On the Efficient Management of Natural Disaster Risk Using Credit and Index Insurance

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1 Introduction

Credit and insurance markets contribute to economic growth (Arena, 2008; King and Levine, 1993; Levine, 1997; Ray, 1998). Moreover, credit and insurance are complements, providing additional benefits when both markets are in place (Arena, 2008). For example, Grace and Rebello (1993) demonstrate that insurance facilitates borrowing by lowering the cost of capital for firms. Yet, credit can also act as a substitute for insurance (Binswanger and Rosenzweig, 1986). When insurance markets are underdeveloped, credit allows borrowers to transfer the risk of disagreeable states of nature to lenders.

Index insurance against natural disasters is expanding insurance markets in developing and emerging economies. This type of insurance bases payments on an objective measure of a disaster (e.g., weather station data to estimate drought) and so can be used in a variety of contexts where traditional insurance is infeasible. Index insurance has gained some prominence as a mechanism to enhance credit markets and so increase financial inclusion. Among other examples, the World Bank has tested bundling index insurance with agricultural production loans in Malawi (GFDRR, 2011). We developed insurance against severe El Niño, which is now being used by a microfinance intermediary (MFI) to protect its portfolio as it expands lending in northern Peru (Collier and Skees, forthcoming). Fonkoze, an MFI in Haiti, bundles household-level index insurance against earthquakes and severe storms with its loans (Fonkoze, 2011).

Insurance for households predominate donor-funded index insurance projects, yet many institutional constraints and high costs challenge the development of insurance markets for households. The costs include household-level capacity building and delivery of small-value insurance products. Household insurance against disasters will not follow the path of microcredit due to their myriad differences (Murphy et al., 2011). For example, with insurance it is the household that incurs the upfront cost and bears the counterparty risk, whereas with microcredit it is the lender. With some exceptions, the scalability and sustainability of household-level index insurance projects are unclear; many markets will not survive when donor support ends. Moreover, too much emphasis has been placed on index insurance as a developing country proxy for developed country agricultural insurance with insufficient consideration of its best use for contributing to economic development. That model focuses on protecting insureds from yield risk associated with a single crop in a single season. This framework is rather outmoded but still in widespread use. It has limited the relevance of index insurance for managing disaster risks, leading to serious questions regarding its value for development (e.g., see Binswanger-Mkhize, 2012). These observations have motivated us to rethink our approach in recent years by orienting it toward 1) a stronger emphasis on facilitating economic growth, and 2) conditions that lead to viable markets (e.g,. Skees and Barnett, 2006; Skees, 2008)

Markets established with products designed for financial intermediaries (FIs , e.g., banks, microfinance intermediaries) are more likely to be viable because they lead to large-value sales with much lower transaction costs than household products. Moreover, FIs are quite vulnerable to disaster risk and so constrain lending to vulnerable regions and economic sectors (e.g., agriculture). Index insurance for FIs improves their ability to manage disaster risks and can enhance financial inclusion and lower interest rates (Collier and Skees, forthcoming; Miranda and Gonzalez-Vega, 2011). As a result, the authors have taken a position that index insurance designed to manage the portfolio risks of FIs, rather than products for their borrowers, may be the more effective starting point for the development of disaster risk markets serving the financial sector (e.g., Skees et al., 2007).

This paper considers the potential implications for household economic growth of prioritizing index insurance markets for households versus FIs. Specifically, we evaluate the potential of these two approaches for managing credit risk, lowering interest rates, and increasing household investment in production. FIs have a long history of assisting borrowers managing disaster-related credit risks through loan restructuring and forgiveness. We compare a scenario in which index insurance for FIs enhances their ability to assist borrowers in managing cash-flow fluctuations versus one in which households manage credit risks themselves by insuring. We develop a dynamic household model in the spirit of Solow (1956), Piketty (1997), and (Barro and Mankiw, 1995). This model includes a representative household that attempts to maximize current and future consumption through capital accumulation. Household production is exposed to a disaster risk, and a lender and insurer offer products to facilitate production.

This model can be used to demonstrate that insurance for households can smooth consumption across states of nature. The value of insurance for consumption smoothing is an important (and old) finding of neoclassical models; however, as Chantarat et al. (2012) note, consumption smoothing is a “zero sum game” if it does not change behavior. Instead, this paper explores insurance as a mechanism to expand financial services and increase household investment. In this context, insurance has the potential to facilitate economic growth.

We begin modelling with a standard set of neoclassical assumptions — perfect, competitive, and complete markets, no transaction costs, etc. Households strongly benefit from using credit and insurance in the model. These financial products allow households to reallocate funds across 1) time periods, and 2) states of nature. Reallocation across time allows households to leverage future wealth to expand current production opportunities. Credit is the most common mechanism used for this intertemporal reallocation. Reallocation across states of nature allows households to move resources from agreeable states to disagreeable ones. Insurance is the most common mechanism used for state-contingent reallocation. However, both insurance and credit contain state-contingent and intertemporal aspects. Because of non-repayment risk, lenders must account for states of nature in setting interest rates. To prevent adverse selection opportunities, insurance must be sold in a period before the presence of a disaster is known. As a result, credit and insurance products can be designed in ways where their functions significantly overlap. This substitutability allows for flexibility in product development.

Under neoclassical assumptions, the net present value of any financial product is zero. State-contingent transfers occur at the actuarially fair rate, and intertemporal transfers occur at the representative discount rate. In this context, we design credit and insurance products to limit household risk in borrowing. The results demonstrate that households can experience the same cash flow across periods with either mechanism. Additionally, the cost of managing the risks associated with household production decisions are passed to households via borrowing interest rates.

Next, we alter several assumptions and examine the effects. First, we consider more limited access to market-rate funds for lenders in the form of a yield curve where short-term funds carry a higher interest rate. This yield curve increases the cost of managing disasters with credit for households; however, insurance can reduce this cost. We evaluate two financial structures: 1) the household purchases insurance and takes a traditional loan; and 2) the lender insures its portfolio and offers households a loan product that includes disaster forgiveness. These structures generate identical cash flows for households.

Second, we consider the implications of basis risk for index insurance products. Basis risk describes the possibility of a discrepancy between the severity of the disaster as experienced by the household and that as measured by the index used for payouts. Households and lenders need different indices acting as the measure for payouts because household production is geographically concentrated compared to the portfolio of production investments held by the lender. We consider the case of a household using measurements from the closest weather station as an index of the disaster while the lender uses a weighting of data from several weather stations that represent the geographic distribution of its portfolio. Using properties of estimators, we demonstrate that basis risk is lower for the lender product. This result suggests that lender-level index insurance better protects households against disaster-related credit risks than household-level index insurance.

Third and finally, we consider the condition of an imperfect relationship between the occurrence of a disaster and household losses. In this context, only a portion of households would default when the disaster occurs; however, all insured households would receive an index insurance payment based on the measure of the event. Each household is uncertain whether it will be one of the ones that would default so a household-level index insurance market would motivate all households to insure. At the aggregate level, this strategy over-insures the credit exposure, which has the high opportunity cost of lowering household production investments and so slowing economic growth. Alternatively, managing disaster-related credit risk through lender-level index insurance in this context does not lead to over-insuring and so benefits households by lowering their borrowing costs, allowing them to increase production investments.

2 Model

We develop a model in the tradition of Solow (1956). An infinitely-lived, risk-averse representative household attempts to maximize consumption by accumulating capital in the presence of natural disaster risk. In the spirit of cite Piketty (1997), who developed an extension of the Solow model, we introduce stochastic shocks at the micro level and evaluate their influence on market interest rates. A lender and insurer also enter the model and are risk neutral. For these analyses we assume that the lender and insurer are operating under neoclassical economic assumptions — complete markets, perfect competition, full information, no transaction costs, etc. While many neoclassical growth models include lenders (e.g., Aghion and Bolton, 1997; Barro and Mankiw, 1995; Piketty, 1997), few include insurers.

Webb et al. (2002) develop an extension of the Solow model in which the contributions of banking and insurance to productivity are modelled in the aggregate, at the macroeconomic level. Similar to the way that Solow models technology, they model insurance and banking services as a scalar that enhances the productivity of capital and labor in their model. In contrast, our model focuses on the micro-level contributions of banking and insurance and explicitly includes them as elements of the production process. We recognize that developing and emerging economy financial markets are increasingly integrating with international markets and assume the lender and insurer have access to an international bank and reinsurer, respectively. Barro and Mankiw (1995) demonstrate that international investment can increase output in developing and emerging economies, speeding convergence with developed economies. The contribution of international investment creates local production opportunities.

Neoclassical growth models evolve through an unconventional sequence (e.g., see Aghion and Bolton, 1997). To better place this paper in that literature, we adopt the following approach. Each period is divided into two sub-periods, which we will call *morning* and *evening*. During the morning, the household makes production investment decisions, including whether to borrow or insure as part of the production process. In the evening, the household realizes its production returns, settles accounts such as outstanding loans, and allocates its wealth between consumption and saving capital for the next production period.

2.1 Households

The representative household attempts to maximize utility over an infinite time horizon, which is represented using the Bellman equation

$$V(k) = \max_{c,l \geq 0} \{U(c) + \beta E[V(k')]\} \tag{1}$$

where V is the household's value function, U its concave utility function, β its discount rate, c consumption, l the level of loans it borrows, and k household capital. Capital is comprised of consummable, illiquid, infinitely divisible assets. Households invest in a production strategy and can borrow to increase their potential returns. They pay an interest rate r, and fully collateralize the loan. Under borrowing, the household production function is

$$f = \psi(k + l)^{\alpha} \tag{2}$$

where ψ represents a covariate disaster risk to which the household is exposed and $\alpha < 1$.

Households operate under a cash flow constraint. If production returns are less than the loan payment ($f < (1+r)l$), then the borrower defaults and the lender exercises its right on collateral for the owed principal and interest, sells it at a fire-sale rate ν, and uses that amount to settle the household liability.[1] For simplicity, we assume that borrowers only realize this liquidity problem when a natural disaster occurs, which happens with probability θ. Thus, borrowing households face the following income distribution

$$y = \begin{cases} f - rl, & \text{with probabiblity } 1-\theta \\ f_\psi - rl - \nu((1+r)l - f_\psi), & \text{with probabiblity } \theta \end{cases} \tag{3}$$

where f_ψ represents returns under disaster conditions and $\nu > 1$. Households choose whether to consume net income and capital or save it to contribute to next period's capital stock. Therefore, capital evolves based on the process

$$k' = s(y + (1-\delta)k) \tag{4}$$

where s is the savings rate and δ is the depreciation rate ($s, \delta \in [0,1]$).

2.2 Lender

The lender serving the representative household borrows all funds from an international bank at interest rate r and lends locally. At this starting point where loans are fully collateralized, the lender does not incur risk from the transaction. Thus, it loans to its borrowers at its marginal cost, i.e., interest rate r. Borrowers limit the use of credit due to their risk exposure. Maximizing expected utility with respect to l indicates that, among other things, the optimal loan allocation is a function of the disaster exposure of the household and its capital level.

Fully collateralized lending is rather extreme, and in practice, lenders are often willing to accept borrower risk to enhance lending opportunities. Whether the risk transfer is in the form of delayed loan payments or principal forgiveness, the expected cost of the transfer is passed to borrowers in the lending interest rate. Thus, the only sustainable strategy for relaxing collateral requirements is increasing interest rates. Risk transfer is never free.

[1] Alternatively, we arrive at the same formulation if the household decides to sell its assets at fire-sale prices to meet its liabilities.

The lender is a type of investor in its borrowers because as the capital of the borrower grows, the lender can generate more revenues. The lender wants to increase its revenues and so offers loan products with features that allow borrowers to manage their disaster risk. The model can be used to identify optimal product structures; however, these analytical solutions are rather cumbersome and not particularly enlightening. Instead, we describe frequently used product structures recognizing that households benefit from smoothing returns across agreeable and disagreeable states of nature and make comparisons using the modeling framework.

Because the disaster occurs with probability θ, the actuarially fair *rate* of risk transfer for a product that provides a full payment in disaster periods is θ. We accept the premise that households would like to pay for risk transfer during agreeable states and forego payments in disagreeable states — in other words, households do not pay risk transfer premiums during disaster periods. As a result, we use the premium rate structure $p = \frac{\theta}{1-\theta}$ throughout, which allows households to fully pay risk transfer premiums during non-disaster periods.

First, we consider a loan with a feature that forgives the interest on the loan for the first period and defers the payment of the loan until the end of the second period.[2] The expected cost to the lender of offering this interest rate forgiveness is θrl so the interest rate for the loan with a deferment clause is $r(1+p)$, which is paid at the end of the first period. Household cash flow associated with this loan is shown in Table 1.

Table 1: Cash flow for loan with deferment clause

Period 1		Period 2		Probability
Morning	*Evening*	*Morning*	*Evening*	
l	$-(1+r+pr)l$	0	0	$1-\theta$
l	0	0	$-(1+r)l$	θ

Instead, the lender could offer a loan that had a disaster forgiveness clause, pending regulatory approval of such a product.[3] For that benefit, the actuarially fair interest rate

[2] In practice, lenders provide this feature sometimes implicitly and sometimes explicitly. Lenders often provide this benefit informally through loan restructuring or offering a "grace period" in which borrowers are not required to service a loan. The costs of these benefits are implicitly embedded in lending interest rates. In Peru, loans in the fishing industry offer a period of deferred loan payment in the event of an El Niño. This feature is explicitly written into the loan contract and borrowers pay a higher interest rate for it.

[3] In practice, the primary way that lenders offer debt forgiveness is loan write-offs after a disaster. Lenders

would be $r+p(1+r)$. Household cash flow under this loan with disaster forgiveness is shown in Table 2.

Table 2: Cash flow for loan with forgiveness clause

Period 1		Period 2		Probability
Morning	*Evening*	*Morning*	*Evening*	
l	$-(1+r+p(1+r))l$	0	0	$1-\theta$
l	0	0	0	θ

2.3 Insurer

Alternatively, suppose that a local insurer offers insurance against the natural disaster and transfers this risk to an international reinsurer. First, the insurance could also be used to defer the loan payment in a similar manner as the loan with a deferment clause described above. In this case, the sum insured is rl and the household takes out a traditional loan. The insurer gives households the market interest rate for paying its premiums at the beginning of the period for a payout that would occur at the end of the period such that the total premium is $\frac{prl}{1+r}$. We assume households prefer to buy the insurance with a loan and repay the lender at the end of the period. If the disaster occurs, the borrower uses the insurance payout to pay the interest on its loan, and the lender allows the borrower to defer its principle payment to the next period. This arrangement would lead to the same cash flow as shown in Table 1. Alternatively, the household could fully insure its loan for a premium of pl. This arrangement would lead to the same cash flow as shown in Table 2.

2.4 Summary

Under neoclassical assumptions, cash flows under the loan and insurance products are identical. Both approaches transfer household capital from agreeable to disagreeable states of nature, which is an attractive quality for risk-averse households. By protecting households

may continue to pursue an investing relationship with borrowers for whom they deemed default was unavoidable due to a disagreeable state of nature and may avoid exercising collateral to increase borrower productivity in the future.

from default and liquidation, these mechanisms increase household expected utility and expected capital. In comparing credit and insurance, perhaps the most notable result is that under these assumptions, insurance adds no value in managing credit risk beyond the structures lenders can provide.

3 Relaxing assumptions

In this section, we alter some of the above assumptions to model real world constraints and evaluate the implications for credit and insurance markets. First, we introduce a type of interest rate yield curve where lenders must pay higher rates for short-term funds. This yield curve increases the cost of unexpected borrowing. Second, we model the insurance mechanism specifically as index insurance. Index insurance can transfer disaster risk but has some error measurement that leads to discrepancies between the disaster as experienced by the insured and as measured by the index. Finally, we consider the role of index insurance in a scenario in which only a portion of households affected by a disaster default.

3.1 Increased short-term borrowing costs

Rather than assuming that the lender has immediate access to international funds (as we did above), suppose that acquiring funds from an international bank is time consuming and so arrive the morning of the following period. If lenders need funds immediately, they must use the short-term market, which charges an interest rate of r_s where $r_s > r$. Each period, the lender must fulfill its debt liabilities. If households fail to repay their loans, the lender either exercises its right on borrower collateral or goes to the short-term markets and borrows at the short-term rate.

As section 2.2 demonstrates, loan products can be developed in a number of ways to transfer risk from households to the lender. From here forward we use the loan contract with debt forgiveness in the occurrence of a disaster as the illustrative case. Higher short-term borrowing costs for the lender increase the cost of providing debt forgiveness. The actuarially fair interest rate for the loan with a forgiveness clause is $r + p(1 + r_s)$. Household cash flow for this scenario is shown in Table 3.

Table 3: Cash flow for loan with forgiveness clause using short-term markets

Period 1		Period 2		Probability
Morning	*Evening*	*Morning*	*Evening*	
l	$-(1+r+p(1+r_s))l$	0	0	$1-\theta$
l	0	0	0	θ

Insurance can add substantial value in this context by reducing the cost of reallocating resources across different states of nature. We consider two options. First, the household could buy insurance at a level equal to the value of the loan. Second, the lender could purchase insurance to manage its cash flow risk and continue to offer households the loan with a forgiveness clause. The insurance, whether purchased by the household or lender, returns household cash flows to that shown in Table 2. In sum, under a condition of higher short-term borrowing costs for lenders, insurance reduces the cost of risk transfer from $p(1+r_s)l$ to $p(1+r)l$.

3.2 Index insurance and basis risk

Now, suppose that the type of insurance product offered is index insurance. Index insurance insures against disasters based on a specific measure of the disaster itself. Commonly, the index is weather data (e.g., rainfall) collected at a weather station. We assume that the weather risk ϕ is perfectly, positively correlated with losses ψ.

Depending on the region, weather stations may be sparsely dispersed. For example, while the source is becoming a little dated, Funk et al. (2003) reports that there are roughly 1,000 quality-controlled weather stations in all of Africa. If these stations were uniformly distributed, the weather station density would be one every 60,000 km^2.

Households and lenders require different measurements for the disaster event, based on their vulnerability. For households, the event is measured based on readings at the closest weather station ϕ_w. As a result, there is some error in the measure as the weather may differ for households from that at the weather station. This measurement error is called *basis risk*. The household index $\hat{\phi}_h$ is

$$\hat{\phi}_h = \phi_w. \tag{5}$$

For the lender, the event is measured based on readings from a group of weather stations representing the geographic dispersion of its portfolio

$$\hat{\phi}_l = \sum_{i=1}^{N} g_i \phi_{wi} \tag{6}$$

where i denotes the sequence of weather stations and g_i is the proportion of the portfolio associated with each weather station such that $\sum_{i=1}^{N} g_i = 1$. The index used by the lender is associated with lower basis risk than the household index, as demonstrated in the following proposition.

Proposition: The index used for the lender is a more efficient estimator than the index used for households.

To make a consistent comparison, we use two scenarios: 1) every borrower insures its disaster risk using the household index and this protection is aggregated to the lender portfolio and evaluated as a weighted average based on the portfolio allocation, and 2) the lender insures its portfolio using the lender index. For a given occurrence of weather for households, the weather at the closest weather station can be written as

$$\phi_{wi} = \phi_{hi} + \epsilon_{hi}$$

where ϵ_{hi} is an error term distributed $N(0, \sigma^2)$.

Household index. The expectation for the household index is

$$\mathrm{E}\,[\hat{\phi}_{hi}] = \mathrm{E}\,[\phi_{wi}] = \phi_{hi}$$

indicating that the household index is unbiased. The variance of the estimator for a given occurrence of weather for households is

$$\mathrm{var}\,(\hat{\phi}_{hi}) = \mathrm{var}\,(\phi_{wi}) = \sigma^2.$$

Let $\hat{\phi}_H$ be the aggregation of the household index to the level of the lender's portfolio. Aggregating the expectation of the household index yields

$$\mathrm{E}\,[\hat{\phi}_H] = \sum_{i=1}^{N} g_i \phi_{hi} = \bar{\phi}_h$$

where $\bar{\phi}_h$ is the weighted portfolio average of the weather occurrence across all borrowing households. The aggregated variance is

$$\mathrm{var}\,(\hat{\phi}_H) = \sum_{i=1}^{N} g_i \sigma^2 = \sigma^2.$$

Lender index. The expectation of the lender index is

$$\mathrm{E}\left[\hat{\phi}_l\right] = \mathrm{E}\left[\sum_{i=1}^{N} g_i \phi_{wi}\right] = \sum_{i=1}^{N} g_i \mathrm{E}\left[\phi_{wi}\right] = \bar{\phi}_h.$$

Thus, $\mathrm{E}[\hat{\phi}_l] = \mathrm{E}[\hat{\phi}_H]$. This estimator is also unbiased. The variance of the lender index is

$$\mathrm{var}\left(\hat{\phi}_l\right) = \mathrm{var}\left(\sum_{i=1}^{N} g_i \phi_{wi}\right) = \sum_{i=1}^{N} g_i^2 \,\mathrm{var}\left(\phi_{wi}\right) = \sum_{i=1}^{N} g_i^2 \sigma^2.$$

Because $\sum_{i=1}^{N} g_i^2 \leq 1$, $\mathrm{var}(\hat{\phi}_l) \leq \mathrm{var}(\hat{\phi}_H)$. The index used for the lender is a more efficient estimator than the index used for households. □

3.2.1 Implications of basis risk for credit and index insurance

In sum, basis risk is lower for the index used by the lender. Basis risk has important implications for how insurance is used. Following on the scenario in Section 3.1 where the lender faces short-term lending costs, we continue our evaluation of index insurance under the two structures already described, loan forgiveness through 1) household insurance, or 2) insurance purchased by the lender and transmitted to households through the lending relationship. Because both household and lender indices are unbiased, comparisons based on expected value are not particularly interest and may even be misleading. Instead, we propose a stress-test associated with a measurement error of probability q^* — e.g., q^* could represent the probability of a measurement error of one standard deviation below the mean. A disaster occurs and the household and lender indices pay with the associated measurement errors of $-\epsilon_h^*$ and $-\epsilon_l^*$, respectively, underpaying relative to the incurred losses.

For the loan product, the lender offers households a loan with a clause that forgives the interest and principal of the loan if the disaster occurs. Then the lender borrows from the international bank to buy insurance and insures its risk at a sum insured of $(1+r)l$. When the disaster occurs, the lender receives a payout of $(1-\epsilon_l^*)(1+r)l$. To meet its liabilities to the international bank, the lender borrows on the short-term market $\epsilon_l^*(1+r)l$ due to the basis. Households must repay the lender at the end of Period 2 for the amount borrowerd on the short-term market. Thus, household cash flow under this scenario is shown in Table 4. A comparison with Table 2 show the cost of basis risk in this specific scenario.

Alternatively, the household fully insures its loan using the household product. The lender wants to prevent household default and so agrees to extend a short-term loan if the

Table 4: Cash flow for loan with forgiveness clause under basis risk

Period 1		Period 2		Probability
Morning	*Evening*	*Morning*	*Evening*	
l	$-(1+r+p(1+r))l$	0	0	$1-\theta$
l	0	0	$-\epsilon_l^*(1+r_s)(1+r)l$	θ

insurance pays less than insured household losses. When the disaster occurs, the household receives a payout of $(1-\epsilon_h^*)(1+r)l$. To meet its liabilities to the international bank, the lender goes to the short term market and borrowers $\epsilon_h^*(1+r)l$. It then passes this cost to households. Thus, household cash flow under this scenario is shown in Table 5. Because basis risk is higher for the household insurance product, i.e., $\epsilon_h^* > \epsilon_l^*$, households can manage their credit risk at a lower cost by having the lender insure and transmit coverage to households.

Table 5: Cash flow for insuring the loan under basis risk

Period 1		Period 2		Probability
Morning	*Evening*	*Morning*	*Evening*	
l	$-(1+r+p(1+r))l$	0	0	$1-\theta$
l	0	0	$-\epsilon_h^*(1+r_s)(1+r)l$	θ

3.3 Index insurance under limited default

Finally, we model the case in which only a portion of households default when a disaster occurs. Households are unaware *ex ante* whether they will default when the disaster occurs. One explanation for this uncertainty is that it is the result of a diversified production strategy by which households earn income from a variety of activities with differing disaster vulnerabilities. To illustrate, a Peruvian producer grows mangos, selling a portion in local markets and exporting the rest. The producer also sells a handicraft in the local market. This producer is vulnerable to severe El Niño events. Depending on the occurrence of El Niño-related torrential rain, it has the potential to 1) reduce yields, 2) close local markets, and/or 3) destroy roads this producer needs to export.

Given a disaster event of probability θ denoted $\phi_h(\theta)$, a portion of households experience large losses ψ_L and consequently experience a liquidity shortage ($f_{\psi_L} < (1+r)l$). Given the disaster, the probability of any household experiencing large losses is ω. Otherwise, households experience a small level of losses ψ_S. Thus, given the disaster event, household income can be written as

$$y(\psi|\phi_h(\theta)) = \begin{cases} f_{\psi_S} - rl, & \text{with probabiblity } 1-\omega \\ f_{\psi_L} - rl - \nu((1+r)l - f_{\psi_L}), & \text{with probabiblity } \omega \end{cases} \tag{7}$$

Suppose the lender requires that all borrowers insure their loans with the household insurance.[4] While only a portion of households (ω) would default when the disaster occurs, to prevent default using insurance for households, all households must insure as if they will experience large losses. As a result, household cash flows follow Table 2.

Alternatively, the lender could purchase protection at a level that matches the portion of the portfolio that would default (ω). Assuming full information, the lender could then offer loan forgiveness only to households experiencing large losses.[5] The expected per-unit cost of providing this coverage for the lender is $\omega p(1+r)$. Household cash flows under this scenario are shown in Table 6.

Table 6: Cash flow for loan with forgiveness clause under limited default

Period 1		Period 2		Probability
Morning	*Evening*	*Morning*	*Evening*	
l	$-(1+r+\omega p(1+r))l$	0	0	$1-\theta\omega$
l	0	0	0	$\theta\omega$

These results suggest that if lenders make household insurance mandatory for their borrowers, that the associated credit risk is over-insured. Over-insuring has the high opportunity

[4]For example, lenders might adopt this policy if households are unable to collateralize loans and the lender wants to offer a lending interest rate with a lower face value. In this case, insuring is a transaction cost of borrowing. Several index insurance pilots have tested lending with mandatory insurance for households.

[5]Assuming incomplete information, the lender would need to provide an incentive compatibility condition that imputes an additional cost on borrowers if they require loan forgiveness. For example, borrowers might face a "cooling off period" in which they could not borrow for one period after receiving loan forgiveness. The formulation and calibration of the incentive compatibility condition affect whether this structure in which the lender insures is more or less attractive than that where households insure under incomplete information. Because lenders regularly restructure and write off loans, we assume they have some information systems in place to evaluate household losses.

cost of lowering household production investments and so slowing economic growth. Alternatively, by the lender purchasing insurance and transferring benefits to households, the household cost of protection against disaster-related default risk is reduced from $p(1+r)$ to $\omega p(1+r)$. This efficiency enhancement increases investment and facilitates household capital accumulation.

3.4 Summary

This section indicates that in the presence of high short-term borrowing costs, insurance markets can add value by managing state-contingent risks. Whether the lender or household insures lending risk, the household experiences the same cash flow. Sections 3.2 and 3.3 demonstrate that managing disaster-related credit risk through lender-level index insurance is more efficient than through household-level index insurance. When lender-level index insurance is used, the benefits to households are transmitted through the lending relationship. These efficiency gains are due to 1) reduced basis risk for lender-level indices, and 2) a lower sum insured needed to manage the risk for lender-level indices. These efficiency gains suggest a long-term role for lender-level index insurance, even as insurance markets for households develop that allow them to more comprehensively manage disaster risk.

4 Conclusion

A colleague told the following story, which is worth repeating. An isolated community wants to be isolated no more, but a highway is not built an inch at a time. Instead, the community clears debris and makes a dirt path. The people walk on the path. The path is too small and uneven for vehicles and so the community widens the path and pours gravel to make a road. The people drive on the road. The road is not strong and cannot support trucks and so the community pours concrete to make a highway. The people drive on the highway.

Insurance markets against natural disasters have the potential to serve many stakeholders with a variety of needs; however, developing sustainable markets is a process. This paper demonstrates that lender-level index insurance has the potential to benefit households by increasing investment opportunities and facilitating economic growth. Moreover, lender-level index insurance can provide comparable or greater benefits to households than household-level index insurance for managing credit risk. As a result, insurance for FIs seems to be an attractive and meaningful first step in regions where disaster risk constrains access to finance. Household vulnerability extends beyond credit risk and so sustainable insurance markets that provide protection against disaster-related asset losses and income fluctuations are an important long-term goal. In many regions, a significant intermediate step might be extending disaster insurance to the asset and business interruption risks of vulnerable small and medium enterprises (SMEs). SMEs employ around 45% of the labor force and generate 30% of GDP in developing countries (Financial Inclusion Experts Group, 2010), and their vulnerability to natural disasters is well documented (Alesch et al., 2001; Tierney, 1995; Zhang et al., 2009). For example, according to the Institute for Business & Home Safety (2007), 25% of US SMEs close after experiencing a natural disaster. SME vulnerability in developing and emerging economies is likely greater.

To test the theoretical results regarding basis risk in Section 3.2, we intend to employ a spatial econometric model using rainfall data and develop a hypothetical index against drought as a next research activity. We will omit a subset of weather stations from data on a network of weather stations to test the hypothetical index used by the lender. These omitted stations are intended to represent the borrowers. We will then use data from the remaining weather stations to predict the level of rainfall experienced at the level of the lender portfolio, i.e., the measure of rainfall at the omitted weather stations in the aggregate. To represent the rainfall experienced by households, we will predict rainfall at a weather station using its nearest neighbor. We hypothesize that the normalized standard error associated with the lender's index is significantly less than that of the household's index. This result would support the theoretical finding that basis risk is lower for lender-level index insurance than household-level index insurance.

Many factors affect the implementation of financial risk management mechanisms for disasters. For example, regulation limits the activities of lenders and insurers in many jurisdictions. These and other implementation considerations are quite important for real-world applications and affect the structures of those products. We do not intend to dismiss or downplay these complicating factors. Rather, our intention is to note that many of the benefits of using household-level insurance to manage credit risk may already be provided through credit contracts and so suggest that the most effective means to enhance financial inclusion through index insurance may be in facilitating the ability of lenders to offer these benefits through lender-level insurance.

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