A Microfinance Model of Insurable Covariate Risk and Endogenous Effort

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1. Introduction

Lack of access to financial markets is a pervasive contributor to poverty among rural households in developing countries. Agricultural production is prone to numerous idiosyncratic and systemic shocks. Without insurance or savings, farmers are often forced to choose between wild swings in consumption and engaging in costly income smoothing practices (Morduch 1995; Dercon 2002). Additionally, exposure to these shocks, along with information asymmetries, high transaction costs, and a lack of collateral, make it prohibitively risky for banks to extend credit to many small farmers (Karlan and Zinman 2009; de Janvry, McIntosh and Sadoulet 2010). This prevents small rural households from taking advantage of profitable opportunities such as adoption of new planting or high-yielding seed technologies, creating a poverty trap (Mendola 2007; Kijima et al. 2008). On the national level, the lack of credit for agricultural technology adoption poses a significant barrier to sustained growth in developing countries, whose economies often heavily depend on their agricultural sector.

One tool that has been proposed to help alleviate these problems is weather based index insurance. Index insurance is an insurance product that pays an indemnity based on the observation of an objective index, such as rainfall. Compared with traditional multi-peril crop insurance, this design dramatically lowers transaction costs, as crop-loss appraisals are not necessary. It also eliminates the information asymmetry problems that plague other insurance contracts, as the farmers have no control over the determination of payouts (Miranda and Farrin 2012).

Despite these theoretical advantages, empirical tests of index insurance implementation have found mixed results. Coupling agricultural credit with index insurance has been shown to not effect or even decrease the demand for the credit (Giné and Yang 2009; Karlan et al. 2010). There have been conflicting results on the adoption rates of separate index insurance contracts. Most work has found relatively low rates in the absense of large premium subsidies (Carter et al. 2014), though some find more promising effects on adoption (Karlan, Osei and Udry 2013; Greatrex et al. 2015). There have been various theories proposed to explain these results, including the importance of basis risk (Clarke 2012; Miranda and Gonzalez-Vega 2011; Mobarak and Rosenzweig 2012), which is the residual risk not covered by the index, and behavioural factors (Elabed and Carter 2015; Carter, Elabed and Serfilippi 2015). Another avenue of research has been to explore how these contracts interact with other factors in the unique contexts in which they are introduced. In this way, costs and benefits of providing index insurance that are not captured in the literature above can be modelled.

As described above, index insurance contracts are generally free of moral hazard problems, as farmers have no control over the weather. Moral hazard generated by other sources, however, may be mitigated or exacerbated by the provision of index insurance. Boucher and Delpierre (2014) find that index insurance increases excess risk-taking when it is introduced within an informal risk-sharing context. They show an interaction exists between index insurance and informal networks meant to smooth idiosyncratic risk across households. When systemic shocks are eliminated with index insurance, households may find it beneficial to take greater idiosyncratic risks since they are insured by the informal network. This represents a moral hazard to the other members of the household's risk-sharing group, as group welfare is decreased when individual risk-taking increases above a threshold. Cheng (2014) studies the introduction of index insurance in the context of a loan where borrowers are able to divert a portion of the funds to finance personal consumption. This credit diversion is a moral hazard to the lender, as it decreases the likelihood of a positive project outcome required to repay the loan. Insurance reduces credit diversion as it reduces the riskiness of borrowers' projects. Given that their projects are now less risky, risk-averse borrowers invest more and divert less funds for consumption.

This paper studies the effect of index insurance on farmers' incentives in a microfinance context under both joint and individual liability lending. We study moral hazard as effort choice, where effort is costly to an agent yet increases the probability that an agent's project yields a positive return (Ghatak and Guinnane 1999; Flatnes 2014). The model proposed in this paper adds to this literature in two ways. First, it deconstructs the risk faced by farmers into two components: idiosyncratic, which is influenced by an agent's effort choice, and systemic, which is independent of effort choice and common across farmers. This provides scope for the introduction of an insurance product that insures only the systemic component of risk. Second, this paper extends earlier one-period models to the case of an infinitely lived household, which allows us to study how the dynamic incentive of remaining creditworthy changes with the introduction of index insurance.

Our model illustrates two channels through which the introduction of index insurance influences an agent's effort choice. The first is the premium effect, which occurs in the case when the premium is collected with the interest when the loan is repaid. The loan is only repaid in the event of a successful project, so the premium (along with the interest) becomes a sort of tax on effort. Thus, the premium effect always reduces an agent's optimal effort for any premium greater than zero. This is consistent with the interest rate effect on moral hazard demonstrated by Stiglitz and Weiss (1981) and adapted to an effort context by Ghatak and Guinnane (1999). The case where the premium is collected upfront in all periods will be discussed later as a future extension. The second is the dynamic incentive effect. The model assumes that agents default if and only if they have unsuccessful projects, and the cost of default is a ban from future lending to perpetuity. If index insurance increases the value that an agent places on remaining creditworthy, then defaulting becomes implicitly more costly. The dynamic incentive effect always increases agents' effort if they are able to choose whether or not to buy index insurance, as they would only purchase the insurance when it is valued positively. If, however, agents are forced to buy index insurance as a condition of obtaining the loan, then this effect can become very negative.

The model studies these effects for both individual and joint liability microfinance contracts. Joint liability generally involves groups of 5 to 20 borrowers who receive individual loans but are held mutually responsible for repayment. These contracts are widely utilized by microfinance institutions due to the perceived benefits of group members' knowledge and ability to monitor one another (Besley and Coate, 1995). While these contracts may be susceptible to disadvantages such as free riding and collusion (Gine and Yang 2009; Gine 2010), Ghatak and Guinnane (1999) argue that if in-group monitoring is sufficiently inexpensive, cooperative behavior can be maintained and moral hazard reduced. This model assumes this cooperative case, where two agents jointly choose an effort level $e^*$and the moral hazard exists only between the group and the bank. The noncooperative case, where moral hazard exists within the joint-liability contract as well, will be described later as a future extension.

2. The Model

A. Individual Liability

We consider a model of an agent with a separable utility function in consumption and effort that maximizes expected utility discounted over an infinite time horizon. If creditworthy, the agent borrows amount l from a microfinance institution and invests in a project that if successful yields a positive return A. The agent chooses an effort level e, which is equal to the probability of a positive idiosyncratic shock, that has an effort cost equal to γe^2. There is also an independent probability τ of a positive systemic shock (i.e. good rains). For a project to be successful, both shocks must be positive, otherwise the agent receives no income, defaults on the loan, and is barred from future borrowing to perpetuity. If the project is successful, the agent repays the loan and earns $c = A - rl$, where r is the interest rate on the loan. In this model there is no saving, so income equals consumption each period. Income in autarchy is normalized to zero. We assume that utility is twice-differentialable in consumption (Ghatak and Guinnane 1999; Flatnes 2014). Written formally:

$$U(c, e) = f(c) - \gamma e^2$$

Where $f(\cdot)$ is a concave function such as CRRA. Since the agent faces the same decision for every period she remains creditworthy, we analyze the effort choice as one decision that will be repeated until default. Using the infinite time horizon allows us to calculate the implicit cost of default. As described above, the probability of the agent remaining creditworthy each round is $e\tau$, and we assume a time discount factor $\delta < 1$. Thus, the agent's maximization problem can be written as:

$$e^* = \underset{e}{\text{Argmax}} \sum_{t=0}^{\infty} (e\tau\delta)^t * (e\tau * f(A - rl) - \gamma e^2)$$

Using a geometric sum we can solve for the utility value of remaining creditworthy as a function of effort choice:

$$V(e) = \frac{e\tau * f(A - rl) - \gamma e^2}{1 - e\tau\delta}$$

Given that the agent chooses e to maximize lifetime expected utility, the implicit cost of default $= -V(e^*)$.

By differentiating $V(e)$, we find that the optimal effort choice in the case of individual liability and no index insurance is equal to:

$$e^* = \frac{1}{\tau\delta} * \left[1 - \sqrt{1 - \frac{\delta * \tau^2 * f(A - rl)}{\gamma}}\right].$$

We see that optimal effort choice is increasing in A, δ, and τ while decreasing in r, l, and γ.

B. Index Insurance

Now consider the case where the agent's loan is coupled with an index insurance product that costs premium ω, and repays the loan in the case of a negative systemic shock. The agent thus remains creditworthy in negative shock periods, but receives no income. The new probability of the contract continuing is: $e\tau + 1 - \tau$. As above, given that the agent makes the same decision in every period in which she is creditworthy, we assume one effort level is chosen for all periods and can solve for the expected lifetime utility value of the loan using a geometric sum:

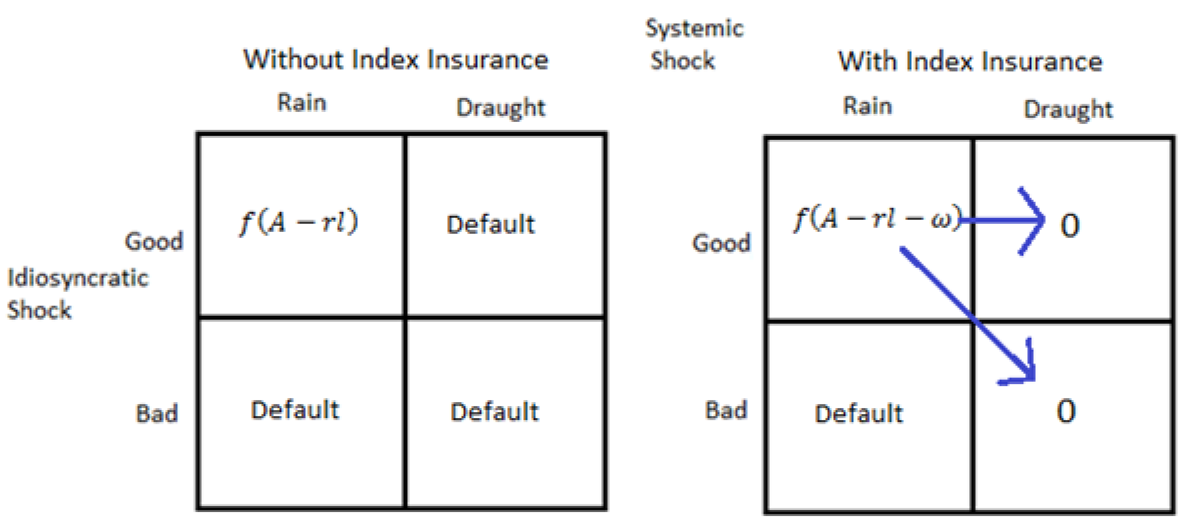
$$V_{ii}(e) = \frac{e\tau * f(A - rl - \omega) - \gamma e^2}{1 - \delta(e\tau + 1 - \tau)}$$

In the case with index insurance, the implicit cost of default is $-V_{ii}(e^*{}_{ii})$, where $e^*{}_{ii}$is the level of effort that maximizes the agents lifetime expected utility and is solved for by differentiating $V_{ii}(e)$:

$$e^*{}_{ii} = \frac{1 + \delta * (1 - \tau)}{\tau\delta} * \left[1 - \sqrt{1 - \frac{\delta * \tau^2 * f(A - rl - \omega)}{\gamma * \big(1 + \delta * (1 - \tau)\big)}}\right].$$

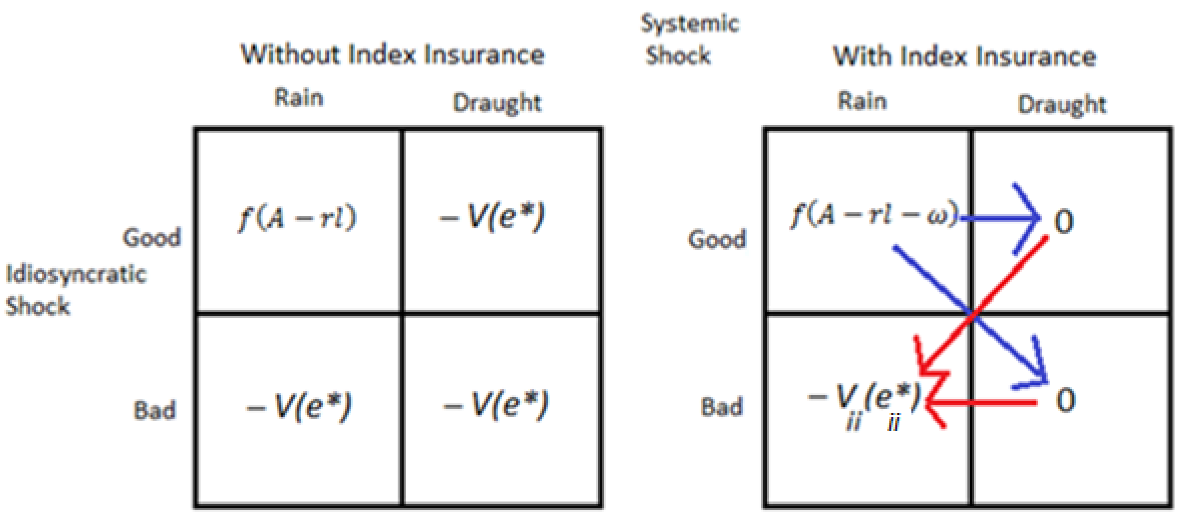
There are two possible channels through which a difference between e^* and $e^*{}_{ii}$ arises, the premium effect and the dynamic incentive effect. The premium effect is caused by the inclusion of the premium with the loan repayment. This results in the premium only being paid in periods where there are a good idiosyncratic and systemic shocks. Since the agent avoids paying the premium if she defaults, it represents a sort of tax on effort. Thus the premium effect strictly decreases optimal effort choice and the effect is larger in magnitude as the premium increases. Figure 1 illustrates that in the static case, the premium effect brings the expected value of good and bad idiosyncratic shocks closer together and reduces the agent's incentive to put forth effort.

Figure 1: Premium Effect



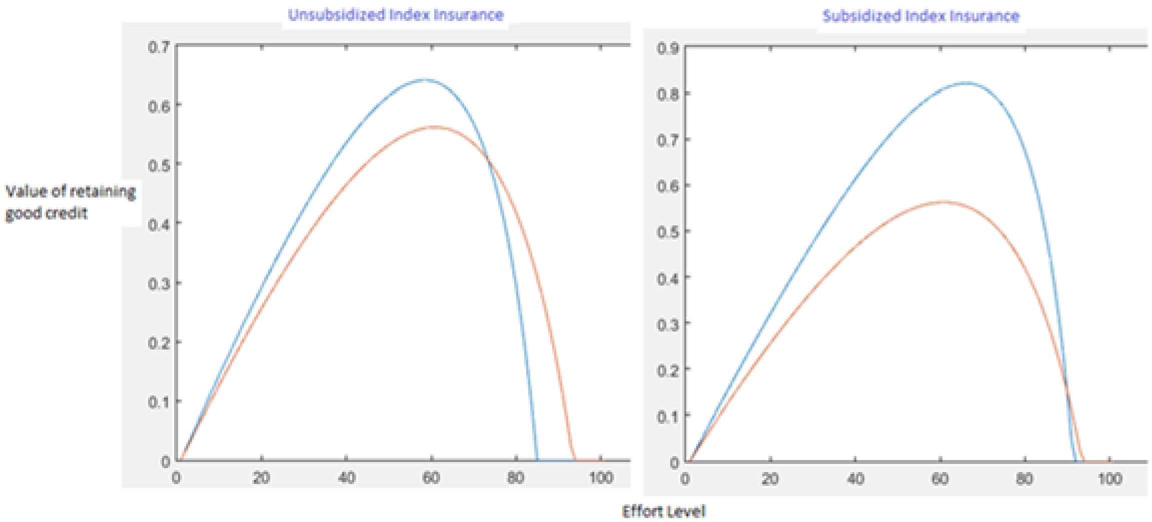
The dynamic incentive effect captures how the change in the value of remaining creditworthy caused by the introduction of index insurance affects optimal effort. One way to clarify this effect is through a car ownership analogy. A person has regular maintenance done on his car because he believes it will increase the long-term value he will gain from the car. If, however, there was 20% chance each year that the car would be taken from him for reasons outside of his control, the long-term value of the car, and by extension the value of car maintenance, would decrease substantially. As a result, he would divert scarce time and resources away from car maintenance. Similarly, an agent exerts effort both to increase expected return this period and to remain creditworthy in order to earn more income in the future. If the agent knows that a draught would take away her credit-worthy status, she will exert less effort in protecting it. Adding index insurance removes the chance of default from draught, which increases the long-term value of credit-worthiness. The dynamic incentive effect strictly increases the agent's optimal effort choice as long as the premium is low enough so that the insurance increases the value the agent puts on remaining credit-worthy. Figure 2 illustrates that the dynamic incentive effect is caused by default becoming implicitly more costly due to the value added by the index insurance.

Figure 2: Premium and Dynamic Incentive Effects



In figure 3, we take parameter values from previous literature and show the effect of index insurance on effort and loan value for two different premium levels. In the unsubsidized case, the premium is roughly 133% of the actuarially fair level. This leads to a small increase in the value of the loan – so the agent would choose to purchase index insurance – but here the premium effect outweighs the dynamic incentive effect and the optimal effort level is slightly reduced. In the subsidized case, the premium is roughly 50% of the actuarially fair level. This leads to a much larger increase in the value of the loan (the red lines for loans without index insurance and are the same in both cases, just with different scaling). Here the dynamic incentive effect outweighs the premium effect and the optimal effort level increases.

Figure 3: Individual Liability - Effect of Index Insurance



Loans with index insurance in blue

C. Joint Liability

Next, we extend the model to consider joint liability loan contracts. We look specifically at two-person cooperative joint liability, where both agents agree on an effort level that maximizes their combined value from the loan (Ghatak and Guinnane 1999). The noncooperative Nash bargaining outcome is considered later as a possible extension. Given cooperation, we treat $e_1 = e_2 = e$. We assume that the loan payout is high enough so that if one agent has a successful project she will be able to repay both her own and her partner's loan. We also assume that if an agent's loan is repaid by her partner, she receives no income but remains creditworthy. With joint-liability, the new probability of repayment = $\tau * (2e - e^2)$. Since the systemic shock is common to both agents, a positive systemic shock is still necessary for repayment. Using the geometric sum formula we solve for the lifetime utility value of remaining creditworthy under this arrangement for a given level of effort e:

$$V_{jl}(e) = \frac{e^2\tau * f(A - rl) + e(1 - e)\tau * f(A - 2rl) - \gamma e^2}{1 - \delta(\tau * (2e - e^2))}$$

As before, we can differentiate $V_{jl}(e)$ to solve for the optimal effort choice of both members of the joint-liability group:

$$e^*_{jl} = \frac{\Phi}{\tau\delta} * \left[1 - \sqrt{1 - \frac{\delta * \tau^2 * f(A - 2l)}{\Phi * (\gamma + \tau * (f(A - 2rl) - f(A - rl)))}}\right]$$

Where:

$$\Phi = \frac{\gamma + \tau * (f(A - 2rl) - f(A - rl))}{(2\gamma + \tau * (f(A - 2rl) - 2f(A - rl))}.$$

For joint-liability, the comparative statics are in the same direction as individual liability but can differ considerably in magnitude depending on the parameters.

Next, we consider adding index insurance to the joint-liability case. As before, the insurance costs premium ω and repays each agent's loan in the case of a negative systemic shock. We assume that both agents receive (or choose to purchase) index insurance. The new probability of repayment equals: $\tau * (2e - e^2) + (1 - \tau)$. Using the geometric sum formula we find that the value of a joint-liability loan contract with index insurance equals:

$$V_{jlii}(e) = \frac{e^2\tau * f(A - rl - \omega) + e(1 - e)\tau * f(A - 2rl - 2\omega) - \gamma e^2}{1 - \delta(\tau * (2e - e^2) + (1 - \tau))}$$

Differentiating $V_{jlii}(e)$, the optimal effort of both members is:

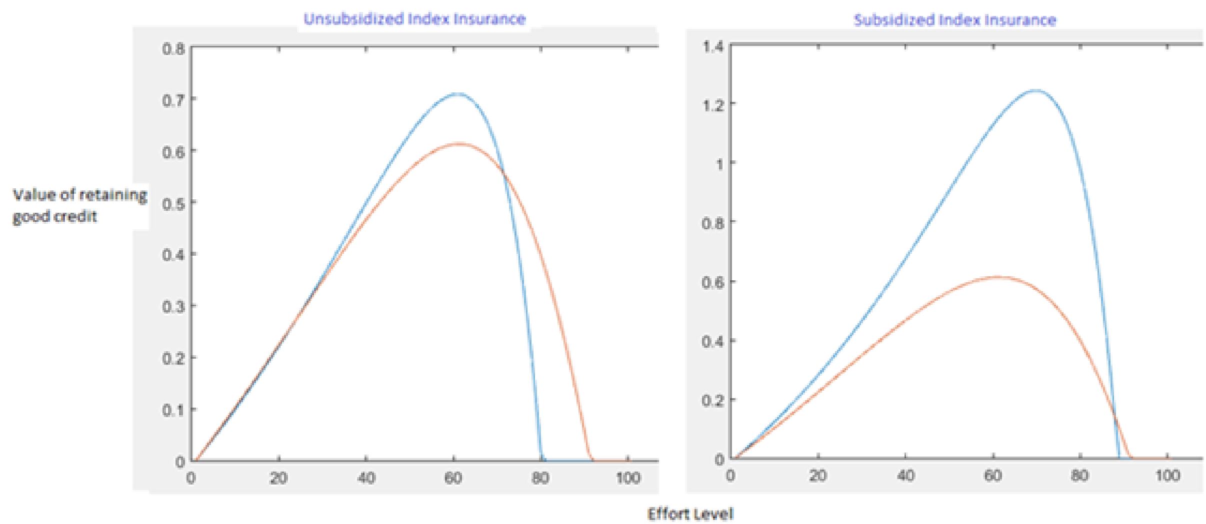
$$e^*_{jlii} = \frac{\Omega}{\tau\delta} * \left[1 - \sqrt{1 - \frac{\delta * \tau^2 * f(A - 2l - 2\omega)}{\Omega * (\gamma + \tau * (f(A - 2rl - 2\omega) - f(A - rl - \omega)))}}\right]$$

Where:

$$\Omega = \frac{(1 + \delta * (1 - \tau)) * (\gamma + \tau * (f(A - 2rl - 2\omega) - f(A - rl - \omega)))}{(2\gamma + \tau * (f(A - 2rl - 2\omega) - 2f(A - rl - \omega))}.$$

As in the case of individual liability, the difference between e^*_{jl} and e^*_{jlii} is driven by the premium effect and the dynamic incentive effect. Figure 4 shows the loan value of different effort choices for two premium amounts: an unsubsidized case of roughly 133% of the fair value and a subsidized case of 50% of the fair value. Comparing Figure 4 with Figure 3, we see that subsidized index insurance leads to a much larger increase in value (and slightly larger increase in effort) in the case of joint liability. This is because joint liability already removes most of the idiosyncratic risk of default, so adding index insurance removes a larger portion of the remaining default risk. For example, under individual liability adding index insurance may double the expected length of time the agent will remain creditworthy, while under joint liability the expected length of creditworthiness for the group is multiplied by five.

Figure 4: Joint Liability - Effect of Index Insurance

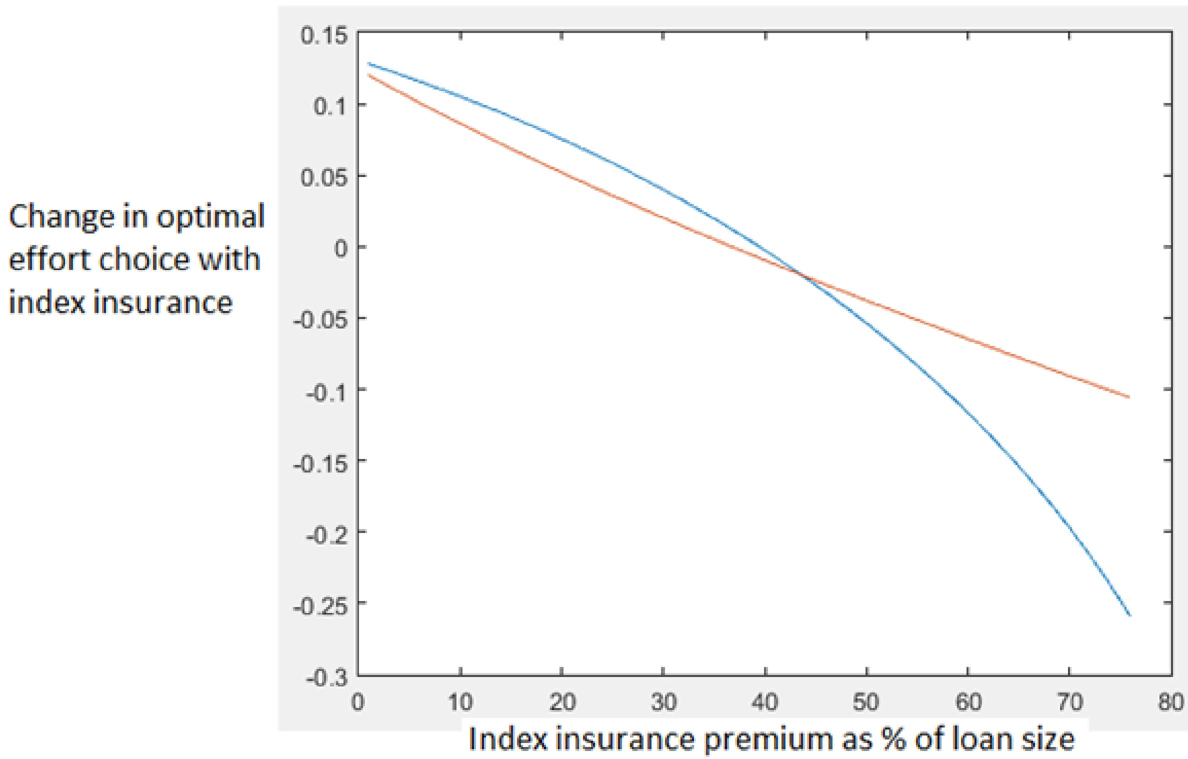


Loans with index insurance in blue

This is no corresponding larger increase in value for joint liability however, in the case of an unsubsidized loaded premium. This is because the value agents attach to joint liability loan contracts is more sensitive to premium increases in our model. Under joint liability there is a $e(1-e)\tau$ probability that an agent will have to pay both her and her partner's loan and premium. Thus, the per-period expected value of taking the loan is lower in joint-liability. As the premium increases and the per-period value of the loan approaches zero, extending the loan for longer periods of time is no longer valuable. In the case where index insurance with a high premium is coupled with the loan without the agents' consent, the change in loan value can become negative and effort decreases more dramatically.

These effects are shown Figure 5. First we see that for both individual liability and joint liability contracts, index insurance increases the effort agents put into projects when the premium is relatively low. Agents perceive low premium joint liability contracts to be particularly valuable and put forth a larger effort increase in order to preserve them for a longer period of time. As the premium increases agents put in less effort, so that index insurance results in a lower optimal effort choice for both contract types once premium reaches a level slightly larger than actuarially fair. As mentioned above, this decline is particularly steep in the joint liability case.

Figure 5: Joint Liability vs Individual Liability



3. Conclusions

This paper presents a basic model of how index insurance affects the level of effort agents invest in microfinance projects. It builds off of earlier static models, but utilizes an infinite time horizon so that the implicit cost of default can be determined endogenously. This implicit cost varies between the different contracts, which gives rise to the dynamic incentive effect that can lead to index insurance increasing effort choice. This is countered by the effect of the premium, so that the net effect of index insurance depends on the parameters chosen. These general trends hold when we consider cooperative two-person joint liability loan contracts. An important difference for joint liability contracts is that they lead to a greater increase in effort for relatively low premiums, but a larger decrease in effort when premiums are high. The final section of this paper considers a number of possible extensions to the basic model and discusses possible results for each.

4. Future Extensions

A. Bank zero profit conditions

The above analysis likely understates the possible positive effect on effort of both index insurance and joint liability contracts by treating the premium and loan interest rate as exogenously given and fixed for all contract types. In reality, banks adjust interest rates and premiums based on their expectation of the default rate of each type of contract. If index insurance and joint-liability decrease the chance that an agent will default, we would expect the bank to offer lower interest rates and premiums in these contracts. In the case where the bank is a nonprofit NGO that charges interest and premiums only to recoup losses from default, the interest rate and premium would be set as shown in Table 1.

Table 1: Bank zero profit conditions

Type of Contract	Interest Rate No I.I.	Interest Rate I.I.	Premium I.I.
Individual Liability	$\frac{1}{\tau e}$	$\frac{1}{\tau e+(1-\tau)}$	$\frac{l*(1-\tau)}{\tau e}$
Joint Liability	$\frac{1}{\tau(2e-e^2)}$	$\frac{1}{\tau(2e-e^2)+(1-\tau)}$	$\frac{l*(1-\tau)}{\tau(2e-e^2)}$

All else equal, joint liability contracts will have lower interest rates and premiums, and in both contract types a portion of the index insurance premium will be offset by a decrease in the loan interest rate. Since the interest rate and premium are functions of effort choice, any change in the interest rate or premium would have a multiplier effect. For example, if a bank decided to increase the interest rate, it would result in less effort, which would lead to more default, which would lead to an increase the interest rate, and so on. Likewise, a reduction in the interest rate or premium would have a positive multiplier effect. In either case, the interest rate/premium and effort choice would converge to a fixed point which could be solved for using numerical methods.

B. Measuring welfare effects

While describing the model we worked under the implicit assumption that overall welfare was improved by giving agents greater incentive to invest effort in their projects. This need not always be the case. If we consider effort as time investment, rural households have various other important uses of time that may have a greater marginal benefit than farming. Ghatak and Guinnane (1999) show that efficient level of effort is where marginal increase in project success is equal to the marginal cost of providing more effort, in this case where: $\tau * f(A) = 2\gamma e$. Thus, efficient effort each period equals:

$$e_e = \frac{\tau * f(A)}{2\gamma}.$$

By threatening to take away credit access to perpetuity, banks may induce an effort choice that is actually too high, where each period agents choose an effort level where the true marginal cost exceeds the true marginal benefit in order to preserve credit. If we take the bank's default punishing mechanism as given however, then the efficient effort equals the much higher:

$$\overline{e_e} = \frac{1}{\tau\delta} * \left[1 - \sqrt{1 - \frac{\delta * \tau^2 * f(A)}{\gamma}}\right].$$

In this case, any increase in effort caused by introducing index insurance and/or joint liability does increase welfare.

C. Allowing effort levels to vary based on realized shocks

One limitation of the model is that same effort cost is paid every period regardless of the realized shock. If, for example, we believe that a large portion of the effort cost of farming occurs during harvest, it seems unreasonable that a farmer is forced to pay the same effort cost in a period when she has no output. This potential issue can be adjusted for, since the effort decision is based on the expectation of future utility. First I will consider the case the effort cost varies based on the outcome of the systemic shock. Let $\mu \epsilon [0,1]$ be the portion of the effort cost an agent pays in years when crops fail because of a negative systemic shock. A value of μ close to zero could imply that the farmer waits for rain before planting, and exerts very little effort in farming during draught years. In expectation, the effort cost parameter for each creditworthy period then equals: $\gamma' = \gamma * (\tau + \alpha * (1 - \tau))$. Given that τ and α are fixed parameters, γ' could be substituted in for γ in all of the results above.

In principle, the same reasoning applies for the effort cost varying with the idiosyncratic shock outcome. In this case, let $\beta \epsilon [0,1]$ be the portion of the effort cost an agent pays in years when crops fail because of a negative idiosyncratic shock. In expectation, the effort cost parameter then equals the function $\gamma'(e) = \gamma * (e + \beta * (1 - e))$. If the effort cost parameter is a function of e then the model no longer has an analytical solution and must be approximated using numerical methods.

D. Noncooperative Nash bargaining in joint-liability contracts

As mentioned above, the model assumes that the agents agree on an effort level that maximizes their joint expected lifetime utility. Ghatak and Guinnane (1999) argue that this can be achieved through the use of monitoring and social capital. If moral hazard within the joint liability contract itself cannot be eliminated however, then the contract can be modelled as noncooperative Nash bargaining game. In this case, the value that agent 1 attaches to the loan equals:

$$V_{jl1}(e_1, e_2) = \frac{e_1 e_2 \tau * f(A - rl) + e_1(1 - e_2)\tau * f(A - 2rl) - \gamma {e_1}^2}{1 - \delta\tau * (e_1 + e_2 - e_1 e_2)}$$

To solve for the optimal effort choice of agent 1, we first differentiate $V_{jl1}(e_1, e_2)$ with respect to $e_1$only and then apply the symmetry condition that $e_1 = e_2 = e$. The optimal value of e in this case must be approximated using numerical methods. Expected results are that the effort levels found under Nash bargaining are less than in the cooperative case, and that providing index insurance results in either a smaller increase or larger decrease in the effort level, depending on the premium.

E. Fixed outside income and the case where premium is charged upfront in all periods

The model above assumes that the only way an agent may earn income is through using a microfinance loan to run a successful project. We can expand the model to add a fixed income source that is not dependent on effort, such as a remittance or pension. Let π be a fixed income amount that the agent receives every period regardless of the shock realizations. Assume $0 < \pi < rl$, so that fixed income is not sufficient to repay the loan in periods of negative shocks. In the individual liability case without index insurance, the new value attached to credit-worthiness is:

$$V(e) = \frac{e\tau * (f(\pi + A - rl) - f(\pi)) - \gamma e^2}{1 - e\tau\delta}$$

Given the concavity of $f(\cdot)$, we see that the value of remaining creditworthy (and thus optimal effort choice) decreases as fixed outside income increases. With outside fixed income we can examine the difference in the effect of charging the premium upfront in all periods versus combining the premium with the loan interest rate. The value of the loan contract with index insurance and the premium charged upfront is:

$$V_{ii}(e) = \frac{e\tau * f(\pi + A - rl - \omega) + (1 - e\tau) * f(\pi - \omega) - f(\pi) - \gamma e^2}{1 - \delta(e\tau + 1 - \tau)}$$

In this case there is no premium effect on effort, as the agent no longer avoids paying the premium by defaulting. The dynamic incentive effect is reduced however, as the agent is exposed to the risk of paying the premium and having her project fail. This risk is particularly severe when π is small, given the concavity of $f(\cdot)$. For set values of the agent's risk aversion and the insurance premium, we predict there will be a value of outside income π^*such that if $<\pi^*$, the agent will choose a higher effort level when the premium is included in the loan repayment.

An important consideration here is that our basic model is very limited in its capacity to incorporate more realistic income dynamics. We chose to use this simple model because it allows us to capture the general trends of the effects we are interested in and express them in analytical solutions. If we wish to further expand agents' income sources and measure the levels of effects, a different route would be required. This could involve building a more complicated dynamic model that would have wealth as a state variable and be solved numerically using dynamic programming.

F. Empirical Applications

A final possible extension would be to test whether the predictions of the model are consistent with what we find in observational data. In particular, is there an effect of having index insurance on the number of hours per week a farmer works in her field even in years with good rains? The model predictions could also be tested through the use of a framed field experiment.

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