A Heterogeneous Agent Model of Credit-Linked Index Insurance and Farm Technology Adoption

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Abstract

Protection from downside risk is a determinant of technology uptake among subsistence agricultural households. Access to credit, insurance and savings may stimulate technology adoption where new methods are riskier but higher yielding or require sunk costs. In this paper, we employ a dynamic, stochastic, heterogeneous agent model where farm households have access to contingent credit and make savings, technology and loan repayment choices. Our approach is novel as insurance is modeled as a meso-level product, where the bank is indemnified before any payouts are distributed to borrowers; thus, it accounts for both supply- and demand-side concerns, showing a flow of effects when index insurance contracts are sold to risk aggregators for whom basis risk is lower. Results show letting the lender lay first claim on indemnities lowers default, which can decrease interest rates and expand credit access. Insurance and savings may also spur technology uptake.

Keywords: weather insurance, technology adoption, numerical methods
JEL Codes: C61, D14, D81, G22, O16, Q12

1. Introduction

An extensive risk-coping literature is omnipresent in development economics research, with work focused around the question of whether or not poor households can informally manage risk in the absence of formal financial tools. There has been evidence of informal risk sharing through reciprocal lending within social networks, resulting in fairly smooth household consumption profiles when controlling for village-level consumption patterns (Townsend, 1994; Udry, 1990).[1] However, these risk sharing arrangements, while effective at managing idiosyncratic risk, may be insufficient when a systemic shock simultaneously lowers the income of all households in a region.

The failure of households to fully insure can result in severe repercussions. In this paper, we focus on the tradeoff between uncertainty of income and higher returns to investment that can cause poor agricultural households to remain in persistent poverty. While interlinked index insurance is only one policy option that has the potential to help these households emerge from a dynamic poverty trap, we employ such a mechanism because it is a feasible option given the stylized facts of agrarian economies in low-income countries: risk-averse households using uninsured credit for consumption rather than investment, credit constraints stemming from systemic risk exposure, a lack of traditional insurance due to high transactions costs, and informal insurance that smoothes consumption fairly well in the face of idiosyncratic shocks.

While the richness of the model presented provides the potential to conduct a number of policy analyses, the motivation of this paper is to address questions that will offer inferences on the formulation of development policy that aims to alleviate rural poverty and increase food security. Namely, this paper will focus on three principal questions:

1. What types of credit and insurance schemes reduce the incidence of default among rural borrowers, so that financial institutions are able to continue lending, expand lending, or lower interest rates on borrowing?

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[1]Note that informal risk sharing does not necessarily protect households against even idiosyncratic income shocks. Jalan and Ravallion (1999), for example, find evidence of differential (but never full) insurance across income deciles among a panel of Chinese households.

2. Does the availability of insurance induce subsistence farming households to adopt high-technology methods that increase output and provide higher incomes on average?
3. Under what conditions does high-technology adoption result in welfare gains relative to the employment of traditional technology?

Similar to the findings of Janzen, Carter, and Ikegami (2012), where access to insurance reduces households' vulnerability to a fall into poverty as well as increases the likelihood of reaching a high-level equilibrium, we find that, under certain conditions, households with access to interlinked credit-insurance contracts are more likely to adopt high-technology farming practices.[2] Because the choice to adopt technology reflects an increase in welfare for the household should it choose to adopt (i.e., the household's value function is greater with technology than without), this indicates that an environment in which insurance is available and bundled with credit may induce welfare gains from technology adoption. Additionally, although technology adoption is the highest where credit and insurance are separately available to rural households as opposed to being offered as a bundled product, this policy is also the one in which loan default rates are the highest. It is, therefore, important to approach the proceeding policy analysis in a manner that can reconcile the seemingly divergent goals of high technology adoption and low rates of loan default. Along these lines, results suggest that contingent credit contracts – because they lower default even when households adopt riskier but higher yielding farming practices – can increase sustainability of credit markets by reaping positive rates of return for rural banks.

When farm households are also able to save, technology uptake is higher for two reasons: (i) savings allows for self-financing of the technology investment cost, which does not include additional transactions costs (e.g., the interest rate on a loan or the premium associated with an index insurance contract); and (ii) when farmers can save, they can further smooth consumption from period to period – and without the uncertainty associated with index insurance coverage – so that higher but more volatile income does not have to be entirely consumed when consumption is high and marginal returns to additional consumption are low. One caveat of the ability to save is that it confounds the positive effect of index insurance on credit markets; the ability to save reduces the household's penalty for loan default, and thus results in adverse credit market effects when insurance and loan contracts are not carefully designed. In addition, we find that savings and credit are substitutes – but not perfect substitutes. When saving is an option, households with low levels of accumulated wealth still choose to insure as well as save, both to finance technology investment and to supplement consumption in years of low-income realizations.

A notable difference in the approach in this paper is the way in which indemnity payments are disbursed. Miranda and Gonzalez-Vega (2011) find that mandatory, unsubsidized index insurance for individual farmers can diminish a bank's internal rate of return; this is due to the perverse effects of premium burdens that disincentivize borrowers from repaying loans. However, they do not consider the effects of contingent credit or credit-linked insurance. For the purposes of this paper, contingent credit refers to a loan that is coupled with an index insurance contract that covers the value of the loan upon maturity (principal plus interest), the premium for which is deducted from the loan value before it is disbursed. In the contingent credit setting the bank is the insured agent, although it passes on the insurance costs to the borrower through a higher interest rate on credit; the bank receives any indemnities from the index insurance contract, which allows it to forgive debt for borrowers when adverse weather conditions occur. We also briefly examine what we call credit-linked insurance, which is similar to contingent credit but increases index insurance coverage to the entire portion of a borrower's agricultural income that is determined by systemic factors, not solely the value of the loan. Under this setting, the bank passes on indemnities net of a borrower's debt to the borrower. Thus, technology adoption among farm households is expected to be greater under the latter contract type.

Due to the contract design of contingent credit, the flow of indemnity payments prevents one type of strategic default that can occur if indemnities are paid directly to individual farmers. We also run a model where, similar to the contingent credit model, insurance is mandatory for those who wish to borrow, but where the initial claimant is the borrower himself and not the lending institution. Two "reference" scenarios – one of credit only and one of non-interlinked credit and insurance markets – provide further sources of comparison. This paper thus contributes to the existing literature by laying out a dynamic model that incorporates the benefits of a meso-level index insurance

[2] This is the case in the baseline model, which includes a load on insurance and thus makes it actuarially unfavorable to the insured; actuarially fair insurance further increases technology adoption relative to a scenario in which no insurance is available.

product, but does so with a greater emphasis on demand-side considerations.[3]

The rest of the paper is organized as follows: Section 2 provides a review of the recent literature on index insurance and agricultural risk; Section 3 introduces a representative agent model under scenarios that differ in the interaction between credit and insurance markets and the flow of insurance indemnity payments, as discussed above, and subsequently extends the representative agent model to a heterogeneous agent model; Section 4 presents the numerical results of simulations of the heterogeneous agent model under base parameter assumptions, examining farm household behavior in both the absence and presence of a savings market; Section 5 offers a sensitivity analysis of the results, particularly with respect to risk aversion, insurance coverage, and premium loads; Section 6 concludes.

2. Poverty, Risk and the Role of Insurance in Technology Adoption

2.1. Informal Risk-Coping Mechanisms Versus Formal Insurance

In the absence of access to affordable insurance, rural households in developing countries attempt to protect themselves from risk using informal, non-market mechanisms. Many empirical studies have found evidence of non-market risk sharing within low-income communities (Ligon, Thomas, and Worrall, 2002; Foster and Rosenzweig, 2001; Coate and Ravallion, 1993). However, most of this risk sharing applies only to idiosyncratic risk, and generally provides very limited protection against systematic shocks such as droughts and floods (Sawada, 2007).

Informal risk-coping mechanisms employed by agricultural households come at the sacrifice of profitability, a tradeoff that is clearly explained by classical portfolio theory (Heady, 1952). Risk presents an impediment to the adoption of more profitable agricultural production practices in developing countries, such as the adoption of fertilizer and high-yield seed, accumulation of herds, or expansion of farm size (Clarke and Dercon, 2009; Mude et al., 2009; Cai et al., 2009). Poor households often make safer, lower return investments, and may even vary consumption to stay above a dynamic asset threshold (Zimmerman and Carter, 2003; Carter and Lybbert, 2012; Lybbert and McPeak, 2012). As such, farmers in developing countries on average make lower incomes than would be possible if they had access to formal insurance to protect their income and investments.

The availability of formal insurance may induce poor, rural households to make productive investments they would not have made had they had access only to informal risk-coping mechanisms. In one of the few empirical studies to date on index insurance and investment, Karlan et al. (2014) find that insurance availability leads to significantly larger agricultural investment, as well as riskier production choices; thus, the authors conclude that, for their sample of Ghanaian farmers, uninsured risk is a relatively more important determinant of low technology adoption compared to capital constraints faced by households. Using data from Malawi to calibrate and estimate a stochastic, dynamic optimization model, de Nicola (2012) finds that weather insurance increases long-term consumption, as well as induces households to adopt riskier but higher yielding hybrid seed varietals; however, if only a single, low-technology farming option is available, insurance is found to *reduce* total input investments, as it weakens farmers' precautionary motives to overinvest.[4] Other studies corroborate that uninsured risk accounts for deficiencies in technology uptake and inefficient production choices among low-income households (Dercon and Christiaensen, 2011). More importantly, the trade-off between profit variability and average returns is large, and the loss of efficiency associated with informal risk-coping strategies is higher among low-income households (Rosenzweig and Binswanger, 1993); the existence of uninsured weather risk thus results in increased income inequality. Additionally, formal insurance may further encourage farm investment when it is paired with access to other types of finance (Carter, Cheng, and Sarris, 2011).

While farm households may not be able to make fully efficient resource allocations in the absence of complete risk markets, they have practical means to partially mitigate risk. Other determinants of technology adoption can serve an insurance purpose even where there are no formal markets for risk management. Where consumption credit is available to agrarian households, for example, it can take on the role of an insurance contract and hence influence risk behavior and production decisions (e.g., technological innovation and investment levels) of farmers (Eswaran

[3] Chantarat et al. (2013), for example, examine demand-driven design of livestock index insurance, but market the product at an individual level. While they look at implications for the risk exposure of the insurer, implications for credit performance of insured borrowers are not explored.

[4] It is important to note that de Nicola (2012) assumes actuarially fair insurance premiums, zero basis risk, and farmers who observe a realization of idiosyncratic risk before making an insurance purchase decision.

and Kotwal, 1989). This is often the case with informal credit arrangements, where repayment structure may be conditional upon production and consumption shocks faced by both the borrower and the lender (*see*, e.g., Udry (1990)).

2.2. Index Insurance

Almost twenty years ago, Gautam, Hazell, and Alderman (1994) studied risk-coping strategies in India and found that there exists major latent demand for formal insurance products, as households cannot spread risk effectively at the local level when affected by a systemic shock. The authors were among the first to suggest the use of a rainfall index-based insurance product as a means to reduce costs stemming from moral hazard. Their novel approach of charging the same premium and making the same indemnity to all policyholders within a given proximity to the same weather station is the very methodology still being used today in many agricultural insurance pilots.

Index insurance products pay out when the realized value of an underlying index either exceeds (e.g., in the case of flood insurance) or falls below (e.g., for drought insurance) a given threshold. The index must be exogenous to the policyholder but should also be significantly correlated with the policyholder's actual losses (Barnett, Barrett, and Skees, 2008). That a policyholder cannot affect the realization of the index is the feature of index-based contracts that does away with moral hazard; because actual losses are not indemnified, households are incentivized to minimize farm losses – even when they are weather-related.

In addition, index-based products are unique in that, unlike traditional agricultural insurance, all buyers of a particular policy in a given year face the same degree of risk. As the payouts are completely determined by an independent index – not by actual farm outcomes, which may be influenced by an individual's risk behavior or skill in agricultural management – insurers do not face the same problems with adverse selection that plague policies whose indemnities are based off of actual losses. These characteristics of index insurance contracts lower the risk load on charged premiums, as well as reduce monitoring costs to the insurer. Transactions costs associated with claims verification are also eliminated, which can further reduce premiums faced by farm households.

While index insurance can be optimally designed in theory (Miranda, 1991), successfully implementing index-based programs has proved more difficult. There have been considerable demand-side complications in pilot programs offering voluntary contracts to individuals, even where premiums are heavily subsidized (*see* Mosley (2009) for an outline of a World Bank pilot in Ethiopia; Cai et al. (2009) for an analysis of a sow insurance pilot in China). Upfront premium payments may be problematic for liquidity-constrained households (Gine et al., 2010); as such, competing *ex ante* uses for funds (e.g., for fertilizer or inputs) may prevent households from purchasing insurance, even if they have a high willingness to pay for the product. In a pilot program in Ethiopia, for example, farmers with lower marginal returns for inputs (i.e., those who already use a relatively high amount of fertilizer) are found to be more likely to adopt index insurance than those with higher returns at the margin (i.e., those who use relatively less fertilizer and could greater improve yields with additional application); increased demand for insurance is only highly responsive to the random allocation of price discount vouchers (McIntosh, Sarris, and Papadopoulos, 2013). Other explanations for low index insurance uptake include unfamiliarity with a product or insurer as well as the presence of basis risk.

Mandatory credit-insurance bundling has been proposed where the premium payment is implicit, reflected in higher interest rates on loans. However, such policies may reap results that seem counterintuitive. For example, in a randomized controlled trial (RCT) in Malawi, farmers' demand for credit is found to decrease when loans are bundled with a rainfall insurance contract, even though there is considerable risk of income loss due to drought (Gine and Yang, 2009).[5] In an RCT offering indemnified loans to Ghanaian farmers, no significant difference is found in loan uptake among treatment and control groups, although farmers in the treatment group are found to shift production to a more perishable crop (Karlan et al., 2011).

Even with well designed contracts and an informed client base, offering farm-level index insurance contracts may be infeasible due to idiosyncratic risk faced by households, which increases basis risk inherent in index insurance coverage. In many cases, the appropriate market for weather index insurance may not be individual households but instead local-level risk aggregators – such as MFIs, farmers' cooperatives, input suppliers, and, in some cases, local

[5]Gine and Yang (2009) explain the lower demand for weather-indexed loans as a result of a culture of default in the study area; the implicit limited liability property of the loan contracts allows for default with little penalty, and thus borrowers are not willing to pay for formal risk reduction when they previously enjoyed similar benefits at no additional cost.

and national governments – who indirectly face weather risk due to their interdependence with farmers exposed to such risk, and also face less basis risk than would an individual farmer (Barnett and Mahul, 2007; Miranda and Farrin, 2012).

2.3. Spillover Effects: Insurance and Credit Markets

The establishment of a formal insurance market can interact with other segments of financial markets, namely the credit market. If an MFI's portfolio is made up of rural borrowers who are insured against catastrophic risk in particular under an index insurance contract, the MFI is less likely to become insolvent due to systematic default (Barnett, Barrett, and Skees, 2008). Thus, access to index insurance may also expand the population of impoverished households that has access to credit, especially in agricultural regions. While uninsured borrowers are left vulnerable to catastrophic shocks and may choose not to borrow at all as a result (Armendariz and Morduch, 2005), if insured, households can borrow both *ex post* for consumption smoothing and *ex ante* for productive activities knowing that they are less likely to default and face severe penalties for doing so.

While the ability to obtain index insurance may increase credit access, there is additional concern for the possible negative spillover effects that might arise from insuring the poor. Although index insurance may eliminate moral hazard in insurance markets, it may increase moral hazard in other markets if the policy is not carefully designed. Insurance can "crowd out" credit markets by implicitly reducing the severity of punishment when households default on loans (Clarke and Dercon, 2009). Index insurance, by effectively increasing the minimum welfare level a household can achieve should it default, reduces incentives for repayment and, in turn, results in lenders having to cut back on the amount of credit they can profitably offer to clients. It is noteworthy that the converse may also be true: index insurance could reduce moral hazard in credit markets under special circumstances. In Morocco, for example, the country's public agricultural bank has a policy of forgiving farm loans following drought; if weather insurance were made available, borrower repayment discipline may increase as drought would be less likely to influence the ability to repay (Skees et al., 2001).

2.4. Savings and Insurance

Just as insurance and credit decisions are interlinked in rural economies, the same may be true of households' savings decisions. While much of the poor remain unbanked (Ardic, Heimann, and Mylenko (2011) estimate that 64 percent of adults in developing countries are excluded from financial markets), the option to save – whether formally or informally – can have a significant impact on farm risk management strategies.

Rural households who can save in good years to increase consumption in the face of negative production shocks may be able to self-insure. For example, using regional rainfall data matched to household-level farm income data, Paxson (1992) finds that Thai rice farmers have a large marginal propensity to save out of transitory income; such savings are used to smooth consumption despite income variability. In a thorough review of how low-income households save, Rosenzweig (2001) reports significant consumption smoothing across years – even in response to large income fluctuations – as well as a crowding out of informal insurance mechanisms where formal financial institutions exist; findings, however, also suggest that the lack of complete insurance and credit markets, in combination with low and volatile incomes, manifests in inefficient asset stocks and compositions among farmers, as well as increased inequality.

Farmer-owned, government-monitored savings accounts have been proposed as an alternative to crop insurance, where the former could serve a risk management purpose while avoiding difficulties in premium rating associated with the latter (Colson, Ramirez, and Fu, 2014). However, such programs have been recommended for cost savings in a U.S. setting, where the banking system is strong and federal subsidies for crop insurance are high. Little empirical research exists to examine the role of savings as a substitute for insurance in developing countries.[6]

Finally, earlier work by the authors suggests that index insurance may be a mezzanine product for farmers in low-income countries. While extremely low-income households are found to be too poor to finance upfront premium payments, households with enough wealth will use savings as a substitute for insurance; it is the middle-income

[6] Jutting (2000), for example, discusses the difficulties of implementing formal social security programs in low-income countries where agriculture is the dominant source of income; Dercon (2002) shows that public safety nets are likely to help poor rural households manage risk, although their impact can be limited and may create negative externalities for those not covered.

households, who have some accumulated savings but maybe not enough to protect them from a catastrophic income shock, who benefit from the existence of a formal insurance product (Miranda and Farrin, 2012).[7]

3. The Model

3.1. The Representative Agent Model

In this model, we consider an infinitely lived, representative agricultural household that may borrow a loan of a fixed quantity, L, in any given period. That the loan size is set reflects a situation in which credit is offered for a specific investment (e.g., the loan amount is chosen to be just enough for an inputs package). Note that a borrowing household need not use the funds for their intended purpose and may instead spend the loan on own consumption.[8] If the household chooses to take out a loan, it may be the case that it must also purchase an index insurance contract that is linked to the loan; if so, the premium is deducted from the borrowed amount before the loan is disbursed. This contract can cover only the value of the loan or, in the alternative, the entire expected value of the crop; implications of the type of loan-coupled insurance coverage will be discussed subsequently. The household may later choose to default on its loan, but faces a punishment if it does so. If the household is not required to purchase insurance as a condition of the loan, it may also be able to separately purchase insurance – whether or not it decides to take out a loan. Finally, the household may also save a portion of its income for future consumption (or, in the alternative, it may draw on any past savings to increase current consumption).

Four scenarios are considered: two "reference" scenarios where insurance and credit are not interlinked, and two scenarios in which a household's decision to take up a loan renders mandatory the purchase of an associated index insurance contract. Specifically, the model scenarios are:

- No Insurance: Only credit is available; neither the households nor the bank have access to index insurance.
- Optional Insurance: All farmers have access to index insurance and their decisions to borrow and/or purchase insurance are independent.
- Mandatory Insurance: Borrowers are required to purchase index insurance coverage equal to value of the loan principal plus interest as a condition of acquiring a loan.
- Contingent Credit: Borrowers are offered contingent credit contracts in which they are not required to repay their loan if an indexed event occurs. The bank purchases index insurance coverage equal to the value of the loan plus interest and passes the premium costs to the borrower in the form of a higher interest rate. Under both mandatory insurance and contingent credit regimes, households may purchase insurance if and only if they opt to take out a loan.[9]

Utility of the household is derived from earnings from farm production, which are stochastic. Farm production occurs through one of two channels: a traditional farming technology that requires no additional cost but results in lower average income, or a high-yield technology (e.g., fertilizer adoption) that carries an upfront cost and results in more variable income due to the sensitivity of the technology to weather risk. Households begin each period with the knowledge of their current credit, debt and disposable wealth (current income and insurance payments plus accumulated savings) states, and make four discrete choices to maximize the expected, discounted present value of lifetime utility of wealth:

1. To default on or repay an outstanding loan;
2. To take out a loan for the current period or go without borrowing;
3. To purchase insurance coverage in the current period for the upcoming crop season; and

[7] Note, however, that this study did not consider a farmer's option to choose his production technology.

[8] *See*, e.g., Kotir and Obeng-Odoom (2009), where Ghanaian households are found to divert a significant proportion of microcredit loans to household consumption.

[9] This condition has practical significance, as it is often the case that MFIs are chosen as distributors of agricultural insurance contracts, and thus tend offer the product to their existing client-borrowers.

4. To adopt a high-yield or traditional farm technology.

The household makes an additional, continuous choice of how much of its current income it saves; this decision includes the option to dissave, i.e., draw from its previously accumulated savings to increase current consumption.

For the household's dynamic optimization problem, the state variables are thus:

- A *credit state*, i, equal to 1 if the household is creditworthy in the current period (i.e., it has never defaulted or has exogenously re-entered the credit market after a past default) and 0 if the household is currently credit unworthy.
- A *debt state*, j, equal to 1 if the household currently holds debt (i.e., it has an outstanding loan and has chosen to repay), and 0 if the household has no loan, decides to default, or has its debt canceled by the triggering of a contingent credit contract.
- A *disposable wealth state*, $w \geq 0$, composed of current, technology-contingent agricultural income, any insurance payments the household receives, and past savings.

We now introduce a parameter, ϕ, as a tool in the numerical approach to model transition functions for the debt and wealth states for different types of bundled credit and insurance. Because the two bundled credit-insurance scenarios vary only in the entity (borrower or lender) that serves as the initial claimant of the index insurance indemnity, we use ϕ to characterize both settings using a single equation. Setting $\phi = 0$ reflects mandatory insurance, where the indemnity is paid first to the borrower. Under this regime, any indemnity payments factor into a household's disposable wealth, as the household that takes out an insured loan is not required to repay said loan to receive the benefits of the insurance. On the other hand, $\phi = 1$ embodies contingent credit, where the lender first receives any indemnities. From the household's perspective, the contingent credit contract factors into the debt state by effectively canceling out loan repayment requirements (i.e., j changes from 1 to 0 for a contingent credit borrower) in the adverse weather state.

Transitions for the debt state, which is stochastic due to its dependence on the systemic portion of income that is indemnified by the index insurance contract, follow the rule:

$$\tilde{j} = j'(1 - \phi\tilde{z})$$

where $\tilde{z}$ is a systemic component of income and $j' = \{0, 1\}$ reflects a household's decision to borrow or not in the current period (where a loan is attached to an index insurance contract). Now, we define $h(\tilde{z})$ as the indemnity schedule on the index insurance contract (recalling that index insurance contracts do not cover idiosyncratic income shocks). The indemnity schedule does not vary by technology choice, as the insurance-linked loan is intended for the purposes of technology adoption regardless of how the household actually chooses to use it. Specifically, we designate the parameter η as the portion of debt that is covered by the index insurance contract, so that $h(\tilde{z}) = \eta\tilde{z}$. As a simplification we let $\tilde{z}$ take on one of two values, so that $\tilde{z} = 1$ indicates a period in which the household experiences a systemic shock (e.g., a drought) and $\tilde{z} = 0$ is indicative of normal systemic conditions. Thus, for $\eta = 1$, a household with an outstanding loan would have its debt erased in a drought year ($\tilde{z} = 1$) and would otherwise be responsible for full repayment of the loan should it choose not to default.[10]

To characterize disposable wealth, define $\tilde{y}_l$ as stochastic income from predetermined technology l, for $l = 0, 1$, where income is decomposed as:

$$\tilde{y}_l = \bar{y}_l(1 - \beta_l\tilde{z})\tilde{\epsilon}_l$$

Technology l is equal to 1 if the household adopts high-technology farming and 0 if it employs traditional farming. Expected income under normal conditions is $\bar{y}_l$. To reiterate, $\tilde{z}$ represents a systemic shock (e.g., rainfall), which is indexable but can differentially affect income depending on the household's choice of technology. The parameter β_l corresponds to the portion of income lost due to systemic factors, and reflects the insurability of technology l through an index-based contract (the larger the β_l, the greater is the proportion of income explained by the systemic factor

[10]To streamline the numerical analysis, we make the assumption that $\eta \geq 1$, so that, at minimum, a household's full loan debt is covered by the index insurance contract. This allows for the treatment of the debt state as a discrete variable.

measured by the index, and thus the more value the insurance contract provides the household). On the other hand, the more variable the mean-one, idiosyncratic risk, $\tilde{\epsilon}_l$, the less attractive the insurance contract is to its holder. A low β_l combined with a highly variable $\tilde{\epsilon}_l$ (i.e., losses due to weather are small, whereas risks not covered by the contract are relatively large) indicates that there is a substantial amount of basis risk faced by the household if it chooses to take out a loan linked to an index insurance contract.

Let σ_l denote the volatility of the idiosyncratic income factor for technology l. Finally, we assume $\tilde{z}$, $\tilde{\epsilon}_0$, and $\tilde{\epsilon}_1$ are mutually serially independent and identically distributed over time, and $y_1(1-\beta_1 p) > y_0(1-\beta_0 p) > 0$. The latter assumption translates to expected income from the high-technology option being greater than that of the traditional option, where both income types are strictly positive.[11]

We specify stochastic income as a combination of idiosyncratic and systemic components, where the idiosyncratic shock, $\tilde{\epsilon}_l$, is multiplicative. This reflects the notion that, in a good year, household-level shocks can positively or negatively affect average income. For example, a household may suffer from an illness of one of its working members or experience a farm equipment malfunction that would adversely affect its earnings; it may also be the case that the household's farm plots experience better rainfall in a given season than what is average for the area, and as a result its yields are higher and income is positively affected. However, these types of idiosyncratic shocks can also exacerbate or ameliorate an income shortfall in a bad season.

Similar to the case of the debt state transitions, whether or not the wealth state is endogenously determined by indemnity payments depends on the scenario under which the model operates. State transitions for wealth, which is also stochastic, are characterized by the function:

$$\tilde{w} = (1 + r_s)(w + s') + \tilde{y}_{l'} + (\eta - \phi j')(1 + r_L)Lk'\tilde{z}$$

where $s' \in [-w, y_l]$ is the household's chosen level of savings for the current period, r_s is the risk-free interest rate on savings, and r_L is the interest rate on the loan. We denote k' as the household's discrete choice to take out an insurance contract, where this decision may be restricted by the household's loan choice depending on the prevailing credit-insurance regime. Because savings is generally informal in low-income countries, we assume $r_s = 0$ in the base model (note that setting the rate on savings to be negative may even be more representative of developing economies).

We use an example to clarify how the wealth transition works. Let $j' = k' = 1$ and $\phi = 0$, so that the household has an outstanding loan with mandatory insurance, where the household first receives the indemnity and thus may decide whether or not to use any such indemnities toward its debt repayment. The term with η in parentheses reflects the possibility of net payments from index insurance above the value of the loan. Thus, an insured, borrowing household will receive the proportion η of its debt obligation as an indemnity if poor weather conditions prevail; this indemnity increases its disposable wealth, but, if the household is the initial claimant of the insurance policy, does not directly affect the debt state.

The action variables are, therefore, the credit, debt, insurance, technology and savings choices, i', j', k', l' and s' that will partially determine the endogenous state variables in the following period.

Additional model parameters are:

1. $p \equiv$ the probability of drought, so that a farm household experiences normal crop conditions with probability $(1 - p)$.

2. $P \equiv$ insurance premium (where insurance is coupled with a loan).

   Specifically, the coupled loan-insurance contract is available at a premium of

   $$P = (1 + \theta)\eta p L$$

   where θ is the premium load. Thus $\theta = 0$ reflects the case of actuarially fair insurance; $\theta > 0$ reflects actuarially unfavorable insurance (which is common in practice in private markets, as insurers must account for

[11] For the numerical simulation, we use Gaussian quadrature to discretize the idiosyncratic shocks, $\tilde{\epsilon}_l$, so that they take on a finite number of values that correspond to a lognormal, mean-one, continuously distributed error term. In the results presented here, we allow for 5 idiosyncratic shock values for each technology.

transactions and ambiguity costs in order to break even); and $\theta \in [-1, 0)$ reflects subsidized insurance, where a negative premium load is usually associated with government-run or donor-sponsored insurance projects – especially those in the pilot phase.[12]

3. $K \equiv$ technology investment cost.

   In the case of a non-durable technology purchase (e.g., fertilizer), there is only a cost related with input purchase; this cost is independent of the previous period's technology choice as the investment is completely reversible and depreciates after one crop season. If the goal of a lending project is to induce technological adoption among smallholders, it may be the case that the lender sets $L \geq K$, so that the borrowing household does not face liquidity constraints if it wishes to invest in the high-technology farming option.

4. $\gamma \equiv$ cost parameter that captures the stigma of default when a household is or becomes credit unworthy.

   Note that γ is an additional penalty, as a defaulting household is also unable to borrow freely in the future as would one that is credit worthy. One way to consider the stigma parameter is as a social cost of default, where households who have reneged on formal insurance-credit contracts may be less likely to receive informal loans from extended family or community members.

5. $\mu_i \equiv$ exogenous probability of reinstatement into creditworthiness, conditional on a household's current credit state, where $\mu_i \in (0, 1]$ for $i = 0, 1$.

   Because a household that is creditworthy will remain so until it chooses to default, $\mu_1 = 1$ and $\mu_0 = \mu$, where a higher μ indicates a lesser punishment for default. This would be the case, for example, where lenders are unable to detect when clients have previously defaulted due to a lack of a well functioning credit rating agency or even the ability to identify an individual. Let $\overline{\mu}_i = 1 - \mu_i$.

6. $\delta \in (0, 1] \equiv$ the farm household's time discount factor.

The farm household's dynamic optimization problem can now be expressed in the form of a single Bellman equation whose value function represents the maximum expected present value of lifetime utility, $V_{ij}(w)$, given the household's creditworthiness, *i*, debt, *j*, and disposable wealth, *w*, at the beginning of the period. To summarize, under mandatory insurance, indemnities are made directly to the borrower and any insurance payments factor into the state variable for wealth, as they become part of the household's disposable income. Under contingent credit, indemnities contribute to the debt state variable and serve to reduce the amount a non-defaulting household must repay on its loan. Again, under the case of contingent credit, the insured borrower cannot, after realizing a systemic shock, take the money and run.

Recalling the state transition functions for *j* and *w*, the household's Bellman equation takes the form:

$$V_{ij}(w) = Max_{s' \in [-w, y_l]; i', j', k', l' \in \{0,1\}; j' \leq i' \leq i} u(c) - \gamma(1 - i') + \delta E_{\tilde{z}\tilde{\epsilon}}[\overline{\mu}_{i'} V_{0\tilde{j}}(\tilde{w}) + \mu_{i'} V_{1\tilde{j}}(\tilde{w})]$$

where

$$c = w - s' - i' j(1 + r_L)L + j'L - k'P - l'K$$

The constraint on *j'* restricts a household from borrowing if it has defaulted in the past or is currently choosing to default. Once a household has defaulted, it cannot take action to regain its status of creditworthiness; instead, only the exogenous probability μ_i dictates a credit unworthy household's ability to re-enter the credit market. We leave the stigma penalty, γ, outside of the period utility function; the concept of "stigma" often has a non-pecuniary connotation, and thus we do not wish to restrict the penalty to be in dollar terms, as it would be interpreted had we included it within the household's utility function.

The following additional constraints will differentiate credit-insurance regimes within the model:

[12] In the absence of subsidies, values of θ less than 0.5 are rare; values on the order of 1.0 are common.

- No Insurance: $k' = 0, \phi = 0$;
- Optional Insurance: $\phi = 0$;
- Mandatory Insurance: $j' = k', \phi = 0$; and
- Contingent Credit: $j' = k', \phi = 1$.

Let the farm household's utility function be twice continuously differentiable, strictly increasing and strictly concave, with utility increasing in wealth and $lim_{c \to 0} u'(c) = \infty$. For the numerical analysis in the subsequent section, we assume period utility is isoelastic, taking the form $u(c) = c^{(1-\alpha)}/(1-\alpha)$, so that farm households display constant relative risk aversion.

3.2. The Heterogeneous Agent Model

To simulate a village economy, we expand the model to allow for heterogeneous agents. While agents do not differ in preferences, they do experience distinct histories of idiosyncratic shocks over time. These diverse histories create a distribution of wealth within the economy; we exploit the heterogeneity in wealth, as agents who differ in initial wealth and shocks will make different savings, borrowing and technology choices. Thus, the representative agent model can be straightforwardly transitioned to a heterogeneous agent model through Monte Carlo simulation. With such a model, we can simulate ergodic distributions of key economic variables at the village level. When calibrated to fit the conditions of an economy of interest, the model is especially useful in comparing welfare effects of various development policies.

3.3. Finding a Numerical Solution

With the continuous choice of savings and the discrete choices of repayment, borrowing, insurance and technology a household can make, the household's decision process can be viewed as a maximization over conditional value functions. Specifically, a household can choose from a finite number of (possibly constrained) choice sets over binary decisions, {*Credit Repayment, Loan, Insurance, High Technology*}. For each of the choice sets, the household will choose the level of savings, ${s'}^{*}_{i',j',k',l'}$ that optimizes its value function. The final household decision set will be that associated with the conditional value function with the highest value.

To computationally solve the farm household's conditional Bellman equations, we use collocation to numerically approximate the value function by using a series of known basis functions whose unknown coefficients are estimated using a series of rootfinding routines, one for each chosen node at which the Bellman is required to be satisfied (Miranda and Fackler, 2002). This method reduces a problem of infinite dimension to a finite one, where residuals can be calculated to analyze the goodness of fit of the approximation.

4. Results

4.1. Insurance and Credit Market Depth

One of the main questions posed in this research is whether or not index insurance can successfully deepen the credit market, either through lowering interest rates on borrowing or extending credit access to regions that had previously been unbanked due to an overwhelming amount of risk faced by banks with portfolios dominated by agricultural borrowers.

To assess the effect of insurance on the rural credit market, we numerically solve the Bellman equation under each of the four scenarios using the base parameterization, varying the interest rate on credit from 0 to 100 percent across simulations. Using the no insurance regime as a baseline, we solve for the optimal interest rate, i.e., the one that maximizes lender profits. Holding that level of profits fixed as a target profit, we then calculate the interest rate necessary to achieve the target profit in the three remaining scenarios.

Results show that target profit levels can be achieved under lower interest rates in the contingent credit regime, where credit and insurance are bundled and the lender is the initial claimant on insurance indemnities. For example, under base parameterization, the maximum achievable bank profit under no insurance and no savings is earned with an interest rate of just over 10 percent; the prevailing interest rates for the same profit level are just over 4 percent for

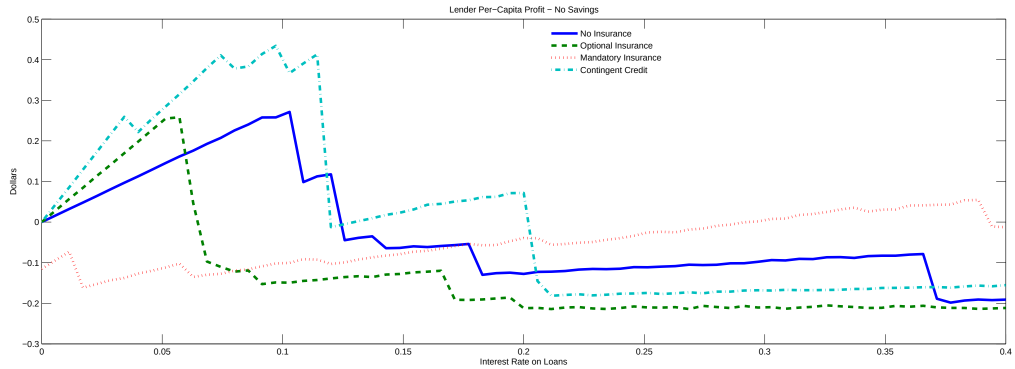

Figure 1: Bank Profits as a Function of Interest Rate on Credit – No Savings

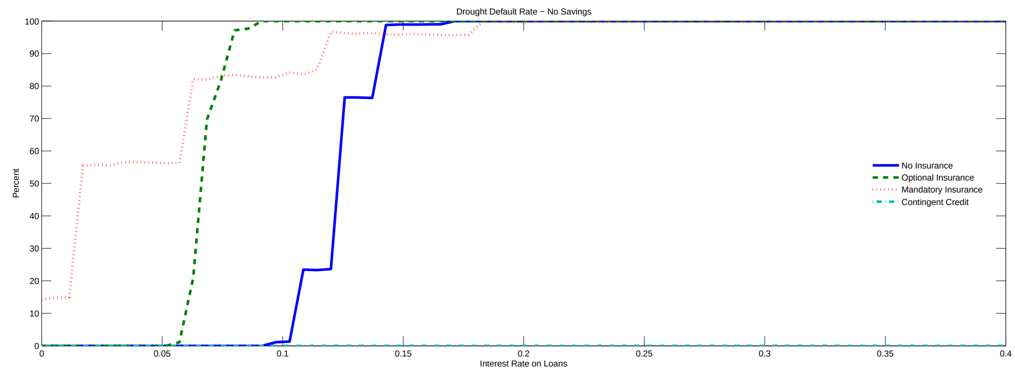

Figure 2: Drought Default Rate and Interest Charged on Loans – No Savings

contingent credit and about 6 percent for optional insurance.[13] Lower interest rates spur borrowing as well, with loan uptake at above 45 percent for contingent credit; the borrowing rate decreases to less than 25 when no insurance is available. Figure 1 plots bank profits by interest rate for the four scenarios.

The implications of these results are important when considering bank sustainability. If a bank requires a certain level of profits to cover its administrative and risk-bearing costs, it may choose not to operate in areas or under regimes where only low (or negative) profits can be realized. In such a case, agricultural households would lose access to credit altogether, and would likely resort to more extreme informal risk-smoothing mechanisms at the cost of higher income opportunities.

4.2. Results Under Base Parameterization - No Savings

We first examine the model results under a restricted setting in which no savings is allowed. For each of the four scenarios, we use Monte Carlo methods to run $100,000$ simulations and calculate five long-run averages that characterize the relevant economy:

1. Rate of Loan Uptake;
2. Rate of Insurance Uptake;
3. Rate of High Technology Adoption;

[13]The interest rate for the mandatory insurance scenario fails even to achieve the target profit level under no insurance; per capita profits are less than 0.1 at maximum, whereas the target per capita profit is approximately 0.25.

Table 1: Definition of Base Parameters of the Model

Parameter	Value	Definition
α	2.00	Coefficient of Relative Risk Aversion
L	0.12	Loan Size
r_L	0.20	Interest Rate on Loans (Fixed Rate Scenario)
r_s	0.00	Interest Rate on Savings
γ	0.00	Stigma of Default
μ_0	0.02	Probability of Regaining Creditworthiness, $i = 0$
K	0.12	Cost of High-Technology Farming
$\bar{y}_0$	1.00	Expected Normal Income, Low Tech
$\bar{y}_1$	1.30	Expected Normal Income, High Tech
β_0	0.40	% Income Shortfall in Drought, Low Tech
β_1	0.65	% Income Shortfall in Drought, High Tech
σ_0	0.10	Idiosyncratic Income Volatility, Low Tech
σ_1	0.10	Idiosyncratic Volatility, High Tech
r_s	0.00	Interest Rate on Savings
p	0.20	Probability of Drought
η	1.00	Percent of Loan Insured
θ	0.50	Insurance Loading Factor
δ	0.90	Time Discount Rate
s_{max}	3.00	Maximum Savings (When $\neq 0$)

4. Rate of Default (in Drought and Normal Conditions); and
5. Rural Bank Profits.

A list of the base parameter values can be found in Table 1. For this analysis, note that we fix the interest rate on loans to 20 percent. Such an exercise provides valuable information about how rates of default and technology adoption vary if a bank were to charge the same interest rate on borrowing under various credit-insurance regimes (this would be expected without the bank having further knowledge of borrower behavior under different financial environments). When interest rates are allowed to vary to meet target profit levels, on the other hand, default rates are similar and close to zero due to the nature of the target-profit-finding process by which the interest rate is derived. Figure 2 illustrates how default rates vary by interest rate under the four scenarios.

Results (presented in Table 2) indicate that, as expected, default is the lowest under contingent credit, where insurance is available if and only if a household takes out a loan, and where any resulting indemnities are first paid to the bank. A noteworthy comparison is to be made between default rates under optional and no insurance cases. Default rates are identical during drought years and higher in normal years with optional insurance, despite the fact that households have access to – and choose to purchase – insurance. This seems to indicate that financial products that are not interlinked may not be complementary and supports the literature of negative spillover effects. With mandatory insurance, drought default rates are higher than with contingent credit, which corroborates the notion of perverse incentives when fewer punishments exist for default.

We offer two observations as to why default is lower under mandatory insurance compared to both optional and no insurance: (i) compared to households that can only access credit, the availability of insurance protects subsistence households against downside risk, diminishing the probability of an extremely low realization of disposable income; and (ii) the linkage between the credit and insurance contracts not only results in a household being barred from taking out credit should it default (as is the case where credit and insurance are separately available), but also prohibits a credit-unworthy household from being insured. Thus, when normal conditions prevail, mandatory credit households tend to repay their loans even when they do not receive index insurance indemnities, so as to have the future possibility of being indemified when income is low. We offer an explanation as to why normal condition default is higher among contingent credit households than mandatory insurance households: the higher rate of technology adoption among contingent credit households leaves them with higher incomes in good years, which makes default more attractive – especially if the household has experienced a negative idiosyncratic shock and does not have its loan forgiven; recall

Table 2: Simulated Long-Run Averages of Key Economy Indicators, Base Parameterization – No Savings

Variables	No Insurance	Optional Insurance	Mandatory Insurance	Contingent Credit
Have Loan	5.7	4.0	12.4	14.3
Have Insurance	0.0	79.2	12.4	14.3
High Tech	18.9	74.6	13.9	25.5
Default – Drought	100	100	99.7	0.0
Default – Normal	23.0	56.7	0.3	16.0
Per Capita Bank Profits	-0.2	-0.3	-0.1	0.1

that under contingent credit, households can only choose to default in normal years when $\eta \geq 1$.

Rates of borrowing do not differ greatly moving from mandatory insurance to contingent credit, although there is a divergence in loan uptake when comparing the cases of interlinked credit-insurance contracts with optional and no insurance. The higher propensity to borrow under regimes offering bundled products indicates that it is the insurance – not the credit – that is of relative value to the household. This finding is especially visible when looking at results for optional insurance: while fewer than 5 percent of households opt to borrow, almost four out of five choose to insure.

A principal motivation of this paper is to examine whether or not insured households are more likely to adopt technology. The answer to this question differs depending on the type of insurance offered, although in certain settings we do see increased technology adoption with insurance. Nevertheless, more investigation is required to examine the motivations for subsistence households' choice of farming technology. High-technology use is the most prevalent under optional insurance; this is, however, in part due to the ability to default on a loan with very little punishment. Along similar lines, households under mandatory insurance are less likely to adopt technology than their counterparts under contingent credit, as the former class of households can default with indemnity payments in their pockets while the latter are incentivized to adopt high technology to reap the benefits of their investment in good times.

It is also important to note that, for tractability, certain nuances of a rural village economy are hard to capture in this dynamic model. In the model, households know the exact structure of the index insurance contract and the distribution of income under each technology choice; there is risk, but no uncertainty. Empirical observations often include mistrust of insurers, confusion about the insurance products themselves, and a lack of agricultural extension and education that would result in closer-to-optimal results from new technology. The rate of technology uptake we present in these results, therefore, should be seen as an upper bound.

4.3. How do Baseline Results Change with Savings?

We now incorporate the option to save into the model to analyze how this additional risk management strategy affects borrowing, insurance, and technology uptake. Our biggest finding is that savings, while it spurs technology uptake more so than index insurance, creates perverse effects in the credit market. The ability to accumulate risk-free savings allows households to self-finance the technology investment, which lowers loan uptake considerably; the few households who do take out loans default, the exception being for contingent credit in a drought year (where default is not possible). Because there is little demand for credit when savings is an option, insurance uptake is similarly low in the bundled insurance-credit regimes. Interestingly, insurance uptake remains high under the optional insurance scenario, with over 90 percent of households choosing to purchase an index insurance contract. Lender profits are negative across the board, which indicates that credit markets would not be sustainable in this type of savings environment.

Because of the divergence in technology uptake rates in the results with savings and what is seen in observational studies in agrarian low-income economies, it is unlikely that such frictionless savings exists in these environments. We briefly examine the difference in results when we allow for the depreciation of savings over time. Such a parameterization suggests either losses from inflation or from the risks involved with informal savings (e.g., theft, obligations to give money to kinship group members who fall on bad times, or physical losses if savings is kept in kind). Table 3 presents results with both frictionless and negative returns savings.[14] In this analysis, we calculate two additional

[14] In Table 3, we present savings wealth and savings multiplied by 100 for greater resolution. Wealth is current agricultural income plus previously accumulated savings, as well as any indemnity payments a household might receive in the current period from an insurance contract it purchased in the previous period. Savings is the average quantity a household chooses to save out of its income in every period.

Table 3: Simulated Long-Run Averages of Key Economy Indicators, Base Parameterization – Savings

Variables	No Insurance	Optional Insurance	Mandatory Insurance	Contingent Credit
Have Loan	2.9	2.9	3.3	3.6
Have Insurance	0.0	90.1	3.3	3.6
High Tech	83.8	85.1	83.9	83.9
Default – Drought	100	100	99.9	0.0
Default – Normal	100	100	80.4	100
Per Capita Bank Profits	-0.3	-0.3	-0.3	-0.3
Per Capita Wealth	146.3	136.5	145.3	146.1
Per Capita Savings	37.7	25.0	36.7	37.1
Negative Returns to Savings ($r_s = -0.25$)				
Have Loan	5.7	3.0	12.1	14.6
Have Insurance	0.0	79.6	12.1	14.6
High Tech	51.1	74.6	51.8	52.9
Default – Drought	100	100	99.7	0.0
Default – Normal	23.0	89.9	0.1	15.6
Per Capita Bank Profits	-0.2	-0.3	-0.1	0.1
Per Capita Wealth	107.0	111.6	107.8	107.3
Per Capita Savings	6.6	3.0	7.0	6.5

long-run economy averages, per capita wealth and per capita savings.

When savings is available but subject to depreciation, the results change to look more like the case where no savings is available. The change is positive in terms of credit market performance, while high technology adoption is lower – but still much higher than the case in which insurance, but no savings, is available. Households hold a moderate amount of savings and choose to insure, especially under optional insurance. Bundled credit-insurance households, similar to no insurance households, seem to use savings more to smooth consumption, although the former are more likely to take out loans; fewer bundled credit-insurance households choose to insure and adopt high technology relative to optional insurance households.

The model results with savings bring to light a key finding for financial and risk market policy in developing countries. First, informal savings without depreciation are extremely negative for credit markets, but positive for technology adoption. Second, savings that depreciate do not negatively impact the credit market relative to a no-insurance case, but technology adoption is lower relative to the frictionless savings case. Thus, policymakers may want to look into options to link credit, savings, and insurance; this way, savings can be formalized to reduce default, and may not depreciate as much as they would in an informal setting. A good example of such an arrangement, which we reserve for future analysis, is commitment savings (*see*, for example, Brune et al. (2011)).

5. Sensitivity Analysis

5.1. Effects of Risk Aversion and Coverage Type on Technology Adoption

Rural households that practice subsistence agriculture are risk averse, and often extremely so. There are means of eliciting risk preferences through survey questionnaires, and risk aversion measures have been estimated in the development literature.[15] Binswanger (1980) was one of the first to use experiments to measure pure risk aversion using actual rather than hypothetical payments in lotteries; subsequent studies have used similar methods to assess risk at the household level. In a related work, Binswanger and Sillers (1983) find only a “narrow band” of risk preferences

[15] Gandelman and Hernandez-Murillo (2014) estimate relative risk aversion coefficients for 55 developing countries, with point estimates ranging from 0.13 to 3.02; using experimental evidence from Ethiopia, Yesuf and Bluffstone (2007) find that risk aversion in low-income countries is increasing in games involving losses and in a household’s dependency ratio, and decreasing in wealth, past success, and where the head of the household is male.

Table 4: Sensitivity Analysis – Rate of Technology Adoption under Two Insurance Schemes (No Savings, $r_L = 0.20$)

	No Insurance	Optional Insurance	Mandatory Insurance	Contingent Credit
High Risk Aversion (α = 2) Contingent Credit (η = 1)	18.9	74.6	13.9	25.5
High Risk Aversion (α = 2) Credit-Linked Insurance (η = 2)	18.9	74.8	16.1	71.8
Low Risk Aversion (α = 0.75) Contingent Credit (η = 1)	79.3	80.9	79.5	79.6
Low Risk Aversion (α = 0.75) Credit-Linked Insurance (η = 2)	79.3	94.1	79.5	79.7

among pastoralists across different agroclimatic environments, cultural norms and absolute living standards in low-income countries, where most households are found to be moderately risk averse; however, because experiments are played with gains only and with relatively small amounts of money – and households' risk aversion is found to increase with the payoff scale – the authors caution that experimental results should set a *lower* bound for risk aversion estimates. Thus, to the extent that measures of risk aversion vary due to structural or cultural factors – or are subject to error – it is important to study policy implications of insurance programs under different assumptions on the level of risk aversion among households.

In our baseline scenario, we select α to make the household highly risk averse, as such a parameterization supports the stylized facts of subsistence agrarian economies. We vary the coefficient of relative risk aversion in a household's period utility function to examine how behavior might change should households be less risk averse. We find that the more risk averse a household – and in the absence of savings – the greater the impact of the availability of insurance on technology adoption. However, this impact declines as the premium load on insurance increases. In addition, the magnitude of the effects of insurance on technology adoption – especially where index insurance is independent of credit – tends to fluctuate depending on the type of insurance coverage offered.

As an alternative to insurance that only covers the value of the loan, we also simulate a case in which a larger portion of the farm household's income is insured. In the numerical analysis, this is done by choosing $\eta > 1$.[16] Holding all other parameters at their base levels and with no savings, relative to a case in which only credit is available, a more risk averse household is slightly more likely to adopt the high-yield technology if only the loan is insured with contingent credit, but much more likely to adopt under higher coverage levels.[17] Also interesting is the credit market effect for contingent credit contracts under higher coverage levels; because higher interest coverage offers more protection from downside risk, loan and insurance uptake increases to almost 90 percent and normal weather default drops close to zero, drastically increasing per capita profits for the bank.

Under low risk aversion (and similar to the case of high risk aversion and riskless savings), technology adoption is high, but default rates are higher and banks realize negative profits with very little loan uptake. Technology uptake is not particularly sensitive to the level of insurance coverage if households are relatively less risk averse, although higher coverage reaps higher technology adoption under optional insurance.

5.2. Premium Load and Effect of Subsidized Insurance

One consequence of incomplete financial markets in developing countries is that, although credit is available, rural households may be hesitant to take out a loan if they are without means to manage downside risk; because they risk default with uninsured credit, they simply refrain from borrowing altogether. The findings of this analysis offer supporting evidence of this hypothesis, as loan take-up rates are higher for bundled contracts. This holds under actuarially fair premium loads and in the baseline case, where the load is 0.5. Table 5 provides a comparison of results under actuarially fair and subsidized insurance settings.

When the insurance premium is fair or subsidized ($\theta \leq 0$), not only is insurance uptake higher for bundled contracts, but loan uptake increases and default rates decrease. Oddly enough, technology adoption with insurance

[16] For the numerical sensitivity analysis, under otherwise base parameterization, we use $\eta = 2$ (*see* Table 4).
[17] Results are similar in a case that allows savings, but where savings have a negative rate of return.

Table 5: Sensitivity Analysis – Actuarially Fair and Subsidized Insurance (No Savings, $r_L = 0.20$)

	No Insurance	Optional Insurance	Mandatory Insurance	Contingent Credit
Fair Insurance ($\theta = 0$)				
Have Loan	5.7	4.0	20.2	54.7
Have Insurance	0.0	87.2	20.2	54.7
High Tech	18.9	74.6	21.8	74.2
Default – Drought	100	100	56.1	0.0
Default – Normal	23.0	56.8	0.0	0.0
Per Capita Bank Profits	-0.2	-0.3	0.2	1.3
Subsidized Insurance ($\theta = -0.5$)				
Have Loan	5.7	7.3	76.3	76.3
Have Insurance	0.0	100	76.3	76.3
High Tech	18.9	74.0	74.0	74.0
Default – Drought	100	100	0.0	0.0
Default – Normal	23.0	15.1	0.0	0.0
Per Capita Bank Profits	-0.2	-0.2	1.8	1.8

- while it remains high under subsidized insurance contracts - is largely at its peak when premiums are actuarially fair; as premium loads increase above zero, technology adoption declines. Contingent credit contracts see no real increase in technology uptake moving from fair to subsidized insurance, while technology adoption is higher under fair optional insurance. With very inexpensive insurance, those with optional insurance do not have to take out a loan to make a technology investment, but are still reimbursed for high technology investment costs should they choose to insure on a technology that they did not adopt; the choice to insure – whether or not technology is adopted – is a no-brainer.

Overall, however, technology adoption under subsidized, bundled insurance is higher than under no insurance. For mandatory insurance, default decreases with an insurance subsidy, likely due to the relative increase in importance of staying credit worthy to be able to access discounted risk coverage. The same is true for contingent credit, where default in normal years decreases to zero under both fair and subsidized insurance.

Yet another policy implication arises in terms of the level of subsidy. Comparing actuarially fair and highly subsidized insurance, households under contingent credit do not differ much in terms of default and technology adoption rates. If a policy goal is technology adoption among rural smallholders, this might indicate that external funds may only be needed to subsidize positive premium loads, as households indicate a willingness to pay for - and to adopt technology under - actuarially fair insurance when it is bundled with credit.

6. Conclusion and Implications

Through the use of numerical simulation techniques, we compare policy options regarding access to credit, insurance and savings for subsistence farmers in a developing country setting. Results have implications for both the supply and demand sides of credit and insurance markets, as well as for the role of insurance in technology uptake.

When households are required to purchase insurance in order to take out a loan, the designation of an initial claimant of indemnities paid is highly significant. Holding interest rates constant across regimes, drought default rates are higher under mandatory insurance where households first receive the indemnity; this results in a riskier portfolio of borrowers for the lending institution. In the alternative, when the bank first receives indemnities, so that the insurance contract serves as a contingent credit contract for the borrower, default rates are relatively lower. In the former case, indemnity payments contribute to a household's disposable wealth, making default and autarky (until exogenous re-entry into the credit market) more attractive. In the latter, a household that has an outstanding loan is disincentivized from reneging on the loan contract: in good years, income is high enough that a risk-averse household would derive utility from consumption smoothing through the purchase of insurance, for which creditworthiness is a requirement; in bad years where the loan is fully covered by the indemnity, the choice to default becomes trivial, as a borrowing household has its debt erased per the terms of the contingent credit contract.

While simulations show that technology uptake is greatest under a regime in which both credit and insurance are offered independently to a farm household, default rates are also the highest under such conditions, holding interest rates constant. In addition, technology uptake does not differ greatly among bundled schemes, regardless of to whom the index insurance indemnities initially flow. In contrast, under a given interest rate, default rates are significantly lower where insurance is a mandatory condition of loan uptake and where the bank is the initial claimant in the insurance contract.

If interest rates are allowed to vary so as to equate the bank's profit level across regimes, the interest rate under the contingent credit scenarios is lower than that under non-bundled credit and insurance; however, compared to a no-insurance setting, bank profits using optimal interest rates may be lower if credit and insurance are independent, or if the household is the initial claimant of a bundled credit-insurance contract. Thus, an important result of the presence of contingent credit markets is an expansion of the local credit market due to an increase in borrowing that stems from lower interest rates; lower interest rates are the product of lower default rates, as households are indirectly indemnified against weather-related income losses.

When farm households are also able to save, this additional risk management option changes the decision-making process for credit, insurance and technology. The presence of a savings mechanism reduces the rate of borrowing, but increases delinquency among those who still choose to borrow even though they may save. Fewer households with savings choose to insure, even when insurance coverage may be purchased separately and without the obligation of also taking out a loan. Households who can save are also more likely to adopt high-technology farming practices, which has implications for the long-term earning potential of low-income farm households. When savings depreciate over time, credit market results are similar to that of a no-savings environment, but technology uptake is higher. When insurance coverage exceeds the loan value, both insurance and technology uptake drastically increase under contingent credit. Credit market performance also improves.

Taken together, credit, insurance and savings play an integral role in farm risk management. The more risk management options a household has in its portfolio, the more likely it is to adopt technology that will increase its income and consumption in the long term. The role of index insurance – especially when it is built into a loan as a contingent credit product – is one of facilitating credit availability and affordability in rural areas, as well as of serving as a substitute for savings for poorer households who do not have enough accumulated wealth to fully protect themselves from a catastrophic income shock. Findings regarding the interaction between credit, insurance and savings leave room for future work – particularly with respect to how to formally bundle savings with credit and insurance to increase technology uptake and reduce default.

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