^I(\theta)]d\theta > 0 \; \forall y < \bar{\bar{\theta}}$$

Figure 3.2illustrates the squeezing of the PDF created by index insurance.

3.3. **Credit Supply.** We assume that credit markets are competitive and that banks are willing (at the margin) to offer an agricultural loan that offer an expected return equal to an endogenously given opportunity cost of funds, $\bar{\pi}_a$. After first exploring the nature of marginal loan offer (and

---

[7]This implicitly assumes that the farmers can choose the optimal insurance coverage level to reduce the basis risk, so that insurance contract always reduces farmers' risks
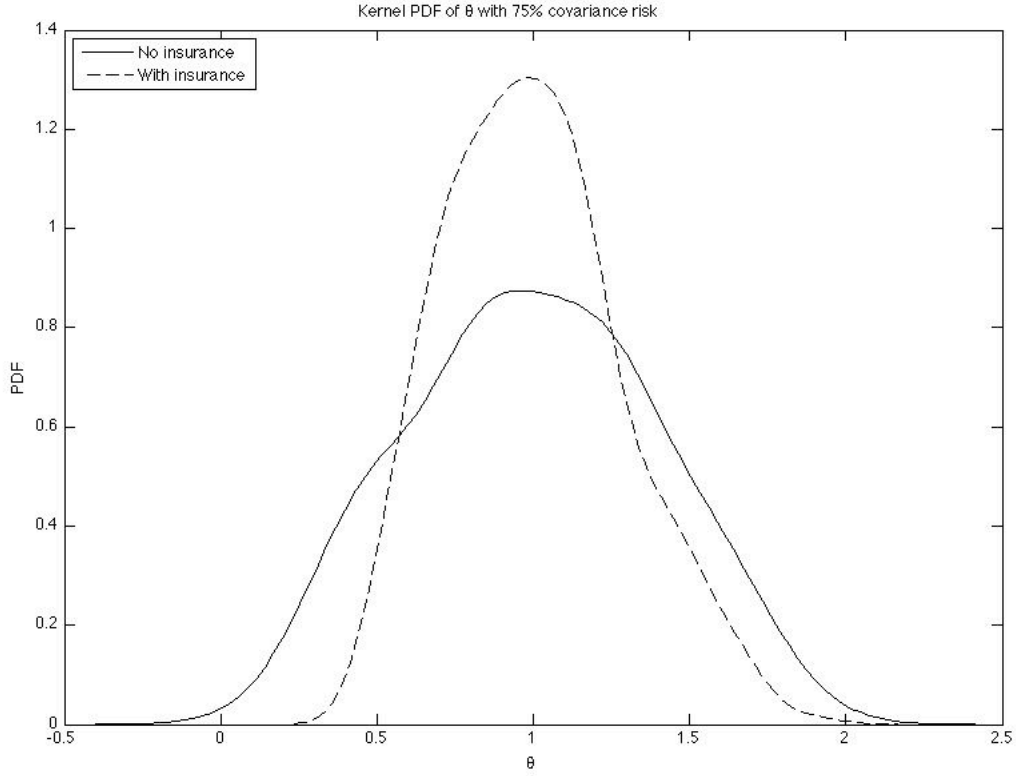
Kernel PDF of θ with 75% covariance risk

FIGURE 3.3. Index Insurance as Mean Preserving Squeeze

the impact of insurance on contract terms), Section 3.3will explore aggregate supply of agricultural credit by the lender with and without insurance.

*The Iso-expected profit contract locus.* Under a standard loan contract $\ell(K, r, \chi)$, lender profits are given by:

$$(3.7) \qquad \pi = \begin{cases} (1+r)K, \ if \ \theta > \tilde{\theta} \\ \chi + \theta g_h(K), \ \text{otherwise} \end{cases} .$$

Under this specification, lender's profits are concave in the random variable $\theta$ so that they would act like as if they are "risk averse". Lenders' expected profits is given by:

$$(3.8) \qquad E(\pi) = [1 - F(\tilde{\theta})]rK + \int_0^{\tilde{\theta}} (\chi + \theta g_h(K) - K)f(\theta)d\theta$$

First we assume that $\bar{\pi}_a$ is fixed and $E(\pi) = \bar{\pi}_a$. Using the implicit function theorem, we can characterize the iso-expected profits contract locus as those combinations of interest rates and

10

collateral requirements that just yield expected returns equal to $\bar{\pi}_a$ . As shown in Figure 3.3, the locus is downward sloping as $\frac{\partial r}{\partial \chi} = \frac{F(\tilde{\theta})}{(1-F(\tilde{\theta}))K} < 0$. When borrowers are insured the locus becomes less steep as risk diminishes through mean preserving squeezes ($\frac{F(\tilde{\theta})}{(1-F(\tilde{\theta}))K} < \frac{F^I(\tilde{\theta})}{(1-F^I(\tilde{\theta}))K} < 0$) [8]. The insured iso-expected profit locus lies below the uninsured locus if loans are not fully collateralized ($\chi < (1+r)K$).[9]

In general, we would not expect a lender to be genuinely indifferent between the different points on the iso-expected profit loci. As explored by a number of papers, higher collateral/lower interest rate contracts diminish incentives for morally hazardous behavior and adverse selection by lenders (for a recent treatment, see Boucher et al. (2008)). In the analysis here, we ignore borrower heterogeneity that might generate adverse selection (e.g., differences in borrower honesty or individual level heterogeneity in the structure of risk). We also ignore potential sources of morally hazardous behavior (e.g., credit diversion as in Carter (1988) or non-contractible effort as in Boucher et al. (2008)). Instead, we follow Stiglitz and Weiss (1981)and simply assume that lenders demand that borrowers present a minimum amount of collateral in order to leverage of a loan of size $K$.

While these assumption are somewhat artificial, they allows us to focus on the impact of index insurance in two distinctive, but empirically important environments. The first of these might be considered to be representative of areas of Latin America where agricultural land is individually titled and potentially can be seized in the event of loan default. In these environments, we will assume that lenders require a collateral of value $\chi_h$, as shown in Figure 3.1. In other areas where agricultural land ownership is less individualized and less securely titled (e.g., in many parts of Africa), we will assume that the the loan package requires a lower amount of collateral, denoted $\chi_\ell$ in Figure 3.1. While we could impose additional structure on the model to endogenize collateral levels, our goal here is to show that index insurance and its interaction with small farm productivity and financial markets will exhibit subtle differences across these two types of stylized agricultural economies.

*Aggregate credit supply to the agricultural sector* . The analysis in the prior section considered the conditions of competitive loan supply taking the lender's overall loan portfolio as given. When

---

[8]The slope of the iso-profit locus under insurance is flatter than under no insurance but it is still downward sloping, since uninsured idiosyncratic risks can cause default

[9]As discussed in Section 3 , we assume that households use all income, including insurance indemnity payments, to retire debt before consumption.
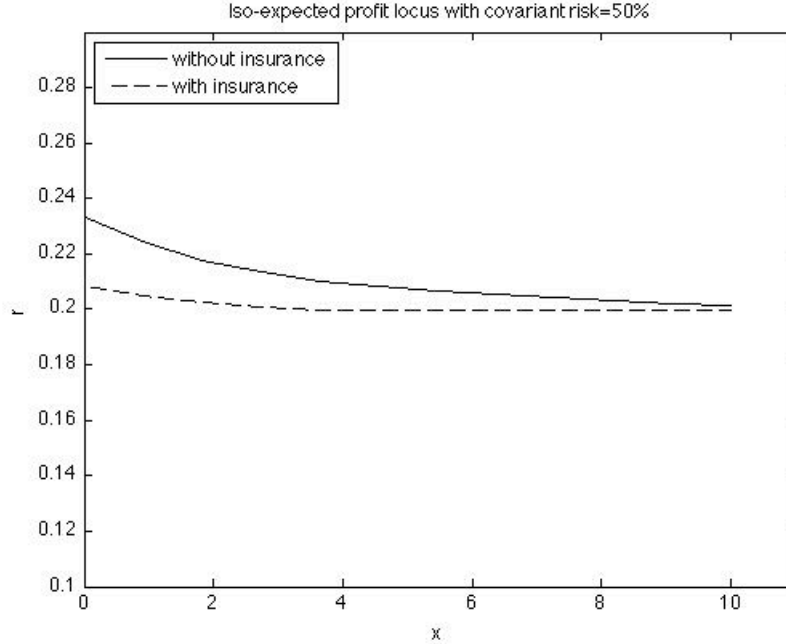
FIGURE 3.4. Iso-expected profit locus with $\bar{\pi}_a = 20\%$

loan repayment is subject to purely idiosyncratic shocks, the lender's overall portfolio will be self-insuring. However, a portfolio of agricultural loans will not be purely self-insuring as a negative covariant shock (e.g., a drought) could trigger a large scale episode of default.

To explore this issue further, this section examines the lender's portfolio decision and aggregate credit supply. We assume that in the short-run, the lender has sufficient loanable funds to extend $n$ loans of size $K$. We further assume that the lender can extend type $a$ agricultural loans, or type $b$ loans, which we assume to be risk free (or subject only to idiosyncratic shocks and therefore self-insuring). The lender's gross rate of return, $G$, on the portfolio of $n$ loans will be given by:

$$(3.9) \qquad G = \frac{\sum_{i=1}^{n_a} \pi_i(\bar{\pi}_a) + n_b \bar{\pi}}{n}.$$

where $\bar{\pi}_a = E(\pi_i)$. In addition, the lender faces a penalty function, $P(G)$, that reduces net lender portfolio returns when the $G$ falls below a critical threshold level $\tilde{\pi}$. Specifically, net portfolio returns $(N)$ are given by:

$$(3.10) \qquad N = G - P(G) = \begin{cases} G \,, \text{if } G > \tilde{\pi} \\ G - \tilde{P}(G) \,, \text{otherwise, where } \tilde{P}', \tilde{P}'' \leq 0 \end{cases}$$

The penalty for low portfolio return occurs for several reasons. First, when the lenders realize too low a return on the loan portfolio, it runs afoul of reserve and other regulatory requirements. Second, when the portfolio return is too low, the lenders have to sell a large amount of collateral at the same time to repay depositors, which drives down the price of collateral and lenders' net return. Next, low return from the portfolio forces lenders to borrow from the money market and pay for high interest rates. Lastly, from a political economy perspective, the lender understands that a massive default, driven by a drought or other unfavorable event, will likely trigger a political economy reaction with the government tempted to mandate at least partial default forgiveness.[10]

Now assuming the expected net portfolio return is exogenous in a competitive market, lenders have to satisfy the participation constraint in which $E(N) \geqslant \bar{\pi}$. Given this constraint, lenders have to adjust $\bar{\pi}_a$ as the composition of the whole portfolio changes. Let $F_G$ and $f_G$ denote the CDF and PDF of $G$. Taking the expected value of $N$, the Lender's Participation Constraint (LPC) can be written as:

$$(3.11) \qquad \bar{\pi} + \frac{n_a}{n}(\bar{\pi}_a - \bar{\pi}) - \int_0^{\tilde{\pi}} P(G)f_G(G)dG \geq \bar{\pi} \qquad (LPC)$$

where the integral term is the expected penalty. Using implicit function theorem, the expected return of agricultural loan can be written as a function of the quantity of agricultural loans, $\bar{\pi}_a = \bar{\pi}_a(n_a)$. $\bar{\pi}_a(n_a)$ depicts a aggregate supply curve of agricultural loans. Figure 3.5 shows that in absence of formal insurance and with low collateral requirement, $\bar{\pi}_a$ has to increase dramatically above $\bar{\pi}$ to maintain the participation constraint as the share of agricultural loans rises in the lending portfolio (the black solid line). This is because low collateral requirement exposes lenders to large covariant risk and increases the probability of paying penalty . The penalty policy $P$ implies an increasing marginal cost of unit agricultural lending when lenders are exposed to covariant risks. The introduction of formal insurance reduces the cost of credit and thus flattens the supply curve (the black dashed line). Thus, when loans are insured, $\bar{\pi}_a$ keeps constant at a low level of $\bar{\pi}$ as the number of agricultural loans increases. Furthermore, as the collateral level increases, uninsured $\bar{\pi}_a$ (the red and blue solid lines) decreases and insured $\bar{\pi}_a$ (the red and blue dashed lines) keeps equal to $\bar{\pi}$ . In Figure 3.5, all the dashed lines and the blue solid line overlap as a straight line at the level of $\bar{\pi}$. Insurance isolates the rate of return of agricultural loans $\bar{\pi}_a$ from the impact of the collateral

---

[10]Following the 1998 El Nino event, the Peruvian government instituted a "financial rescue" that instructed agricultural lenders to forgive outstanding debt (see Trivelli ).
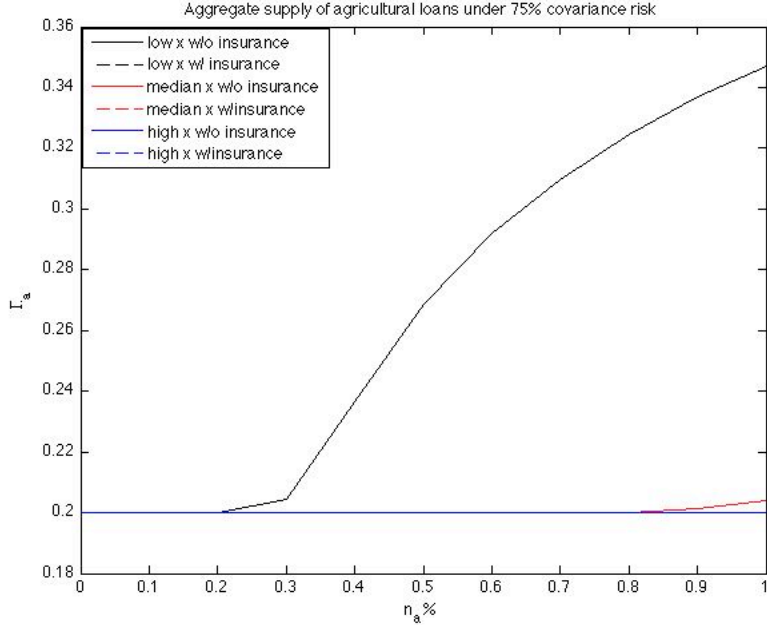
FIGURE 3.5. Aggregate Supply of Agricultural Credit–Rate of return

level. Appendix C provides a mathematical proof of the shape of the function $\bar{\pi}_a = \bar{\pi}_a(n_a)$ and the determinant factors.

Given a fixed level of $\chi$ , the aggregate supply function can also be written as $r = r(n_a \mid \chi, f^I(\theta), f(\theta), P)$. Figure 3.6 shows the supply curve of credit as collateral level changes and index insurance is introduced. Similar with Figure 3.5, the lower the collateral level, the steeper the uprising supply curve when index insurance is unavailable. Under index insurance the supply curves all become straight lines and lenders would supply as many loans as they could at a fixed price. Note the price level is slightly different: the insured supply curve under low collateral (the black dashed line) is higher than that under median and high collateral (the red and blue dashed line which overlaps) as low collateral exposes lenders to more idiosyncratic risks.

## 4. Demand for credit, insurance and technology Under Alternative Insurance Schemes

This section analyzes farmers' optimal choices of technology and financial contracts. We first analyze the income CDF under four insurance schemes to eschew the risk of high technology: self-insurance by adopting low-yielding technology, implicit insurance provided by loan contracts, formal non-interlinked index insurance and interlinked index insurance. Then we go deeper to look
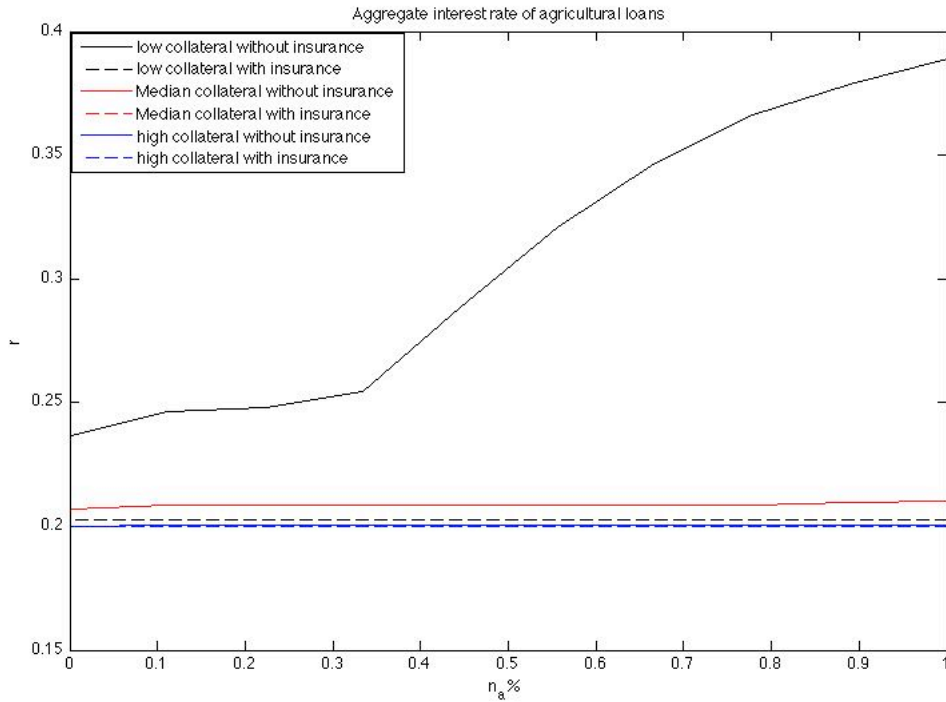
FIGURE 3.6. Aggregate supply of agricultural loans–Interest rates

at farmers' expected utility when formal insurance is unavailable in Section 4.2. We show that in low collateral environment, loan contract provides implicit insurance for borrowers but lenders charge high interest rates. In high collateral environment, interest rates are low but farmers are risk rationed. In both cases, farmers are likely to choose self-insurance and have low demand for credit and high technology. Section 4.3 analyzes the introduction of formal index insurance as an independent market. We show that in low collateral environments, the impact of formal insurance is adverse or minimal due to the existing implicit insurance provided by loan contracts. In contrast, in high collateral environments, the independent insurance substantially improves household welfare, crowding in demand for credit and high technology. We then turn to examine contractual interlinkage in which loans and insurance are linked as a single contract (i.e., because loans are linked, lenders know when a loan is or is not secured by an insurance contract) and loan contract terms are endogenously determined by borrowers' purchase of insurance. We show that even in low collateral environments, interlinked insurance increases uptakes of credit and high technology by inducing lender to lower interest rates and crowding in credit supply. It should be stressed that the analysis is predicated on the simultaneous existence of an improved, capital-dependent technology.
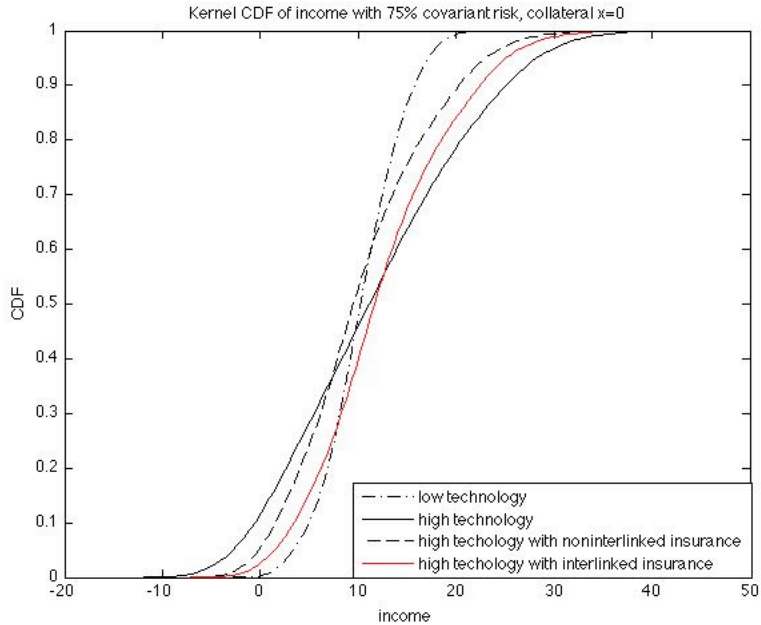
Figure 4.1. Cumulative Distribution of Consumption

4.1. **Stochastic dominance of interlinked index insurance.** This section compares the income CDF under four insurance schemes. In Figure 4.1, the implicit insurance associated with loan contract (the solid line) is hard to compete with the self-insurance (the dash-dotted line) when no formal insurance is available. As mentioned above, however, this self insurance strategy is characterized by uninsured basis risk as well as by substantial loading (i.e., the self-insurance is actuarially unfair as it reduced mean income). The question we ask here is whether index insurance can dominate self-insurance despite the basis risk and loadings associated with it. The introduction of the stand-alone index insurance (the dashed line) makes a small improvement over the implicit insurance but still hardly stochastically dominates self-insurance. The interlinked index insurance shifts the income CDF forward from the dashed line to the red solid line, so that it is very likely to stochastically dominate self-insurance. Thus when interlinked insurance is available, households are more likely to choose high-yielding technology, borrow money and purhcase insurance.

4.2. **Absent formal insurance.** When formal insurance is unavailable, poor small households face two choices, self-insurance of low-yielding technology versus implicit insurance of high-yielding technology financed by credit. Under the specification in Section 3, household expected utility under

the low technology ($V_\ell$) and high technology ($V_h$) are given by:

$$(4.1) \qquad V_\ell = \int_0^{\bar{\bar{\theta}}} u(\theta g_\ell + W + B)f(\theta)d\theta$$

$$(4.2) \qquad V_h = F(\tilde{\theta})u(\underline{c}) + \int_{\tilde{\theta}}^{\bar{\bar{\theta}}} u(\theta g_h - (1+r)K + W + B)f(\theta)d\theta.$$

Note that $\underline{c}$ is a function of $\chi$ and $\tilde{\theta}$ depends on both $\chi$ and $r$. The household will choose high technology and to take the loan contract if $\Delta_l^h = V_h - V_\ell > 0$. Using the expressions above, we can rewrite $\Delta_l^h$ as:

$$(4.3) \quad \Delta_\ell^h = \left[ F(\tilde{\theta})u(\underline{c}) - \int_0^{\tilde{\theta}} u(\theta g_\ell + W + B)f(\theta)d\theta \right]$$

$$+ \left[ \int_{\tilde{\theta}}^{\bar{\bar{\theta}}} [u(\theta g_h - (1+r)K + W + B) - u(\theta g_\ell + W + B)]f(\theta)d\theta \right]$$

where the first term in square brackets is strictly negative (even when $\chi = 0$) indicating low technology outperforms high technology when adverse shocks happen. To make farmers choose high technology, the second term has to be positive.

In high collateral environment, since $\underline{c}$ is very low, the first term is negatively big. Risk-averse farmers are likely to have negative $\Delta_\ell^h$, choosing low technology and not to borrow. This is called risk rationing by Boucher et al. (2008). In low collateral environment, the first term becomes negatively smaller. As the lower bound $\underline{c}$ rises, low collateral offers implicit insurance to borrowers. But meanwhile, since covariance risk is passed to lenders, lenders ask for high expected rate of return and interest rates as discussed in Section 3.3, which makes the second term positively small. Farmers who cannot afford the high interest rates will choose low technology and not to borrow, which we called price rationing. Therefore, in absence of formal insurance the demands for high technology and credit are likely to be low in both low and high collateral environments as shown by the black solid line in Figure 4.2. The rest of the paper focuses on such scenario where $\Delta_\ell^h < 0$ either because of risk rationing (in high collateral environments), or price rationing (in low collateral

17

environments). The next two subsections will analyze how index insurance reduces the two types of credit rationing and crowd in credit supply and credit demand.

4.3. **Non-interlinked index insurance contracts .** This section introduces the first type of formal index insurance contract, the non-interlinked index insurance, and focuses on what section 4.2 called the risk-rationed. The risk-rationed are those households who eschewed the risk of the high technology and instead self-insured their livelihood by choosing the low income activity when collateral level is high. The non-interlinked index insurance contract is independent of the credit market, therefore only influencing the households. We first exam the impact of the actuarially fair non-interlinked contract (defined as above as the contract in which expected indemnities equal the premium) on household expected consumption. Formally, the change of expected consumption (conditional on adoption of the high technology) is equal to

$$(4.4) \qquad E(c_h^I) - E(c_h) = \chi[F(\tilde{\theta}) - F^I(\tilde{\theta})] - \int_{\tilde{\theta}}^{\bar{\bar{\theta}}} [\theta g_h(K) - (1+r)K][f(\theta) - f^I(\theta)]d\theta$$

Integrating by parts and using the properties of mean-preserving spread (equation 3.5 and 3.6 ), the above expression reduces to:

$$(4.5) \qquad E(c_h^I) - E(c_h) = g_h \int_0^{\tilde{\theta}} [F^I(\theta) - F(\theta)]d\theta \leq 0$$

which is always negative when loans are not fully collateralized and equal to zero when loans are fully collateralized. It indicates that at least in terms of expected income, the lower the collateral level, the more households lose from the non-interlinked contract.

Strictly speaking, farmers make optimal choices based on $V_h^I$ and $V_l$ , which represent the value function of high technology under non-interlinked insurance and low technology respectively. Whether farmers will adopt high technology depends on the sign of $V_h^I - V_l$, which can be written as

$$(4.6) \qquad \Delta_l^{h^I} = V_h^I - V_l = (V_h^I - V_h) + (V_h - V_l) = \Delta_h^{h^I} + \Delta_l^h$$

where $\Delta_l^h < 0$, but the sign of $\Delta_h^{h^I}$ is ambiguous. Since the non-interlinked insurance contract is isolated from loan contract, interest rate is determined by $r = r(\chi, n_a, f(\theta), P)$, not affected by insurance contract. Then we have

$$(4.7) \qquad V_h^I = U(\underline{c})F^I(\tilde{\theta}) + \int_{\tilde{\theta}}^{\bar{\bar{\theta}}} U[\theta g_h - (1+r)K + W + B]f^I(\theta)d\theta$$

and

$$(4.8) \quad \Delta_h^{h^I} = V_h^I - V_h = U(\underline{c})[F^I(\tilde{\theta}) - F(\tilde{\theta})] + \int_{\tilde{\theta}}^{\bar{\bar{\theta}}} U[\theta g_h - (1+r)K + W + B](f^I(\theta) - f(\theta))d\theta$$

After integrating by part of $\Delta_h^{h^I}$ twice, we have

$$(4.9) \qquad \Delta_h^{h^I} = U'(\underline{c})g_h \int_0^{\tilde{\theta}} [F^I(\theta) - F(\theta)]d\theta + \int_{\tilde{\theta}}^{\bar{\bar{\theta}}} [\int_0^{\theta} (F^I(y) - F(y))dy]U'' g_h^2 d\theta$$

Since $\theta$ is a mean-preserving spread of $\theta^I$, the first part of $\Delta_h^{h^I}$ is non-positive and the second part is positive. As can be seen from equation (4.5), the first part of $\Delta_h^{h^I}$ represents the marginal utility of the change in expected consumption, and the second part means the change of utility due to reduction of consumption fluctuation. This indicates that risk neutral farmers for who the first term is negative and the second term is zero, would always prefer without the implicit insurance rather than the non-interlinked insurance. This is consistent with the conclusion drawn from the expected income.

As for the risk-averse farmers, the sign and magnitude of $\Delta_h^{h^I}$ can be determined by collateral requirement. If fully collateralized with $\chi = (1+r)K$ and $\tilde{\theta} = 0$, the first part shrinks to zero and $\Delta_h^{h^I}$ is positive, indicating that farmers will be willing to buy the non-interlinked insurance since the expected income is unchanged and the risk exposure is reduced. The insurance would crowd in risk-rationed by reducing household's risk of losing collateral. If $\chi = 0$ and $\tilde{\theta} > 0$, $\Delta_h^{h^I}$ decreases and is more likely to be negative, indicating farmers will not be willing to buy the non-interlinked insurance since they are already insured by loan contract and insurance premium lowers the expected income. Intuitively, under a low collateral environment, the lender bears most of the risk. Insurance is valuable to lenders by transferring the risk from the lender to the insurance provider, but yields

no benefit to the household who nonetheless pays for insurance premium. In contrast, under a high collateral environment, the household who bears nearly all the risk, enjoys the gains from the insurance. The dashed line in Figure 4.2 illustrates the certainty equivalent of $V_h^I$ as a percentage of that of low technology. We see that the CE under non-interlinked insurance is even lower than that under implicit insurance ($\Delta_h^{h^I}$ is negative) when $\chi$ is low. As collateral rises, the CE of the non-interlinked becomes higher than implicit insurance, and finally higher than self-insurance of low technology. This indicates that the non-interlinked insurance only works for the risk rationed in a high collateral environment.

4.4. **Interlinked insurance contracts .** This section introduces the other type of formal insurance, the interlinked index insurance, and focuses on the price-rationed. We define the price-rationed as those who refuse to borrow due to the high interest rates. Farmers choose between the interlinked insurance and self-insurance, $V_h^{II}$ and $V_l$ , which represent the value function of high technology under interlinked insurance and low technology respectively. Farmers make decisions based on the sign of $V_h^{II} - V_l$, which can be disaggregated as

$$(4.10) \qquad \Delta_l^{h^{II}} = V_h^{II} - V_l = (V_h^{II} - V_h^I) + (V_h^I - V_h) + (V_h - V_l) = \Delta_{h^I}^{h^{II}} + \Delta_h^{h^I} + \Delta_l^h$$

where $\Delta_l^h < 0$ and $\Delta_h^{h^I}$ increases in $\chi$ as shown in the above section. The rest of this section explores the factor influencing the sign of $\Delta_{h^I}^{h^{II}}$.

As shown in Section 3.3, households' purchase of index insurance influences lenders' expected return. Under the interlinked insurance, the interest rate the lender offers is endogenously determined by index insurance contract as $r^I = r_m(\chi, n_a, f^I(\theta))$. Because $\tilde{\theta}$ is a function of interest rates , the critical point with interlinked insurance is denoted as $\tilde{\theta}^I = \tilde{\theta}(r^I)$. Then the value function of high technology with interlinked insurance $V_h^{II}$ becomes

$$(4.11) \qquad V_h^{II} = U(\underline{c})F^I(\tilde{\theta}^I) + \int_{\tilde{\theta}^I}^{\bar{\bar{\theta}}} U[\theta g_h - (1 + r^I)K + W + B]f^I(\theta)d\theta$$

The difference of expected utility between interlinked and non-interlinked insurance, $\Delta_{h^I}^{h^{II}}$ can be written as

$$(4.12) \quad \Delta_{h^I}^{h^{II}} = V_h^{II} - V_h^I = \int_{\tilde{\theta}}^{\bar{\bar{\theta}}} (U[\theta g_h - (1 + r^I)K + W] - U[\theta g_h - (1 + r)K + W + B])f^I(\theta)d\theta$$

$$+ \int_{\tilde{\theta}^I}^{\tilde{\theta}} (U[\theta g_h - (1 + r^I)K + W + B] - U(\underline{c})) f^I(\theta)d\theta$$

As Figure 3.6 shows, when $\chi < (1 + r)K$, $r^I < r$, and $\tilde{\theta}^I < \tilde{\theta}$. Then $\Delta_{h^I}^{h^{II}}$ is positive when loans are not fully collateralized. When $\chi = (1 + r)K$, $\Delta_{h^I}^{h^{II}}$ is equal to zero. Thus $\Delta_{h^I}^{h^{II}}$ is always non-negative and decreasing in $\chi$. This means the interlinked insurance is always at least as good as non-interlinked insurance for households. Interlinkage will thus being to crowd-in more credit demand because the interest rates will be lower when farmers purchase interlinked insurance. Since $\Delta_h^{h^I}$ is increasing in $\chi$, the interlinked insurance has advantages over the non-interlinked in the low collateral environment. The dotted line in Figure 4.2 denotes the CE of $V_h^{II}$ as a percentage of that under low technology, which always lies above the CE of $V_h^I$. The gap between the dashed and the dotted line representing $\Delta_{h^I}^{h^{II}}$ decreases as collateral increases.

Combining $\Delta_{h^I}^{h^{II}}$, $\Delta_h^{h^I}$, $\Delta_l^h$ together, the dotted solid line in Figure 4.2 demonstrates $\Delta_l^{h^{II}}$. The Certainty Equivalent (CE) of the interlinked high technology for a typical household is almost constant around 1.5% more than that of low technology as the collateral level changes. This can be explained by the mean and variance of the income from interlinked high technology. Since interlinked insurance always brings the cost of unit loan back to a constant level $\bar{\pi}$ as shown in Figure 3.5, farmers' expected income from high technology is equal to

$$(4.13) \qquad\qquad E(c_{h_{II}}) = E(y_h) - (1 + \bar{\pi})K + W + B$$

which is independent of collateral level. The income variance satisfies

$$(4.14) \qquad\qquad Var(c_{h_{II}}) = \frac{Var(y_h)Var(\theta_I)}{Var(\theta)}$$
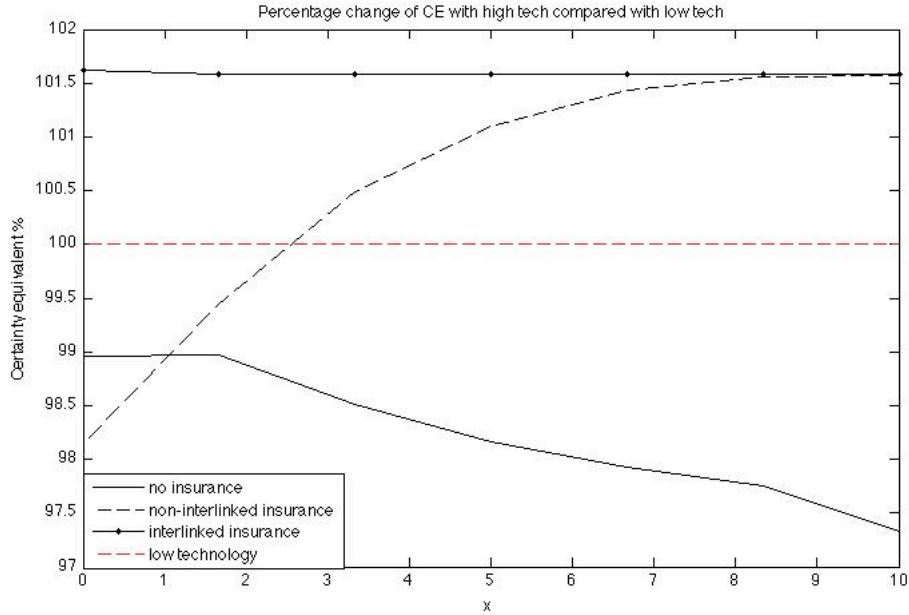
Figure 4.2. Certainty Equivalent of high tech as a percentage of low tech for a highly risk-averse household $\psi = 3$

which is also independent of collateral level. Since the expected utility is mainly determined by the first and second order of income, the above two equations indicate that the CE under interlinked insurance mainly depends on the productivity of the technology and risk structure (basis risk), but is not influenced by the characteristics of the credit market such as collateral level and numbers of agricultural loans.

## 5. Farm Productivity and the financial Market development in the Equilibrium of the credit market

This section analyzes the farm productivity and the credit market development when the credit market reaches an equilibrium. In absence of interlinked insurance or without fully collateralization, the aggregate supply curve of credit is uprising and thus any increase in demand discussed in Section 4 will raise interest rates that choke off the increased expansion . When insurance and credit are interlinked, the credit supply curve is flattened at a constant level and thus the increased demand induced by insurance will not be choked off. As a result, the interlinked index insurance can induce the highly risk-averse and poor smallholders to adopt high technology and purchase financial products. In addition to collateral environment, the performance of interlinked index insurance

contract also depends on basis risk and loading costs of insurance premium. We also analyze the sustainability of the subsidized interlinked index insurance program.

5.1. **Credit Market Equilibrium.** According to Section 3.3, we can write the aggregate supply of agricultural loans, $n_a^s$, as a function of the price $r$ given exogenous factors including collateral level, the distribution function of $\theta$, purhcase of insurance and penalty function:

$$n_a^s = n_a^s(r \mid \chi,\, f(\theta),\, f^I(\theta),\, P) \tag{5.1}$$

According to Section 4, aggregate demand of agricultural loans, $n_a^d$, is a function of $r$ given exogenous factors of collateral, the distribution of $\theta$, purchase of insurance and the distribution of population on risk preference and wealth:

$$n_a^d = n_a^d(r \mid \chi,\, f(\theta),\, f^I(\theta),\, h(\psi, W)) \tag{5.2}$$

. Because the population is heterogeneous in $\psi$ and $W$, the demand function is strictly decreasing in $r$. The credit market reaches an equilibrium when demand equals supply,

$$n_a^s = n_a^d = n_a \tag{5.3}$$

The quantity of agricultural loans and interest rates at the equilibrium, $n_a^*$ and $r^*$ vary on the different insurance schemes associated with high technology: implicit insurance , non-interlinked and interlinked index insurance. Figure 5.1 shows the supply and demand curve of credit under the three insurance schemes in different collateral environments. The equilibrium point of $n_a^*\%$ represents the equilibrium precentage of farmers who obtain an agricultural loan and adopt high technology. The rest of population, $1 - n_a^*\%$, use traditional low technology. In a low collateral environment (the first graph), demand and supply curve under implicit insurance interact at a point with high price and relatively low quantity. When loans are insured with non-interlinked contract, supply curve keeps unchanged but a big part of demand curve moves to the left due to the implicit insurance provided by low collateral. The declined demand drives down both $r^*$ and $n_a^*$ as shown by the black arrow to the left, which coincides with the empirical observation of low uptakes of bundled loan contract by Giné and Yang (2009). When the two financial contracts are interlinked,
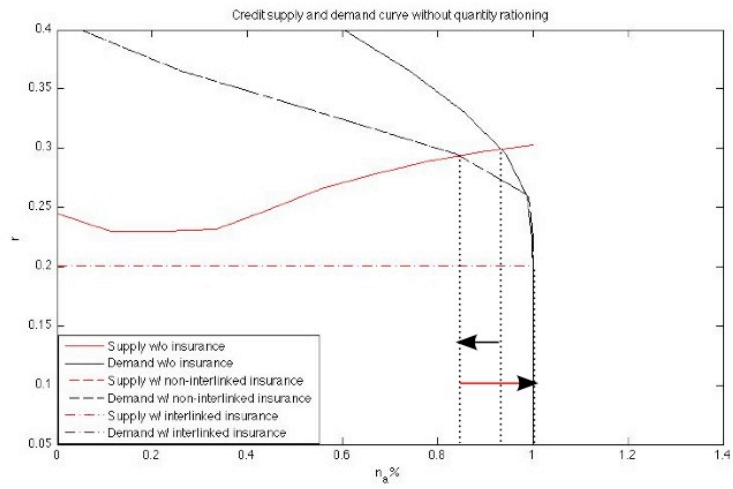
the demand curve is the same as the one under the non-interlinked but the supply curve shifts down and becomes flat. The increased credit supply moves the equilibrium rightward as shown by the red arrow to a point with lower $r^*$ and higher $n_a^*$ . In a median collateral environment, the non-interlinked contract increases demand and improves the equilibrium towards a higher $n_a^*$ but also drives up the price. The interlinked contract increases $n_a^*$ further by lowering the supply curve. Finally in the high collateral environment, the non-interlnked contract induces a big expansion of the demand so that almost the whole population obtain credit. Since the lender is fully insured by the high collateral, the interlinked contract performs as well as the non-interlinked but could not do better.

5.2. **The heterogenous impact of index insurance.** The impact of insurance on individuals varies as their risk preference and wealth change. The empirical evidence from Giné and Yang (2009) shows that wealther indicators have positive (although not significant) impact and risk aversion has negative impact on uptakes of stand-alone/non-interlinked insurance and loan contracts. Figure 5.2 shows critical levels of risk aversion coefficient and wealth $(\psi^*, W^*)$ when the credit market reaches an equilibrium, below which households adopt the high technology and below which they do not. Except risk and price rationing as discussed above, this figure also considers the quantity-rationed who cannot borrow when their wealther level is below the collateral requirement. The solid lines represent $\Delta_l^h(\psi^\star, W^\star) = 0$, the dashed lines $\Delta_l^{h^I} = 0$ , and the dash-dotted lines $\Delta_l^{h^{II}} = 0$. The black lines denote low collateral environment and the red lines denote high collateral environment .
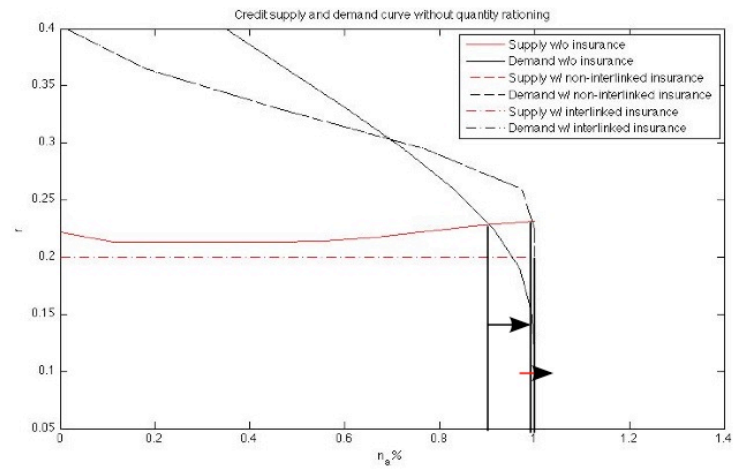
In a low collateral environment, highly risk-averse and poor farmers are price-rationed out of the credit market and cannot afford the high technology. The non-interlinked index insurance worsens the price-rationing and expand the rationing area to the southeast. This is because the implicity insurance provided by low collateral renders insurance "effectively an increases in the interest rate on the loan" (Giné and Yang, 2009). However, the introduction of the interlinked index insurance reduces the price rationing and moves the boundary towards the northwest so much that highly risk-averse and poor farmers are able to borrow from the credit market.

In a high collateral environment, two types of credit rationing occur when stand-alone loan contract is offered. First, poor farmers who are lack of wealth to put as collateral are quantity-rationed out. Second, among those farmers who are eligible to apply for a loan, highly risk-averse farmers are risk-rationed because they fear the loss of collateral. The introduction of non-interlinked insurance contract can reduce risk rationing and crown in the risk-averse farmers into the credit
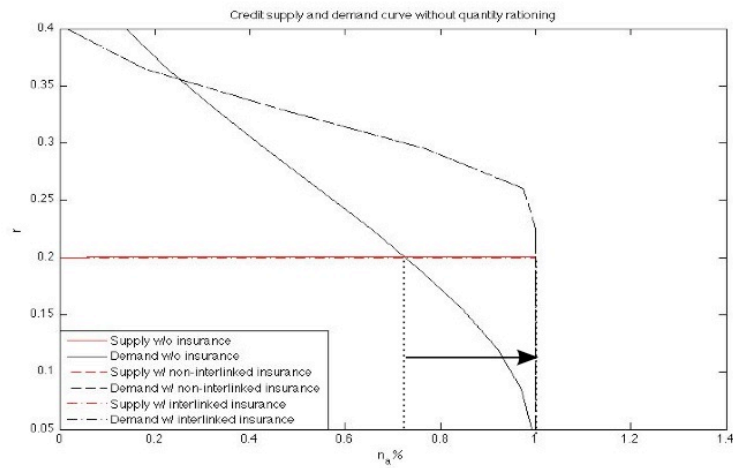
**Low collateral**



Credit supply and demand curve without quantity rationing

**Median collateral**



Credit supply and demand curve without quantity rationing

**High collateral**
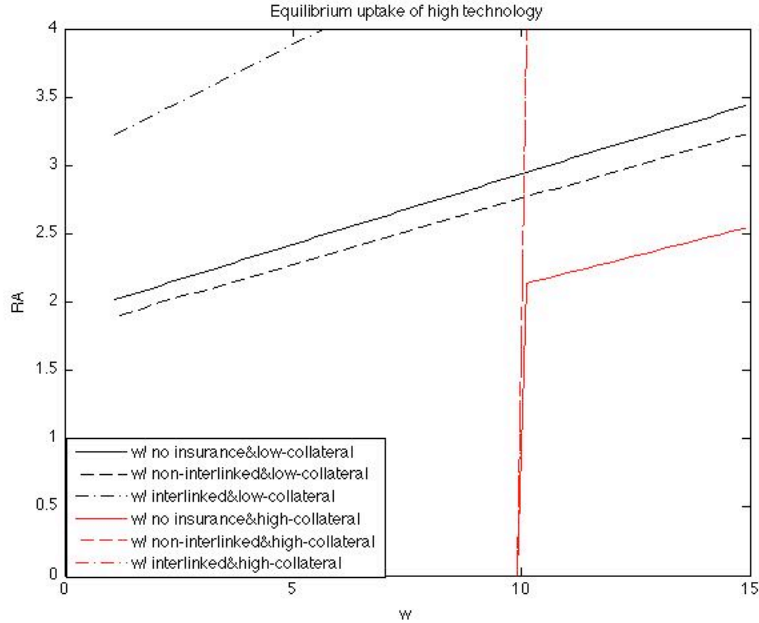


Credit supply and demand curve without quantity rationing

FIGURE 5.2. Equilibrium uptake when x=0/10 and theta_c%=75% with quantity rationing

market. Because lenders are already insured by high collateral, the interlinked contract has little impact on credit supply and thus performs as well as the non-interlinked contract.

5.3. **High Basis risk and high loading costs .** In addition to collateral level, the performance of the interlinked index insurance also depends on the structure of production risk and loading costs of insurance as the stand-alone index insurance. The numerical analysis so far has relied on parameters meant to represent an economy in which risk is predominately covariant. While it is true that increasing basis risk lowers the value of index insurance relative to a first best full insurance counter-factual, the relevant comparison remains with the available self-insurance option. This section explores the way a shift in the composition of risk (from more to less covariant) influences the development of insurance and credit markets.

When the share of covariant risk is low, basis risk of index insurance is high. On the demand side, insured farmers are likely not to be indemnified in a bad year, which reduces the value of insurance and the rightward shift of the demand curve in the last two graphs in Figure 5.1. On the supply side, the aggregate supply curve under index insurance in Figure 3.6 would be flat as well but lies much higher above the supply curve when basis risk is low (below the supply curve without insurance) when loans are not fully collateralized. It is because there is a large amount of idiosyncratic risks in the loan portfolio. Thus high basis risk would reduce $n_a^*$ and raise $r^*$ under the

interlinked contract. We can also see the effect of basis risk from Equation 4.14 that the higher the share of the covariant risk, the higher the ultimate level of welfare the interlinked contract brings and vice versa.

Extremely high loading costs together with basis risk may cause even negative impact of the interlinked index insurance. On the demand side, high loading costs not only eats up the income in a good year, but also substantially increases the probability of default in a bad year that is due to idiosyncratic risk. Correspondingly, on the supply side, the total default rate may increase when farmers purchase index insurance, so that the lender has to raise interest rates if households purchase index insurance. In other words, given extremely high loading costs and basis risk, the interlinked index insurance may crowd out credit demand and credit supply, leading to even more severe credit rationing than the non-interlinked insurance and implicit insurance schemes.

Compared with 30% loading costs and 75% covariant risks assumed in the above figures, Figure 5.3 assumes a 100% of loading costs and 25% of covariant risks. The high loading costs and basis risk causes a significant reduction of credit demand but a very small effect on credit supply. Note that only in a low collateral environment index insurance raises interest rates by a small amount. This result is qualitively consistant with the result fromMiranda and Gonzalez-Vega (2010)'s simulation set in a similar environment as in Figure 5.3. Even in remote rural areas where the loading costs are extremely high, the interlinked contract can be as valuable as we have analyzed in the above sections if goverment provides subsidy to pay for all or part of the loading costs. Some doubt the sustainability of the government subsidy program, since the amount of subsidy needed may create a big burden for government. The next subsection explores the cost-benefit of govenment subsidy and shows the feasibility of subsidized index insurance program.

5.4. **The sustainability of government subsidy.** One sustainable way to subsidize insurance is that government uses the increased tax revenue induced by insurance from the sectors related with agricultural production (including farmers, lenders and insurers) to finance the subsidy. The tax revenue equals to the product of tax rate $r$ and GDP which is

$$(5.4) \qquad GDP = \sum_{i=1}^{n_a} E(y_h) + \sum_{i=n_a}^{N} E(y_l) = n_a^* E(y_h) + (N - n_a^*) E(y_l)$$
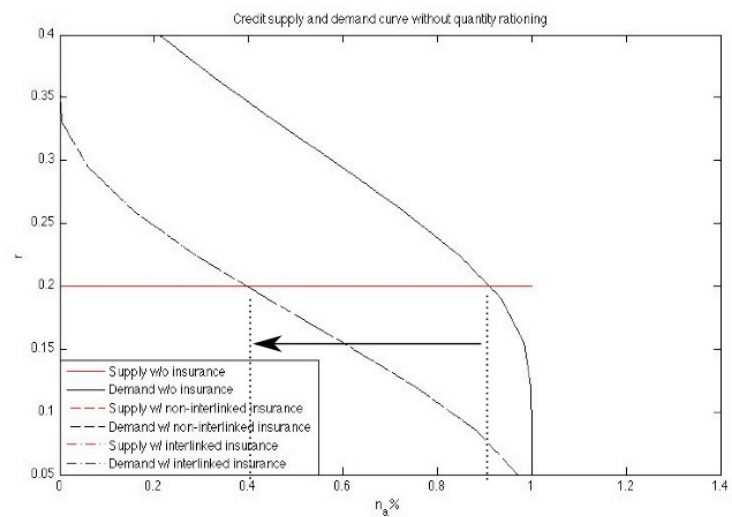
Low collateral
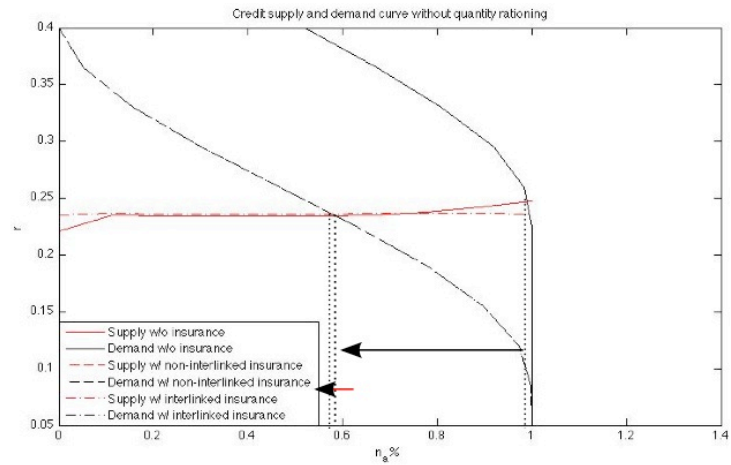


Median collateral
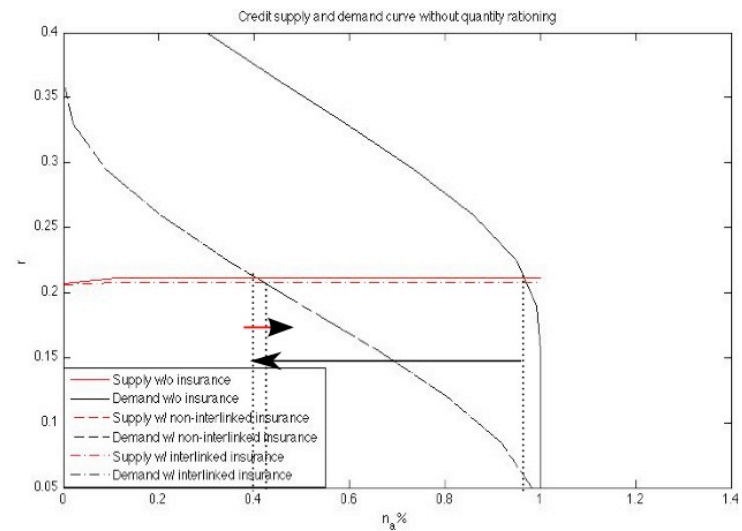


High collateral

If government pays loading costs and farmers pay the actuarially fair premium, the ratio of the maximum loading costs the government can afford over tax rate is equal to

$$(5.5) \qquad \frac{\beta_h}{t} = \frac{(GDP_I - GDP_h)}{n_a^* z_h g_h}$$

where $GDP_I$ denotes the GDP under the interlinked insurance and $GDP_h$ without insurance. Under the specification of simulation in Appendix A, the ratio is equal to 1.79, meaning that a tax rate of 16.76% allows government to cover 30% loading costs without creating extra burden to government budget and provide an actuarially fair interlinked index insurance to poor households. [11]

## 6. Conclusion

While the uptake of novel index insurance contracts has at times been disappointing, the simple explanation that uptake is slow because index insurance contracts are not actuarially fair and have basis risk overlooks the fact that small farmers in low income economies typically self-insure using mechanisms at that are costly (actuarially unfair) and expose the farmer to significant basis risk. These inefficient forms of self-insurance thus leave ample space in which they can be stochastically dominated by formal index contracts. The analysis here shows that this kind of stochastic domination is most likely to occur when index insurance is combined with the introduction of improved technologies and credit contract. The stochastic dominance of interlinked index insurance over self-insurance depends on the productivity of the associated technology and basis risk. Further, in the environments of low collateral, large number of agricultural loans and high covariant risk found in many parts of the developing world, index insurance must not only be introduced with improved technologies, but it must also be contractually interlinked with the credit contracts needed to capitalize the adoption of the new technology. Put differently, in low collateral, heavy agricultural loan portfolio and high covariant risk environments, neither credit nor insurance markets are likely to be able to develop absent such interlinkage. While subject to empirical confirmation, these theoretically grounded observations have significant implications for the design of efforts to promote both small farm productivity growth and rural financial market deepening.

## References

**Binswanger, Hans P. and Mark R. Rosenzweig**, "Behavioural and material determinants of production relations in agriculture," *Journal of Development Studies*, 1986, *22* (3), 503–539.

---

[11]since the tax rate is relatively small and ex-post, we assume that household's decision-making is not influenced by government's tax.

**Boucher, Stephen, Michael R. Carter, and Catherine Guirkinger**, "Risk Rationing and Wealth Effects in Credit Markets: Theory and Implications for Agricultural Development," *Social Science Research Network Working Paper Series*, April 2008.

**Carter, M.**, "Equilibrium credit rationing of small farm agriculture," *Journal of Development Economics*, February 1988, *28* (1), 83–103.

**Giné, Xavier and Dean Yang**, "Insurance, credit, and technology adoption: Field experimental evidencefrom Malawi," *Journal of Development Economics*, May 2009, *89* (1), 1–11.

**Hazell, Peter B. R.**, "The appropriate role of agricultural insurance in developing countries," *Journal of International Development*, 1992, *4* (6), 567–581.

**Miranda, Mario J. and Claudio Gonzalez-Vega**, "Systemic Risk, Index Insurance, and Optimal Management of Agricultural Loan Portfolios in Developing Countries," *American Journal of Agricultural Economics*, December 2010, *92* (6).

**Smith, Vince and Myles Watts**, "Index Based Agricultural Insurance in Developing Countries: Feasibility, Scalability and Sustainability," 2009.

**Stiglitz, Joseph E. and Andrew Weiss**, "Credit Rationing in Markets with Imperfect Information," *The American Economic Review*, 1981, *71* (3), 393–410.

## APPENDIX A. NUMERICAL SPECIFICATION

Utility function adopts CRRA utility function: $U(x) = \frac{x^{1-a}}{1-a}$ where $x > 0$, $a > 0$ and $a \neq 1$.

Other parameters: $A = 1$, $g_\ell = 10$, $g_h = 25$ , $K = 10$ ,$\bar{\pi} = 20\%$ , $\chi_h = 10$ , $\chi_\ell = 0$ ,$\chi_m = 5/2$, $B = 10$ , $n = 1001$, T=200 (years).

$\theta_c$ and $\theta_s$ are independent, following truncated normal distribution. High covariant risk : $\frac{Var(\theta_c)}{Var(\theta)} = 75\%$; low covariant risk: $\frac{Var(\theta_c)}{Var(\theta)} = 25\%$,$Var(\theta) = 0.27$ .$E(\theta_c) = 1$, $E(\theta_s) = 0$, $\hat{\theta}_c = E(\theta_c)$.

Small loading cost $\beta = 30\%$; big loading costs $\beta = 100\%$.

Penalty function $P(G) = \{ \begin{array}{ll} 0 & \text{if G}>\tilde{\pi} \\ p * \bar{\pi} - p * \bar{\pi}/\tilde{\pi} * G & \text{,otherwise} \end{array}$ , where $\bar{\pi} = 2$, $\tilde{\pi} = 0.8$, $p = 4$ .

Population distribution $\psi \in [0,4]$, $W \in [1, 15]$ if quantity rationing exist, W$\in [11,20]$ if no quantity rationing. $\psi$ and $W$ are independent and each, after normalization, follows a beta distribution (2,2).

## APPENDIX B. PROOF OF MEAN-PRESERVING SPREAD

**Property B.1** $\int_0^{\bar{\bar{\theta}}} [F(\theta) - F^I(\theta)]d\theta = 0$. The mean of $\theta^I$ is expressed as $E(\theta^I) = \int_0^{\bar{\bar{\theta}}} \theta f^I(\theta)d\theta$. Since $\theta^I$ is a function of $\theta$, the mean can be also expressed as $E(\theta^I) = \int_0^{\bar{\bar{\theta}}} [\theta + s(\theta)]f(\theta)d\theta = \int_0^{\bar{\bar{\theta}}} \theta f(\theta)d\theta + \int_0^{\bar{\bar{\theta}}} s(\theta)f(\theta)d\theta$. Since by the definition of $z_t$, $\int_0^{\bar{\bar{\theta}}} s(\theta)f(\theta)d\theta = 0$, $E(\theta^I) = \int_0^{\bar{\bar{\theta}}} \theta f^I(\theta)d\theta = \int_0^{\bar{\bar{\theta}}} \theta f(\theta)d\theta = E(\theta)$. Then $\int_0^{\bar{\bar{\theta}}} \theta[f^I(\theta) - f(\theta)]d\theta = 0$. Using integration by part, we have

$$(B.1) \quad \int_0^{\bar{\bar{\theta}}} \theta[f^I(\theta) - f(\theta)]d\theta = \theta[F^I(\theta) - F(\theta)] \Big|_0^{\bar{\bar{\theta}}} - \int_0^{\bar{\bar{\theta}}} [F^I(\theta) - F(\theta)]d\theta = -\int_0^{\bar{\bar{\theta}}} [F^I(\theta) - F(\theta)]d\theta = 0$$

Therefore the first property is proofed.

**Property B.2** $\int_0^y [F(\theta) - F^I(\theta)]d\theta > 0 \; \forall y < \bar{\bar{\theta}}$. Since $s$ is a function of $\theta_c$, define a new variable $\theta_c^I$ as $\theta_c^I(\theta_c) = \theta_c + s(\theta_c)$ where $s(\theta_c) = 1(\hat{\theta}_c > \theta_c)(\hat{\theta}_c - \theta_c) - z_t$. Denote their CDF as $F_c(\theta)$ and $F_c^I(\theta)$. Let $\theta_c'$ denote $\theta_c$ that satisfies $s(\theta_c') = 0$. Since $z_t > 0$, then $\theta_c' = \hat{\theta}_c - z_t < \hat{\theta}_c$. Take an arbitrary point of $\theta_c^I$ at $\theta_c''$ that satisfies $\theta_c'' > \theta_c'$, and the corresponding $\theta_c'''$ satisfying $\theta_c^I(\theta_c''') = \theta_c''$. Then the cumulative probabilities when $\theta_c \le \theta_c'''$ and $\theta_c^I \le \theta_c''$ are equal to $F_c(\theta_c''')$ and $F_c^I(\theta_c'')$. Since $\theta_c^I$ is a monotonic function of $\theta_c$ and strictly increasing in $\theta_c$ when $\theta_c^I > \theta_c'$, $F_c(\theta_c''') = F_c^I(\theta_c'')$. Since $\theta_c''' > \theta_c''$, $F_c(\theta_c'') < F_c(\theta_c''')$. When $\theta_c < \hat{\theta}_c - z_t$, $F_c^I(\theta_c) = 0$, and $F_c(\theta_c) > 0$. So there exists a $\theta_c' = \hat{\theta}_c - z_t$ such that

$$(B.2) \qquad \begin{cases} F_c(\theta_c) \le F_c^I(\theta_c), \; \forall \theta_c \ge \theta_c' \\ F_c(\theta_c) > F_c^I(\theta_c), \; \forall \theta_c < \theta_c' \end{cases},$$

in other word, the two distributions have a single crossing. Since $\theta_s$ is independent of $\theta_c$, after adding an independent variable the above property still hold for $\theta$ and $\theta^I$.

According to Diamond and Stigliz (1974), if two distributions satisfy Property B.1 and B.2, the two distributions have a relation of mean-preserving spread. Following Diamond and Stigliz (1974), Property B.2 can be derived using Property B.1 and the property of single crossing.

## APPENDIX C. PROOF OF AGGREGATE SUPPLY OF CREDIT

Integrating by parts, the expected penalty can be rewritten as:

$$(C.1) \qquad E(P) = P(\tilde{\pi})F_G(\tilde{\pi}) - \int_0^{\tilde{\pi}} F_G(G)P'(G)dG$$

Using the implicit function theorem, we can derive the slope of the supply curve from the LPC as:

$$(C.2) \qquad \frac{\partial \bar{\pi}_a}{\partial n_a} = \frac{\frac{1}{n}(\bar{\pi}_a - \pi) - \frac{\partial E(P)}{\partial n_a}}{\frac{\partial E(P)}{\partial \bar{\pi}_a} - \frac{n_a}{n}}$$

To sign $\frac{\partial \bar{\pi}_a}{\partial n_a}$ as $n_a$ rises, we will first informally show three partial derivatives, which describe how the distribution of $G$ changes when $n_a$ and $\bar{\pi}_a$ increases and $\theta$ changes to $\theta^I$ respectively. Then based on these relations we will try to disentangle the effect of $n_a$ on $\bar{\pi}_a$. Given the first and second moments of $G$ which can be written as

31

$$(C.3) \qquad E(G) = \frac{n_a \bar{\pi}_a + n_b \bar{\pi}}{n} = \bar{\pi} + \frac{n_a(\bar{\pi}_a - \bar{\pi})}{n}$$

$$(C.4) \qquad Var(G) = \frac{n_a Var(\pi_i) + \frac{n_a(n_a-1)}{2}Cov(\pi_i\pi_j)}{n_a^2} = \frac{Var(\pi_i)}{n_a} + \frac{(n_a-1)Cov(\pi_i\pi_j)}{2n_a}$$

as $n_a$ increases we have the followings for the first partial derivatives. Note that if the covariance between individual agricultural loans was zero, then the $Var(g)$ would quickly drop towards zero as the number of agricultural loans increased (i.e., the portfolio would be self-insuring). However, when the covariance is positive, the variance of the portfolio approaches $Cov(\pi_i\pi_j)/2$ as the number of agricultural loans becomes large. When $\bar{\pi}_a = \bar{\pi}$, $E(G)$ is constant and $Var(G)$ increase, which indicates a mean-preserving spread of $G$. Therefore $\frac{\partial F_G(G)}{\partial n_a} > 0$ and $\frac{\partial E(P)}{\partial n_a} > 0$. When $\bar{\pi}_a > \bar{\pi}$, both $E(G)$ and $Var(G)$ increase, which gives an ambiguous change in $F_G$. When $\bar{\pi}_a < \bar{\pi}$, $E(G)$ decreases and $Var(G)$ increase, indicating that the original $F_G$ stochastically dominates the new one. For the second partial derivative as $\bar{\pi}_a$ increases, it is more obvious that $E(G)$ increase, $Var(G)$ is constant, and thus the new $F_G$ stochastically dominates the origin one. Since $P' < 0$, $\frac{\partial e(P)}{\partial \bar{\pi}_a} < 0$.

Now we are ready to sign the equation of $\frac{\partial \bar{\pi}_a}{\partial n_a}$ when no insurance is available. When $\bar{\pi}_a = \bar{\pi}$, because $\frac{\partial E(P)}{\partial \bar{\pi}_a} < 0$ and $\frac{\partial E(P)}{\partial n_a} > 0$, $\frac{\partial \bar{\pi}_a}{\partial n_a}\big|_{\bar{\pi}_a=\bar{\pi}} > 0$. When $\bar{\pi}_a$ increases and $\bar{\pi}_a > \bar{\pi}$, $\frac{\partial \bar{\pi}_a}{\partial n_a}$ goes down, since $(\bar{\pi}_a - \pi)$ becomes positive and $\frac{\partial E(P)}{\partial n_a}$ may become smaller. Finally the supply curve turn flat since the gain from expected profit of agricultural loans offset the loss from covariant risk. Therefore, the shape of the function $\bar{\pi}_a(n_a)$ is concave. In other words, the penalty function makes the lenders maxim and concave in total portfolio return. As can be easily shown, for a given portfolio of $n$ loans, each one of which has an expected return of $\bar{\pi}$, the distribution function of total portfolio returns becomes more dispersed through a mean-preserving spread as $n_A$ increases. With its expected net profits consequently decreasing in $n_A$, the lender will only offer a significant fraction of its total loans to agriculture if it receives a compensating increase in expected returns on agricultural loans.

Now let us see the impact of insurance on aggregate supply. When output is insured and $\theta$ changes to $\theta^I$, $\bar{\pi}_a$ increases and $Var(\pi_i)$ decreases, since $\theta$ is a mean-preserving spread of $\theta^I$ and $\pi_i$ is a concave function of $\theta$. Because $\frac{\partial Cov(\pi_i\pi_j)}{\partial Var(\theta_c)} < 0$, $Cov(\pi_i\pi_j)$ also decreases with $\theta^I$. Therefore, $E(G)$ goes up and $Var(G)$ goes down. Note that increases in $E(G)$ represents the effect of insurance through partial equilibrium, and decrease in $Var(G)$ represents effect of insurance through market

equilibrium. Furthermore, the $F_G$ with insurance stochastically dominates the one without insurance. Then given insurance $\frac{\partial E(P)}{\partial n_a}$ will decrease and $\frac{\partial E(P)}{\partial \bar{\pi}_a}$ will increase. Therefore, $\frac{\partial \bar{\pi}_a}{\partial n_a}|_{\theta} > \frac{\partial \bar{\pi}_a}{\partial n_a}|_{\theta^I}$ . When $\theta_c$ is fully insured, $Cov(\pi_i \pi_j) = 0$ and $Var(G) = 0$. To satisfy $E(N) = \bar{\pi}$, $\bar{\pi}_a = \bar{\pi}$ has to hold.