Systemic Risk, Index Insurance, and Optimal Management of Agricultural Loan Portfolios in Developing Countries

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Researchers and practitioners in the field of development finance have exhibited growing interest in the use of index insurance contracts to manage the risks faced by poor agricultural producers (Barnett and Mahul 2007; Bryla and Syroka 2007; Miranda and Vedenov 2001). Unlike conventional insurance, which indemnifies the insured based on verifiable losses, index insurance indemnifies the insured based on the observed value of a specified "index." Ideally, an index is a random variable that is objectively observable, reliably measurable, and highly correlated with the losses of the insured and that cannot be influenced by the actions of the insured. Indices that have been employed or proposed for agricultural insurance include area-yields, rainfall, temperature, satellite-measured vegetation indices, regional livestock mortality rates, and El Niño–Southern Oscillation indices.

Index insurance avoids many of the problems that have plagued conventional insurance. Because the insured cannot significantly influence the value of the index, and thus the indemnity paid by the contract, index insurance is essentially free of moral hazard. Because an index insurance contract's indemnity schedule and premium rate are typically based on publicly available information, not privately held information, index insurance is largely free of adverse selection problems. And because index insurance does not require individually-tailored terms of indemnification or separate verification of individual loss claims, index insurance is less expensive to administer. These features of index insurance can substantially reduce its cost relative to conventional insurance, making index insurance more affordable, particularly to poor agricultural producers (Skees 2008).

Index insurance, however, suffers from the drawback that it does not cover all losses that may be experienced by an agricultural producer (Doherty and Richter 2002; Miranda 1991). In particular, since the indemnity provided by index insurance is based on an index, rather than verifiable losses, it is possible for the insured to suffer a significant loss without the insurance contract providing an indemnity. The potential benefits of index insurance ultimately depend on the correlation between the indemnities it provides and the losses suffered by the insured the greater the correlation, the greater the potential benefit.

Unfortunately, due to the paucity of individual farm-level data, empirical assessments of the risk-reduction benefits of index insurance to individual agricultural producers have been few in number (Breustedt, Bokusheva, and Heidlbach 2008). Considerable skepticism thus exists regarding the potential value of index insurance contracts as a mechanism for directly managing farm-level risk. Some analysts have argued that basis risk, the variation in producer income that cannot be explained by the variation in the index, is likely to be substantial, undermining the value of index insurance to individual producers to the point that they would not be willing to pay market premiums for the insurance. These arguments are supported by the fact that the only agricultural index insurance programs currently in operation that exhibit any appreciable volume in sales, such as the Group Risk Plan in the United States are heavily subsidized by the government.

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One potential alternative use of index insurance, however, has been largely overlooked in the academic literature. Although index insurance may provide limited benefits to individual agricultural producers, it may ultimately prove more valuable as a reinsurance instrument to be used by firms that, through their contractual relationships with large numbers of agricultural producers, act either explicitly or implicitly as insurers. The most obvious example is an agricultural insurer. However, other examples include agricultural banks, cooperatives, and processors who conduct business with large numbers of agricultural producers and who, through their contractual relationships and operational policies, absorb a significant amount of risk that would otherwise be borne by their clients.

Consider, for example, an agricultural bank in a developing country that provides small loans to poor agricultural producers (Conning and Udry 2007; Wenner et al. 2007). In good times, producer-borrowers gladly repay their loans in order to remain in good standing with the lender. However, in hard times, producer-borrowers may be forced to default in order to maintain a subsistence level of consumption. Rather than take immediate costly legal action against borrowers to recover delinquent loans, banks typically cooperate with their borrowers, restructuring their loans to allow them to repay once their financial situation improves. In this manner, an agricultural bank provides risk transfer services to its borrowers, which come at a cost to the bank that it ultimately recovers from its borrowers through higher loan interest rates. The agricultural bank thus implicitly acts as an insurer for its borrowers and implicitly charges them a risk premium for this service in the form of higher interest rates (Townsend 2003).

The benefits of index insurance contracts are likely to be greater to an agricultural bank than to individual agricultural producer-borrowers (Skees and Barnett 2006). An agricultural bank effectively diversifies much of the idiosyncratic risks borne by its borrowers and thus can be expected to face lower basis risk than its borrowers individually. That is, an index that measures systemic agricultural production shocks in a bank's geographical scope should track the bank's cash flow shortfalls more closely than those of any one individual borrower. To our knowledge, however, no published research exists that examines how index insurance contracts might effectively be used by agricultural banks to reinsure portfolio risk and whether significant benefits would accrue to its borrowers.

In this paper, we examine how an agricultural bank might enhance its performance through the use of index insurance. We take as a working example the case of a microfinance institution (MFI) in a developing country. Although there are many examples of successful MFIs throughout the developing world, their loan portfolios are typically concentrated in urban areas (Gonzalez-Vega 2003). The ability of MFIs to expand their services to the large number of rural poor whose livelihoods depend on agriculture has been impeded by the incidence of large systemic risks such as droughts, floods, and other weather-related events that render portfolios of agricultural loans many times riskier than portfolios of urban business loans.

We develop a dynamic stochastic heterogeneous agent model of the agricultural producer-borrowers comprised by a bank's loan portfolio. Borrowers face a common systemic income shock, such as may arise from a widespread drought or flood, as well as idiosyncratic income shocks that are uncorrelated with the systemic shocks and that are uncorrelated across borrowers. At the beginning of each period, each borrower must decide whether, given his current income, to default on his agricultural loan. Due to the heterogeneity that exists across borrowers, there are always some borrowers who default, even in the absence of an adverse systemic shock. However, the number of borrowers who default can rise dramatically if an adverse systemic shock is experienced. The model implies that the proportion of borrowers in the bank's loan portfolio who are in different stages of delinquency at any time follows a Markov process whose transition probabilities are fully endogenous and determined by underlying primitives such as the average loan size, the interest rate charged by the bank, the bank's debt restructuring policies, the rate of return that borrowers can realize from their loans, the risk aversion of borrowers, and the levels of systemic and idiosyncratic risk borne by borrowers.

We solve and simulate the model numerically in order to examine the potential impact of index insurance on loan performance and bank equity growth and stability. We ask: If the bank employs index insurance, how should it alter its lending practices to maximize bank profitability? Will the bank's loan portfolio be more resilient to systemic shocks if it uses index insurance? Would the use of index insurance allow a bank to prudently increase the size of its agricultural loan portfolio? Should the bank purchase index insurance to manage its portfolio risk directly or should it require individual borrowers to purchase index insurance as a condition for receiving a loan?

Agent's Decision Problem

Consider an infinitely lived agent who may borrow a fixed amount b in any period, provided his credit is in good standing. Under the terms of the loan, the agent is expected to fully repay the loan, with interest, in the following period. The agent, however, may default on his payment. If the agent defaults, he is declared delinquent and is not permitted to borrow further until his loan is repaid. The agent may remain delinquent for up to N periods. If the agent does not repay his loan within N periods, he is permanently barred from borrowing.

Let $p_i, i = 1, 2, \ldots, N$, denote the amount the agent must pay in order to retire a loan that is i periods old. That is, an agent is expected to pay p_1 in the period after he receives his loan; an agent who defaults on his first payment must pay p_2 in the following period in order to re-establish his credit; an agent who defaults on his first two payments must pay p_3 in the following period in order to re-establish his credit; and so on. It follows that the interest rate charged on a loan that is repaid after i periods is $r_i = (p_i/b)^{-i} - 1$. The interest rate could increase with the age of the loan, as would be the case if the lender imposes late repayment penalties, or it could decrease with the age of the loan, as would be the case if the lender offered relaxed repayment terms to induce delinquent agents to repay their loans.

At the beginning of each period, the agent observes his disposable wealth s and the age of his outstanding loan i. The agent must then decide whether to repay his outstanding loan and take out a new loan, or not repay his outstanding loan, in which case he may not take out a new loan. The agent is assumed to have no access to savings facilities, forcing him to consume all of his disposable wealth, net of any loan repayment, in the current period. Thus, if the agent repays his loan, he consumes $s - p_i$ and derives utility $u(s - p_i)$, and if the agent does not repay his loan, he consumes s and derives utility $u(s)$. We assume that the utility function u is twice differentiable on $(0, \infty)$, with $u' > 0, u'' < 0$, and $u'(0) = -\infty$.

The agent's expected disposable wealth s_{t+1} at the beginning of period $t + 1$ will depend on whether the agent received a loan in period t, a multiplicative exogenous random shock z_{t+1} that is shared by all agents, and a multiplicative exogenous random shock ϵ_{t+1} that is specific to the agent. We normalize our monetary unit of measure such that expected income without a loan is exactly 1 and indicate by $g > 1$ the agent's expected income with a loan. It follows that the expected gross rate of return on a loan of size b is $R = (g - 1)/b$. Thus, if the agent does not take out a loan in period t, then $s_{t+1} = z_{t+1}\epsilon_{t+1}$; if the agent takes out a loan in period t, then $s_{t+1} = gz_{t+1}\epsilon_{t+1}$. We assume that the systemic random shock z_t and the idiosyncratic shock ϵ_t are nonnegative, mutually independent, and serially independent and identically distributed over time, each with a mean of 1. We further assume that the idiosyncratic shocks are independent across agents.

The agent maximizes the present value of current and expected future utility of consumption, subjectively discounted at a per period rate $\rho > 0$. The agent's problem is thus characterized by a Bellman functional equation with two state variables, disposable wealth $s \geq 0$ and age of loan $i = 1, 2, \ldots, N$:

$$V_i(s) = \max\{u(s - p_i) + \delta E_{z\varepsilon} V_1(gz\varepsilon)$$
$$u(s) + \delta E_{z\varepsilon} V_{i+1}(z\varepsilon)\} \quad (1)$$

subject to the boundary condition

$$V_{N+1}(s) = u(s) + \frac{\delta}{1-\delta} E_{z\varepsilon} u(z\varepsilon). \quad (2)$$

Here, $\delta = 1/(1 + \rho)$ denotes the perperiod subjective discount factor; $V_i(s)$ denotes the maximum expected present value of current and future consumption, given that the agent possesses disposable wealth s and a loan of age $i \leq N$; and $V_{N+1}(s)$ denotes the expected present value of current and future consumption, given that the agent possesses disposable wealth s and has been permanently barred from borrowing.

Suppose now that the agent is required to purchase an index insurance contract if he takes out a loan. The index contract requires the borrower to pay a premium π, and the following period provides him with an indemnity $h(z)$ that is contingent on the systemic shock z realized in that period. Under this scenario, the agent's Bellman functional equation must be recast as

$$(3)\quad V_i(s) = \max\{u(s - p_i - \pi) + \delta E_{z\varepsilon} V_1(gz\varepsilon + h(z)) \\ u(s) + \delta E_{z\varepsilon} V_{i+1}(z\varepsilon)\}.$$

Agent's Optimal Borrowing Policy

The agent's Bellman equation with mandatory insurance may be written

$$(4)\quad V_i(s) = \max\{u(s - p_i - \pi) + \delta W_1 \\ u(s) + \delta W_{i+1}\}$$

for $s \geq 0$ and $i = 1, 2, \ldots, N$, where

$$(5)\quad W_i = \begin{cases} E_{z\varepsilon} V_i(g_i z\varepsilon + h_i(z)), & i \leq N \\ \frac{1}{1-\delta} E_{z\varepsilon} u(z\varepsilon), & i = N+1. \end{cases}$$

Here, $g_1 = g$ and $g_i = 1$ for $i > 1$; $h_1 = h$ and $h_i = 0$ for $i > 1$; W_1 is the future value expected by an agent who takes out an index-insured loan; W_i, for $i = 2, 3, \ldots, N$, is the future value expected by an agent who has defaulted on $i - 1$ consecutive payments; and W_{N+1} is the future value expected by an agent who has been permanently barred from borrowing.

Substituting the former expression into the latter and taking expectations yields

$$(6)\quad W_i = E_{z\varepsilon} \max\{u(g_i z\varepsilon + h_i(z) - p_i - \pi) + \delta W_1, u(g_i z\varepsilon + h_i(z)) + \delta W_{i+1}\}$$

for $i = 1, 2, \ldots, N$. This last equation expresses the N unknown values $W_1, W_2, \ldots, W_N$ as a fixed-point of a strong contraction with modulus $\delta < 1$. Thus, the values exist, are unique, and may be computed using nonlinear equation methods (Miranda and Fackler 2002).

Now, for $i = 1, 2, \ldots, N$, there exists an unique s_i^* such that an agent with disposable wealth s and loan of age i defaults on his existing loan if $s < s_i^*$ and repays his existing loan and takes out a new one if $s > s_i^*$. To see this, let

$$(7)\quad f_i(s) = u(s - p_i - \pi) + \delta W_1 - u(s) - \delta W_{i+1}$$

denote the value of repaying less the value of defaulting, given that the agent possesses disposable wealth s and a loan of age i. If this value is positive, the agent repays; if this value is negative, the agent defaults. Due to the assumed properties of $u, f_i(s)$ is continuous and strictly increasing for $s \in (p_i - \pi, \infty)$ with $f_i(p_i - \pi) = -\infty$. Thus, either f_i is everywhere negative, in which case $s_i^* = \infty$, or f_i possesses a unique root $s_i^* > p_i - \pi$, which equals the level of wealth at which the agent is indifferent between repaying and defaulting.

Loan Performance

We now numerically solve and simulate the model in order to assess how mandatory borrower index insurance will affect loan performance, with and without a premium subsidy. With a premium subsidy, the borrower's premium is assumed to be one-half the expected indemnity; without a premium subsidy, the borrower's premium is assumed to be twice the expected indemnity. Loan performance will be measured by the bank's expected internal rate of return (IRR) and the probability of default on a typical initial loan.

In our base-case simulation, we maintain the following assumptions: (*a*) the size of the loan is 20% of the borrower's expected income; (*b*) the interest rate charged by the bank is 40%; (*c*) the borrower realizes an expected return of 80% on the loan; (*d*) the borrower may default for a maximum of seven consecutive periods before being permanently banned from borrowing in the future; (*e*) a systemic shock occurs in any period with a probability of 20% and suppresses the income of all borrowers by 30%; and (*f*) the representative borrower exhibits a constant relative risk aversion of 2.0 and faces an idiosyncratic shock volatility of 20%.

Figures 1 and 2 illustrate the bank's expected IRR and the probability of default, respectively, for a typical loan, as functions of the interest rate charged on the loan, without insurance and with subsidized and unsubsidized mandatory borrower insurance. Borrowers' rarely default when the interest rate charged on the loan is relatively low, implying that the bank's IRR on a loan is close or essentially equal to the interest rate charged on the loan. However, as the loan interest rate rises, the default rate eventually begins to rise, causing the bank's IRR to fall, producing a well-defined maximum IRR. As may be gleaned from both figures, loan performance improves at all interest rates if the borrower is required to buy subsidized index insurance, but deteriorates if the borrower is required to buy unsubsidized

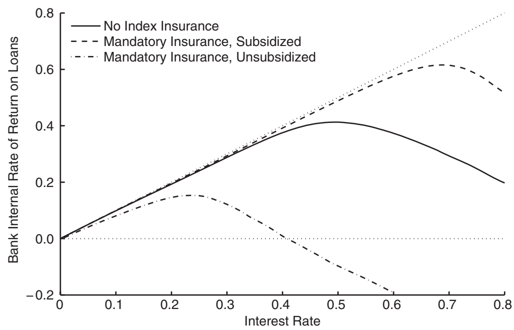

Figure 1. Bank's expected internal rate of return on loans as a function of interest rate

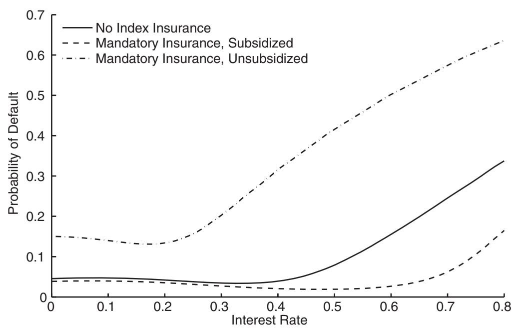

Figure 2. Loan default rate as a function of interest rate

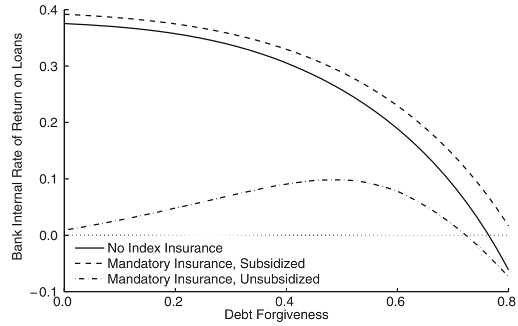

Figure 3. Bank's expected internal rate of return on loans as a function of debt forgiveness

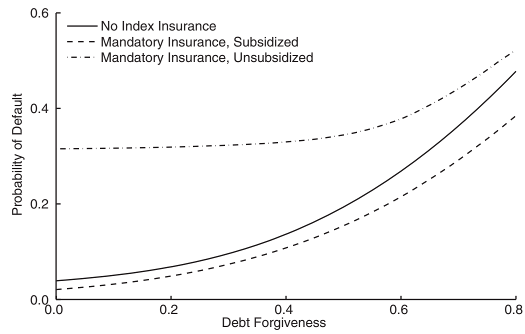

Figure 4. Loan default rate as a function of debt forgiveness

index insurance. In particular, unsubsidized mandatory index insurance raises default probabilities and reduces the bank's loan IRR because the burden of having to pay the insurance premium creates a disincentive for the borrower to repay his loan. One result depicted in figure 1 is that with a premium subsidy, the bank can achieve a higher IRR by charging a higher interest rate on loans, potentially erasing some of the benefits accruing to borrowers from the premium subsidy.

Figures 3 and 4 illustrate the impact of restructuring loans by reducing the payments required by borrowers in default. The parameter "debt forgiveness" in these figures indicates the proportional reduction in required payment on delinquent loans. The figures clearly reveal a moral hazard effect. While reducing payments on delinquent loans increases repayment of delinquent loans, it also provides incentives for borrowers to strategically default on loan repayments in the period after the loan is received. The net effect is to reduce the bank's IRR on loans.

Figures 5 and 6 illustrate the impact of premium loads on loan performance when

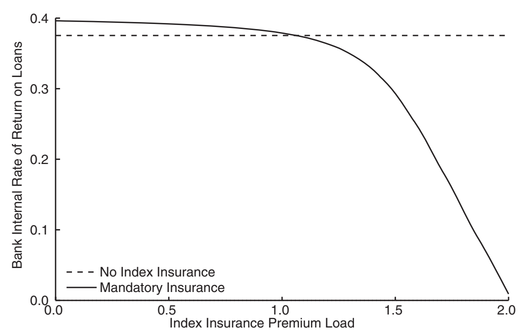

Figure 5. Bank's expected internal rate of return on loans as a function of mandatory index insurance premium load

the borrower is required to purchase index insurance. The parameter "index insurance premium load" here indicates the size of the premium relative to the expected indemnity. Premium loads below one indicate heavily subsidized insurance; premium loads above one indicate unsubsidized premiums that more realistically reflect operational costs. Two

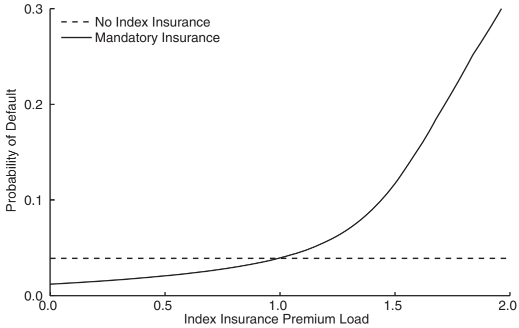

Figure 6. Loan default rate as a function of mandatory index insurance premium load

results depicted on these figures merit comment. First, even substantial premium subsidies will produce only modest improvement in loan performance. Second, more realistic premium loads around twice the expected indemnity can lead to dramatic undesirable impacts on loan performance. The lesson to be drawn here is that requiring borrowers to purchase unsubsidized index insurance when they take out loans is likely to have highly undesirable effects on both banks and borrowers. Moreover, premium subsidies are unlikely to provide benefits that exceed the cost of the subsidies themselves.

Effects on Bank Equity

We now turn to the question of how index insurance might affect the bank's return to equity if the insurance is purchased by the bank rather than the borrower. To this end, suppose now that the number of agents in the bank's loan portfolio is sufficiently large so that the law of large numbers applies across their idiosyncratic income shocks. Then the proportion of agents with loans of age i who default on their loan payments when the systemic shock is z is given by

$$(8) \qquad q_i(z) = \Pr(g_i z \varepsilon \leq s_i^*) = F\left(\frac{s_i^*}{g_i z}\right)$$

where F is the cumulative distribution of ε on $(0, \infty)$. The proportion of agents with loans of age i who repay their loans is therefore $1 - q_i(z)$.

Now, let B_t be an $N \times 1$ vector whose ith element is the number of borrowers who possess a loan of age i at the beginning of period t. Also, let n_t be the number of new borrowers at time t and let μ be an $N \times 1$ vector whose first element is one and whose remaining elements are zero. Then it follows that

$$(9) \qquad B_{t+1} = Q(z_t)B_t + n_t\mu$$

where

$$(10) \qquad Q(z) = \begin{bmatrix} 1-q_1(z) & 1-q_2(z) & \dots & 1-q_{N-1}(z) & 1-q_N(z) \\ q_1(z) & 0 & \dots & 0 & 0 \\ 0 & q_2(z) & \dots & 0 & 0 \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ 0 & 0 & \dots & q_{N-1}(z) & 0 \end{bmatrix}.$$

The bank is assumed to invest its entire equity in loans, starting from some initial endowment E_0. Its equity in period t is therefore the total amount repaid by its borrowers at time t:

$$(11) \qquad E_t = \sum_{i=1}^{N} B_{ti}(1 - q_i(z_t))p_i.$$

Clients who repay their loans and remain in good standing are allowed to renew their loans. The remaining equity is invested in loans made to new clients, subject to an origination fee per dollar loaned γ, which implies that the number of new borrowers is

$$(12) \quad n_t = \frac{1}{(1+\gamma)b} \sum_{i=1}^{N} B_{ti}(1 - q_i(z_t))(p_i - b).$$

We now solve and simulate the model to assess bank equity growth over a fixed ten-year horizon under three scenarios: (a) no index insurance is purchased by either the bank or the borrower; (b) borrowers are required to purchase index insurance at a premium that is twice the expected indemnity; and (c) the bank purchases index insurance at 1.5 times the expected indemnity. In all scenarios, the bank's equity is initialized at a value of 1,000 and the loan origination fee is set equal to 20%.

Figure 7 illustrates the probability distribution of the average annual rate of growth of equity over a ten-year horizon. As can be seen in the figure, requiring borrowers to

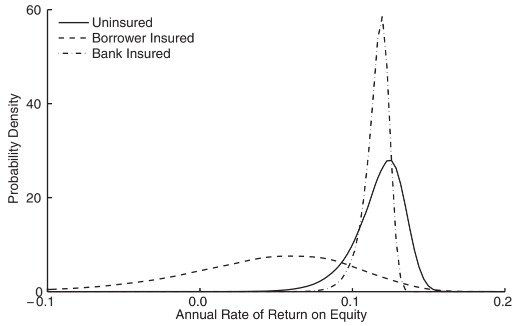

Figure 7. Probability density of bank's average annual rate of return on equity over a ten-year horizon

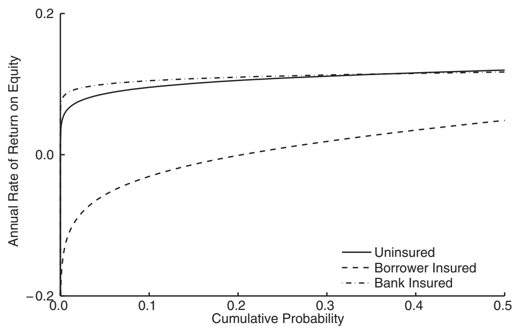

Figure 8. Value at risk, bank's average annual rate of return on equity over a ten-year horizon

purchase unsubsidized index insurance substantially reduces and destabilizes bank equity growth. However, by directly buying unsubsidized index insurance, a bank can dramatically stabilize equity growth without appreciably affecting its expectation.

Figure 8 illustrates the bank equity value at risk over a ten-year horizon. Specifically, it provides the probability that an average annual rate of return will be achieved over a ten-year horizon. As can be seen from the figure, the bank can substantially increase the rate of return that it can achieve with probabilities up through 50% if it purchases index insurance and directly receives the indemnities paid by the insurance, even at premium rates 1.5 times the expected indemnity.

Conclusions

The ability of small banks and MFIs in developing countries to provide credit to poor agricultural producers is often impeded by recurring droughts, floods, and other catastrophic weather-related events that render agricultural loan portfolios appreciably riskier than urban business loan portfolios. In this paper, we have developed a dynamic structural numerical simulation model that allows us to examine how lenders in developing countries might manage their equity risk through the use of index insurance contracts that indemnify based on the observed value of rainfall, temperature, or other weather variable. The model is stylized, and the qualitative simulation results presented (while only representative) are robust based on unreported sensitivity analysis.

Our simulations indicate that requiring individual borrowers to purchase index insurance in order to secure a loan, if the premiums reflect realistic loads to cover operational costs, can have disastrous effects on bank profitability and equity growth. However, the reverse is true if the index insurance is heavily subsidized. In these instances, however, banks have an incentive to raise interest rates, and forgiving part of a borrower's debt has either limited or undesirable impacts on the bank's equity, indicating that a government policy to subsidize loan interest rates is unlikely to have positive impacts on borrowers. However, if a bank directly buys index insurance and uses it to manage the systemic risk inherent in its portfolio, it can substantially stabilize equity growth without appreciably affecting average rate of growth, even if the insurance premiums are unsubsidized. Additional research is needed, including empirical assessments of the main theoretical predictions of our model. However, we hope that the results presented here will help stimulate a substantial debate regarding the proper use of index insurance to promote the welfare of poor farmers in the developing world.

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