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Index-based weather insurance for developing countries: A review of evidence and a set of propositions for up-scaling

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Abstract

Index-based weather insurance is a major institutional innovation that could revolutionize access to formal insurance for millions of smallholder farmers and related individuals. It has been introduced in pilot or experimental form in many countries at the individual or institutional level. Significant efforts have been made in research to assess its impacts on shock coping and risk management, and to contribute to improvements in design and implementation. While impacts have typically been positive where uptake has occurred, uptake has generally been low and in most cases under conditions that were not sustainable. This paper addresses the reasons for this current discrepancy between promise and reality. We conclude on perspectives for improvements in product design, complementary interventions to boost uptake, and strategies for sustainable scaling up of uptake. Specific recommendations include: (1) The first-order importance of **reducing basis risk**, pursuing for this multiple technological, contractual, and institutional innovations. (2) The need to use **risk layering**, combining the use of insurance, credit, savings, and risk-reducing investments to address optimally different categories of risk. For this, these various financial products should be offered in a coordinated fashion. (3) Calling on a **role for state intervention** on two fronts. One is the implementation of public certification standards for maximum basis risk of insurance contracts; the other is "smart" subsidies for learning, data accumulation, initial re-insurance, and catastrophic risks. (4) Using **twin-track** institutional-level index insurance contracts combined with intra-institution distribution of payouts to reduce basis risk and improve the quality of insurance. For this, credible intra-institutional rules for idiosyncratic transfers must be carefully designed. Finally (5), the need for further **research** on the determinants of behavior toward risk and insurance, the design of index-based insurance products combined with others risk handling financial instruments, and rigorous impact analyses of on-going programs and experiments.

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1. The theoretical appeal of index insurance

It is all too well known that risks are high in agriculture and that exposure to **uninsured risks** is a major cause of low yields, slow growth, and persistent poverty. Weather related risks are hugely important for poor people in developing countries as an estimated two-third of them depend on agriculture and natural resources for their wellbeing (World Bank, 2007). This includes not only farmers whose income and consumption directly depend on agriculture, but also residents of rural areas whose employment and business incomes indirectly depend on successful agricultural outcomes as they propagate through the value chain and local linkages. Uninsured weather shocks thus also affect farm workers (Jayachandran, 2006), input suppliers, entrepreneurs and workers in agribusiness, and providers of non-tradable goods and services in the rural non-farm economy. Because weather shocks tend to be covariate over large geographical areas, local informal risk sharing networks that can be effective for idiosyncratic shocks (such as health, unemployment, and theft) offer, in this case, limited protection. State and national governments and development agencies are also affected by weather shocks as they face sudden demands for relief, reconstruction, and recovery for which they may not have access to the necessary financial resources (Cummins and Mahul, 2009).

Weather-related **natural disasters** that affect smallholder farmers can take many forms. Cole et al. (2009) report that 89% of households in Andra Pradesh mention rainfall variability as the most important source of the risks they face. Based on both self-reporting and statistical analysis, Christiansen and Dercon (2007) find that rainfall shocks are the largest source of risk to consumption among Ethiopian households. Over the last 30 years, data from the International Disaster Database show that an estimated 1,000 natural disasters occurred in Africa, affecting 328 million people with damages estimated at US$24 trillion.[1] While floods were the most frequent type of natural disaster events (59% of natural disasters in a list that includes droughts, extreme temperatures, storms, earthquakes, and volcano eruptions), droughts were the hazard that has affected the most people and caused the largest damage cost, accounting for 83% of people affected and 40% of total economic damages. Together, droughts and floods dominate the African risk landscape, with half of Sub-Saharan countries affected by at least one drought every 7.5 years, and half impacted by at least one flooding event every three years. Relative to other regions of the world, mortality from these events is very high in Africa (Dilley, Chen, and Deichmann, 2005).

[1] EM-DAT: The OFDA/CRED International Disaster Database. At least one of the following criteria must be fulfilled in order for an event to be classified as natural disaster: i) 10 or more people killed; ii) 100 or more people affected/injured/homeless; iii) declaration of a state of emergency and/or an appeal for international assistance.

With lack of protection against weather shocks, rural households need to **self-insure**, and this is typically both costly to them and of limited effectiveness, particularly for covariate shocks that cannot be addressed trough mutual insurance. Responses to weather shocks include both ex-post shock coping and ex-ante risk management (see Figure 1). To **cope with shocks**, households must reduce consumption expenditures to achieve asset smoothing and/or sell assets to achieve consumption smoothing (Elabed and Carter, 2014). Reducing consumption to protect assets typically has high immediate welfare costs and can create irreversibilities in health (stunted child development) and education (dropping out of school with low probability of return), thus reproducing poverty across generations (Barnett, Barnett, and Skees, 2008; Maccini and Yang, 2009). Short-term shocks can thus have unexpected long-term consequences, sometimes lasting across several generations. An important function of social protection is precisely to break this inter-generational transfer of shocks, for instance through conditional cash transfers targeted at transitory poverty. Selling productive assets (livestock, seeds, land) to protect consumption undermines income-generating capacity and can push households into poverty traps from which it will be difficult to escape (Barrett et al., 2007). Other disruptive shock-coping responses include costly labor adjustments through migration and child labor, and costly financial adjustments through dis-saving and indebtedness.

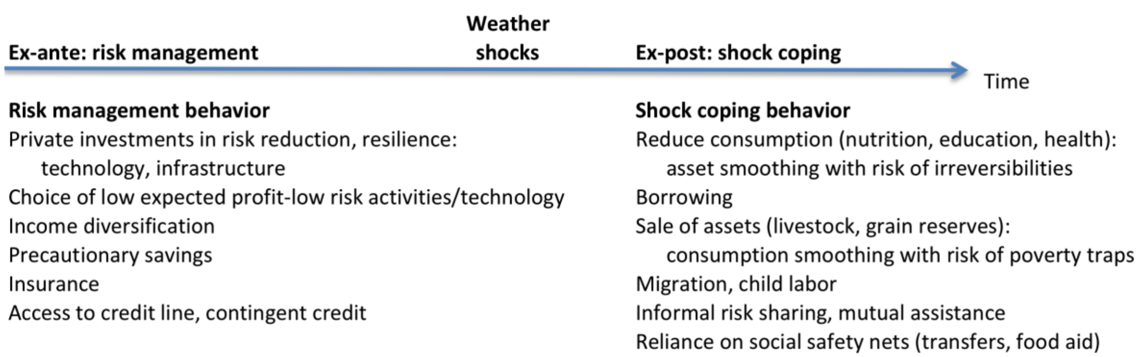

Figure 1. Shock coping and risk management in response to weather shocks

Even though they are the most visible and often the most gripping, responses to uninsured shocks go beyond ex-post coping strategies. They also include costly efforts at ex-ante **risk management** (Figure 1). Since farmers anticipate that uninsured shocks will strike, and that their capacity to cope with shocks is limited and costly, they rationally adjust their behavior to reduce exposure to shocks and invest in reducing the expected consequences of shocks (Rosenzweig and Binswanger, 1993). Risk management responses consist in risk reduction, risk avoidance, risk transfer, and risk retention. **Risk reduction** includes investments in resilience, for instance in irrigation infrastructure and protection against flooding. **Risk avoidance** includes the choice of activities with lower risk if at the cost of lower expected returns. Farmers will choose seed varieties that offer protection against droughts or floods, typically at the cost of a risk penalty in normal years (Dar et al., 2013). In Tanzania, Dercon (1996) observes that poorer farmers grow more sweet potatoes—a low-risk, low-return crop—than richer farmers, trading lower risk for a reduction of up to 25% in average earnings. In farming, even when farmers own collateralizable assets and lenders are willing to lend to them, use of credit is discouraged by fear of losing the productive assets used as collateral with lenders if there is a negative weather shock in what Boucher, Carter, and Guirkinger (2008) call "risk rationing". Income diversification strategies (mixed farming, off-farm work) similarly offer protection against risk, but at the cost of lesser specialization in the most profitable options. Dercon (2000) explains that farm households in Ethiopia increase their participation in non-farm activities to manage uninsured weather risk.

Risk transfer includes contracting for insurance, typically loss adjustment-based as available. Finally **risk retention** includes precautionary savings. Asset portfolios may be distorted toward holding relatively more liquid assets—investing in bullocks instead of pumps in Pakistan—in order to possibly serve for dissaving in the event of a negative weather shock, at an efficiency cost (Rosenzweig and Wolpin, 1993). Risk retention also includes securing access to a credit line for a fixed fee and investing in patron-client relationships to be able to borrow from prominent individuals in the community when adversity strikes (Bardhan, 1994). Risk management is inevitably costly, and its cost in both normal and bad years can exceed the cost of shock coping in bad years. In general, the cost of risk management in contributing to slow growth and poverty has too often escaped measurement.

The obvious policy response to uninsured risks, and the high cost and low effectiveness of self-insurance, is to provide access to insurance. What type of insurance will work depends importantly on whether realized shocks are **idiosyncratic** or **covariate** at the level of the community. The first can be at least partially insured. Harrower and Hoddinott (2005) thus find that in Northern Mali, idiosyncratic shocks are frequent but have little impact on consumption, suggesting the practice of inter-household risk pooling, while negative covariate shocks are almost always associated with consumption declines. Christiansen and Dercon (2007) similarly find that covariate rainfall shocks have large effects on consumption in Ethiopian villages while idiosyncratic rainfall shocks have little or no effect. Mutual insurance for idiosyncratic shocks is however typically incomplete (Ligon, Thomas, and Worrall, 2002) and risks are importantly covariate, requiring more than mutual insurance. Udry (1990) thus finds that in Northern Nigeria smallholder yields are more exposed to covariate risks (58%) than to idiosyncratic risks (42%). In Burkina Faso, Carter (1997) similarly finds that yields are on average more exposed to covariate risks (54%) than to idiosyncratic risks (46%).

This raises the issue of access to **agricultural insurance** for covariate shocks, particularly when these shocks are relatively infrequent but severe, making them difficult to smooth through other financial products such as precautionary savings and quick-disbursing pre-approved loans or credit lines. Industrialized countries have pursued the route of agricultural insurance, but this has typically required high levels of public subsidies. In the United States, farmer-paid premiums only cover about 30% of total costs (USAID, 2006). This is necessary to maintain a system where loss ratios (the ratio of indemnities to premiums) typically exceed 1.5 (Glauber, 2004).

There are two main reasons why conventional insurance contracts based on indemnity payments as against verifiable losses are simply prohibitive in covering small farmers in developing countries (Newbery and Stiglitz, 1981). One is **moral hazard** whereby insured farmers increase risk-taking (or, equivalently, farmers have less incentive to work hard at protecting their crop if harvest is insured) or engage in false declarations of loss that are excessively costly to verify. In both cases, the insurer is doomed to losses, preventing the sale of insurance contracts. The other is **adverse selection** whereby asymmetrical information on risks leads only farmers with risks in excess of insurance premiums to contract insurance. Raising premiums only attracts even riskier famers. Here again, the insurer is doomed to losses, making the insurance market fail, a typical Akerlof (1970) lemons problem. Covariate shocks further complicate the situation for insurance providers who need to reinsure their portfolios of local contracts issued on the basis of the information they have. And reinsurance is notably difficult to obtain as international reinsurance companies demand data on long term risks that are typically not available in the developing country context, and insurance companies' loading costs are high. Add to all this the high costs of contracting with large numbers of dispersed smallholders when there are fixed costs to contracting and poorly developed legal institutions for the enforcement of contracts, and the conclusion is simply that conventional indemnity-based insurance **does not work** for smallholder farmers in developing countries (Hazell, 1992).

Facts broadly support this conclusion. Iturrioz (2009) estimates that Africa accounts for just 1% of global agricultural insurance premiums, Latin America 2%, and Asia 18%. Most smallholder farmers in developing countries have simply no experience with the concept of insurance. In China, weather insurance for crops was a foreign concept for farmers until 2010 when it was piloted by the government under heavy subsidies (Cai et al., 2014). Lack of access to agricultural insurance leaves farmers to face uninsured risks and pushes them into costly and ineffective self-insurance schemes.

Enters **index-based weather insurance** (index insurance for short) as a novel type of insurance contract for smallholder farmers and other rural inhabitants affected by uninsured covariate weather risks. Index insurance can be contracted at the individual, institutional, national, or regional level. The genial design of index insurance is that it delinks insurance payouts from individual-level losses and links them instead to some index falling below or above a given threshold. The theory of index insurance wants this index to be closely correlated with the insured losses, objectively and easily quantifiable, publicly verifiable, and non-manipulable by the insurer and the insured. The index can be based on climatic data collected at meteorological stations, such as rainfall, hail, temperature, and wind. It can also be based on an average outcomes measured over a small area such as average yield or livestock mortality, possibly observed through remote sensing techniques (MDVI). Insurance payments are triggered by the index crossing a given threshold signaling disaster. Farm-level verification is not needed, avoiding both issues of moral hazard and adverse selection, as well as the high costs and long delays of claims verification. Instead of monitoring yields or livestock mortality over thousands of dispersed small farms, a prohibitively costly enterprise, only the local rainfall gauge or the average yield need measurement. It is thus in principle a potentially highly cost effective approach to an unresolved issue of first order of importance, expectedly allowing to deliver much needed insurance to large numbers smallholder farmers and rural inhabitants in developing countries.

The main drawback of index insurance is existence of **basis risk**. This arises from the discrepancy between measured risks at the meteorological station level and the occurrence of weather shocks at the location of the farm of the insured. It may rain more than the trigger level for drought insurance at the meteorological station, while the farmer suffers from drought. In this case, no indemnities are offered when the farmer had incurred the cost of the insurance, and additionally had his crop devastated by drought. The opposite can occur, with drought at the station level, but normal rain at the farmer level, providing the double bonanza of a good harvest and an indemnity payment. If weather stations are few, and microclimates more locally differentiated, basis risk increases correspondingly, making index insurance into a cheap and expedient but low quality product (Clarke, 2011). Area yield measurements have the advantage of protecting against many unspecified perils (not only rainfall, but also other dimensions of climate, pests, and diseases), but discrepancies will similarly occur between area measurement and location specific outcomes. All of this could be fixed, with greater density of weather stations and more accurate local yield measurements, but solutions are costly and require entrepreneurial initiative, often as a public good.

Index-based weather insurance is thus very much **work in progress**, and the jury is still out on how to make it work. Some 15 developing countries have introduced index insurance programs at the individual level and some 20 at the institutional level, often on a limited pilot or experimental basis, and there is much to learn from these experiences. Rigorous academic studies are becoming available, experimenting with novel designs and assessing on-going experiments, in part under the leadership of the USAID-Basis project. But the gap between high promise and low take-up remains large, creating one of the most fascinating current puzzles in development economics. Recent localized successes suggest that we may have reached a stage where, after much fumbling, scaling up is possible. It is the purpose of this article to review these positive and negative experiences, draw lessons, suggest alternatives, and consider options toward scaling up.

2. The impact value of index insurance where implemented

There are a number of developing countries where index insurance has been implemented. This has been both at the individual farmer level (Table 1) and at the regional, national, or institutional level (Table 2). We review the impact evaluations of some of these experiences.

Country	Year	Policy-holder	Project name	Instrument	Scale	Notes
Brazil	2001	Participants in government seed program	AgroBrasil	Area-based yield index	15,000	Government pays 90% of premium
Ethiopia	2007	Teff and bean farmers	HARITA	Rainfall index	300	Ongoing
India	2003	Smallholders growing various crops	BASIX, ICICI Lombard, others	Rainfall, temperature index	150,000	Ongoing. See Cole et al 2009.
India	2007	Potato farmers under Pepsico contract	Pepsico	Temperature and humidity index	4000	Ongoing
India	2004	Smallholders	AIC	Rainfall, temperature index	1,000,000	Government premium subsidy; ongoing
Kenya	2009	Smallholders	Rockefeller	Rainfall index	500	Pilot stage
Kenya	2009	Maize and wheat smallholders	Kilimo Salama	Rainfall index	200	Pilot stage
Malawi	2004	Maize and groundnut	World Bank, Opportunity Intl, others	Rainfall index	1700	See Giné and Yang (2009)
Malawi	2008	Maize, tobacco farmers	MicroEnsure, others	Rainfall index	2500	Initially maize, moved to tobacco; ongoing
Millennium Villages (Kenya, Ethiopia, Mali)	2007	Smallholders	Millennium Villages	Rainfall and satellite-based greenness index	1000	Premiums paid by MVP; not continued
Mongolia	2006	Herders	IBLIP	District-average livestock losses	5000	Ongoing
Nicaragua	2008	Smallholders	World Bank	Rainfall index	200	Pilot stage

Rwanda	2009	Smallholders	MicroEnsure	Rainfall index	500	Ongoing
Tanzania	2009	Smallholders	MicroEnsure	Rainfall index	400	Ongoing
Thailand	2007	Smallholders	BAAC	Rainfall index	400	Ongoing

Table 1. Selected individual-level index insurance schemes.
"Scale" represents authors' best estimates of the number of beneficiaries.
Sources: Hellmuth et al., 2009; Vargas-Hill and Torero, 2009; Burke, de Janvry and Quintero, 2010

Country	Year	Policy-holder	Insurer	Instrument	Scale	Notes
Caribbean	2007	Governments of 16 Caribbean countries	Caribbean Catastrophe Risk Insurance Facility	Insurance indexed to hurricanes and earthquakes	16 countries	Ongoing
Colombia	2005	Government of Colombia	World Bank Contingency Credit Line	Earthquake-contingent debt	Country-level	
Ethiopia	2005	World Food Program	AXA Re	Drought-indexed insurance	Coverage for 62,000 households	Premium paid by donors; not renewed
Malawi	2009	Government of Malawi	World Bank	Weather derivative on rainfall index	Country-level	Intend to transition to private insurer
Mexico	2003	Government of Mexico	Agroasemex (state reinsurance company)	Drought-indexed insurance	~800,000 beneficiaries	Ongoing
Mongolia	2009	Government of Mongolia	World Bank Contingency Credit Line under IBLIP program	Contingent debt, indexed to country-wide livestock losses	5000 herders	Ongoing

Table 2. Selected institutional-level insurance schemes

Impact evaluations of index insurance can focus on changes in ex-post shock coping or in ex-ante risk management. While few rigorous evaluations are available, results tend to show positive outcomes. Focusing on ex-post shock coping, Janzen and Carter (2013) show that access to IBLI, an index-based drought insurance for livestock in Northern Kenya, helps them reduce both asset smoothing and consumption smoothing, two key dimensions of self-insurance. Impact is selective according to wealth position. Poor households are less likely to have to destabilize their consumption in response to drought, while rich households are less likely to have to compromise their accumulated assets. Insured households are observed to be less dependent on food aid and other forms of assistance, indicating their better ability to cope with shocks.

Impact is also achieved on ex-ante investment behavior. Papers show that insurance encourages investment in higher risk activities with higher expected profits. We review some of them in what follows.

Mobarak and Rosenzweig (2013) use a randomized experiment where rainfall index insurance is offered to Indian cultivators. Results show that insurance helps cultivators reduce self-insurance and switch to riskier, higher-yield production techniques. More risky production in turn destabilizes the labor market and hurts agricultural workers. When the same insurance is offered to farm workers, they respond less to changes in labor demand associated to weather shocks, helping smooth wages across rainfall states. The policy implication is that weather insurance must be offered to both cultivators and farm workers to avoid the negative spillover effects of insurance for the first without insurance coverage for the second.

In another experiment, Mobarak and Rosenzweig (2012) show that existence of informal risk-sharing networks among members of a sub-caste increases demand for index insurance when informal risk sharing covers idiosyncratic losses, reducing basis risk. In this case as well, formal index insurance enables farmers to take on more risk in production.

Cai et al. (2012) find that insurance for sows significantly increases farmers' tendency to raise sows in southwestern China, where sow production is considered a risky production activity with potentially large returns.

Karlan et al. (2012) randomize access to both insurance and cash grants. They show that lack of access to insurance is the limiting factor to investment for maize farmers in Ghana, not lack of access to liquidity. Farmers who purchase rainfall index insurance increased agricultural investment by 13%. Importantly, demand for insurance remains strong even when a full market price is charged, equal to the fair price plus a 50% premium. At that price, some 50% of farmers still demand insurance, insuring 60% of their cultivated area. This is to this stage a rare case where insurance demand holds at market prices. They also find that experiencing payouts either oneself or through others is important for demand, indicating the importance of learning and trust.

Cai (2012) demonstrates that weather insurance induces Chinese tobacco farmers to increase the land devoted to this risky crop by 20%. This last finding implies reduced diversification among tobacco farmers, consistent with less self-insurance. The same paper also finds that insurance causes households to decrease savings by more than 30%, suggesting that households were building up extra savings in order to better smooth consumption in the case of a shock.

Finally, Vargas-Hill and Viceisza (2010) use experimental methods to show in a game setting that insurance induces farmers in rural Ethiopia to take greater, yet profitable risks, by increasing (theoretical) purchase of fertilizer.

At the institutional level, CADENA in Mexico provides insurance against drought for smallholder farmers (with less than 20 ha of rainfed land) through a state-level insurance that is fully free to beneficiaries. The unit of analysis is the municipality. Insurance payouts are triggered by cumulative rainfall falling below a threshold in three critical periods of corn cultivation, with rainfall observed at the municipal meteorological station. Fuchs and Wolff (2011) used the rollout of the program across 15 states between 2002 and 2008 to identify impact on corn yields, area cultivated in corn, and per capita income and expenditures. They find that insurance coverage induced ex-ante risk management responses with an 8% increase in corn yields where coverage is available, along with gains in income and expenditures. The latter suggest that behavioral responses extend to agents beyond the farm through spillover effects. Fuchs and Rodriguez-Chamussy (2011) analyzed the impact of insurance payouts on voter behavior in the 2006 presidential election. The unit of analysis is the electoral section, and the question is whether payments received by farmers in the electoral section in 2005 affected voting behavior toward the incumbent political party in the 2006 election. The identification strategy is a regression discontinuity design based on the threshold rainfall levels that trigger payments of the index-based insurance. They find that disaster relief buys votes. The incumbent party is estimated to

have garnered 8% more votes where indemnity payments had been made prior to the election, a gain attributed to voter switching political party rather than to increased electoral turnout.
The conclusion is thus that, where available and affordable, index-based insurance does work for the intended purposes: help achieve more effective shock coping and less costly risk management. The outcome can be more growth and less poverty.

3. The puzzle of low uptake

Uptake is a battle in progress, with successes and failures, but results have to this date been generally disappointing. The few cases where index insurance has been implemented were either free or heavily subsidized, or offering insurance along with other benefits such as subsidized credit and heavy technical assistance. In extensively studied cases in Malawi (Giné, 2009) and India (Cole et al., 2013), take up was only 20-30% with adopters hedging only a very small fraction of agricultural income. Take up among farmers not explicitly targeted in these programs was much lower. There are recent exceptions, with Karlan et al. (2012) reporting a 40-50% take up at fair price plus a 50% loading in Ghana, and insurance inducing an increase in investment in cultivation. In this case, experiencing insurance payouts either oneself or through social networks was an important determinant of demand. In general, however, low uptake is still the norm and it requires addressing the issue of the reasons why this is the case.

4. Reasons for low uptake

4.1. An insurance demand model

Many reasons have been put forward to explain the observed low uptake of weather index insurance (WII). In order to discuss these reasons, it is helpful to organize thinking around an analytical model of the willingness to pay (WTP) for WII by a farmer to be used to identify the various determinants of uptake. The model outlined below pertains to the case of an insurance offered within one crop year, assuming no effects on production decisions. In that sense, the estimated benefit and WTP can be considered as the minimum demand for weather insurance. Any changes in production decisions, induced by the provision of insurance, will provide an additional benefit that is not considered here.

Each year t consists in two periods, indexed j =1 and 2, with incomes y_{t1} and y_{t2}, respectively, which for the purpose of this discussion we take as exogenous and stochastic. In each period, the farmer chooses consumption c_{tj} so as to maximize:

$$W = E\left(\sum_{t=0}^{T} \delta^t \left[u(c_{t1}) + \delta^* u(c_{t2})\right] \Big| I_0\right)$$
$$A_{t2} = A_{t1} + y_{t1} - c_{t1}$$
$$A_{t+1,\,1} = A_{t2} + y_{t2} - c_{t2}$$

where A_{tj} is assets at the beginning of period tj, δ and δ^* are the annual and intra-annual discount rates, and I_0 is information available at time 0. We ignore changes in prices.

The solution to such a problem is theoretically well known (see, e.g., Deaton, 1992a; and Zeldes, 1989). It is, however, in general not analytically tractable. We thus approximate the optimal rule by a formulation commonly used in the literature of the general lifetime optimization problem under uncertainty as well as under liquidity constraints (for useful surveys see Deaton, 1992b; Browning and Lusardi, 1996; and Morduch, 1995):

$$c_{tj} = c_{tj}^{*} + \beta\left(R_{tj} - R_{tj}^{*}\right)$$

where $R_{tj} = A_{tj} + y_{tj}$ denotes the value of resources available to the household at the beginning of period *tj*, namely previous period assets plus current period income from these assets. As such it accounts for both covariate risks, such as price variations, as well as idiosyncratic risks. The starred value of consumption and resources, c^{*} and R^{*} represent the value of trend or permanent real consumption and resources, respectively, which are assumed not to depend on current period random variables, albeit it may include time varying components due to seasonal or lifetime effects.

The parameter β denotes the amount of smoothing that the household does in each period, and is a function of household characteristics. If $\beta = 0$, then there is perfect smoothing, and current consumption is independent of current income or of the value of current assets. If $\beta = 1$, there is no smoothing at all, and current consumption moves exactly as current resources. Notice that perfect smoothing may involve negative values of assets in some periods, namely debts. If this is impossible due to liquidity constraints, then consumption smoothing will not be perfect and the relevant value for β will be larger than zero. In addition the linear approximation may not be valid.

The utility function can then be written as:

$$W = E\left(\sum_{t=0}^{T} \delta^{t}\left[u\left(c_{t1}\right) + \delta^{*} E\left(u\left(c_{t2} \middle| I_{t1}\right)\right)\right] \middle| I_{0}\right)$$

Consider now the provision of an insurance contract to the farmer in the first period of the crop year, whose outcome depends on events of the second period. The contract considered is in the form of a promise to be paid automatically a certain amount per unit of area insured (the indemnity) if a given, undesirable weather event occurs. Denote the amount of the area that is insured as *q*, and the return to the insurance contract per unit of area as *r*. The undesirable weather event underlying the insurance contract is defined on the basis of an index of rainfall or other weather related variables (frost, flood), that can be observed objectively and without error in some well defined location, which is possibly different than the location where the farmer is. The return *r* then relates to the probability distribution function of the weather index. We can define the benefit (or willingness to pay) of this contract as the amount that must be subtracted from income of the first period in the crop year, so that the two-period utility with the contract is equal to the utility without it. Analytically we define the benefit in year *t* to be the solution *B* to the following implicit equation:

$$u\left(c\left(y_{t1} - B\right)\right) + \delta^{*} E\left(u\left(c\left(y_{t2} + rq\right)\right) \middle| I_{t1}\right) = u\left(c\left(y_{t1}\right)\right) + \delta^{*} E\left(u\left(c\left(y_{t2}\right)\right) \middle| I_{t1}\right)$$

Using a second order Taylor expansion, Sarris (2002) shows that the solution is written as:

$$B = \delta E\left(rq\right) + \frac{1}{2}\rho\beta\left[\left(\Delta R_{t1}\right)^{2} - \delta\left(E\left(rq\right)^{2} + 2E\left(rq\Delta R_{t2}\right)\right)\right] \qquad (1)$$

where $\Delta R_{tj} = R_{tj} - R_{tj}^{*}$. This function depends on the degree of consumption smoothing β, the degree of farmer risk aversion ρ, the current level of resources of the household R_{t1}, the expected value and variability of the returns of the insurance contract *r*, and the correlation between the return of the insurance contract with the period-two level of resources R_{t2}.

Uptake of insurance will then occur whenever these benefits are larger than the insurance premium, itself function of the cost of providing insurance (including assessment of damage, when needed) and of a loading factor *m*:

$$\begin{aligned} Uptake &= 1 \text{ if } B \geq premium = cost\,(1 + m) \\ &= 0 \text{ otherwise.} \end{aligned}$$

From this, we see that there are six categories of determinants of uptake of an index-based insurance:

1. Quality of the insurance product/basis risk
2. Availability of other insurance mechanisms/risk layering
3. Expected gains from insurance
4. Lack of knowledge and trust/level of contracting
5. Learning from stochastic experiences
6. Cost of index insurance, price, and subsidies

Among these, there are three determinants of uptake that are specific to index insurance relative to loss-based indemnity insurance:

Basis risk
Learning and understanding
Cost and price.

4.2. Quality of the insurance product: Correlation between insurance payout (*z*) and shock on resources (ΔR_{t2})

a. Weather risk may not be the largest risk the farmer perceives and he may need more comprehensive insurance

Farmers are generally interested in income and wealth losses and not particularly about hedging rainfall shortages. Hence what would be of value to them is a contract that has a negative correlation with their actual negative income shocks. This implies that a WII to be desirable has to correlate not only with the yield of one or more particular crop, but that these crops must be a significant share of the total income of the farmers. So, if a cash crop, for instance, accounts for only a few percentage points of total farm income, then even large negative shocks to the production of such crops will not affect income that much and farmers will not have any WTP for them. In terms of the model above, the last term inside the bracket of equation (1) denotes the (hopefully negative) correlation of the return of the insurance product and the unpredictable resource or income deviations from trend. If the absolute value of this correlation is small, then clearly the demand for this insurance product is small.

b. Basis risk

In the above formulation basis risk can be thought of as the lack of negative correlation between the returns to the insurance *z* and the deviation of current resources *R* from trend. A WII or another insurance product that presumably protects a farmer against a negative income shock should have a return that is negatively correlated with such deviations. It can be readily seen in equation (1), that a negative such correlation implies a positive demand for the insurance. However, if basis risk is large, then that negative correlation maybe small, and hence this may imply a low demand for the insurance product. Skees (2008) and Clarke (2011a) thus argue that basis risk is the main determinant of low demand, especially due to the fact that high basis risk can not only not protect but eventually seriously damage livelihoods.

c. Quality of contract design
The demand for WII depends crucially on how well designed the contract is. It is not easy to design a contract that captures well the different ranges in the rainfall distribution that are crucial for crop growth. This aspect of the WII is compounded by the fact that a proper contract may need to be complicated for accuracy, and hence more difficult to explain to farmers.

4.3. Ability to smooth consumption (β)

The farmer has other existing insurance mechanisms such as self-insurance, family, other social network, etc. In the model above this manifests itself in low magnitude of the consumption smoothing parameter β. It can be seen that a low value of β implies a low value of θ, and this in turn from (1) implies a low contribution to the WTP from the bracketed term. The same factor implies a small magnitude of the deviation of current resources from trend DR_2^r, which can also make the WTP low in (1).

4.4. Discount rate or credit constraint (δ)

a. Insurance not desirable if not related to credit or other investment mechanism
Standalone WII may not be desirable for any of the above (and below) reasons. The time inconsistency problem indicated above may be alleviated if the insurance is combined for instance with credit, that may make the cash flow constraint much less onerous. This suggests that WII combined with credit provision for the seasonal operations maybe much more reliable than standalone WII.

b. Lack of flexibility in terms of payment of premium or indemnity
It has been observed that credit is much more desirable for low income farmers when the terms of repayment are flexible in the sense that if there is an unexpected income loss to the farmer, then the payment schedule can be adjusted accordingly. The great expansion of microfinance, owes a lot to this aspect of microlending. Similarly most local moneylenders owe their success to such flexibility, usually acquired at the cost of a high interest rate. Insurance contracts normally require fixed payment and in advance of the farmer's income realization. If the insurance premium payments can be adjusted to the farmer's current circumstances than demand will be higher. Hellmuth et al. (2009) suggest that insurers could collect premiums when farmers are most able to pay, typically immediately after harvest when crops are being sold. Kilimo Salama in Kenya links the premium payment for a rainfall-indexed insurance to purchase of fertilizers, with a 50-50 cost sharing between the farmer and the seller of the input.

c. Time inconsistency (δ) combined with cash flow problems
Credit gives a farmer the possibility of having resources now, with a promise to pay later. In other words in cash flow terms credit increases cash flow now and reduces it later after cash income has been obtained. On the contrary, insurance implies a cash outflow now for an uncertain return later. If the farmers are cash flow constrained, as is the case in low income developing country agriculture, then trying to sell insurance to such poor farmers that requires them to put up significant cash now for an uncertain benefit later maybe met with significant resistance and lack of demand. This time inconsistency seems to be a make factor in lack of demand in many WII pilots.

4.5. Lack of knowledge/trust on distribution of payout and correlation with shocks

a. Lack of trust in the insurance provider

Trust in the insurance provider is a major issue in contracting insurance, especially in the developing country context where there is little legal recourse in reclaiming insurance payments. For index insurance, the expected payout is more difficult to know because the relationship between weather and loss is not precisely known. If there is asymmetric information where the provider is better informed on risk, farmers must rely on the insurance company in setting a fair price. Relations of trust with the insurance provider are thus very important for uptake. Cole et al. (2013) show that endorsement of the insurance product from a trusted third party increased uptake by 40% compared to farmers who heard of no endorsement. Cai et al. (2014) find that in China trust is established by experimenting payouts to oneself or witnessing payouts to members of your social network. Payouts were the main instrument in building trust. Payouts can in turn be increased by subsidies to boost demand (Cai et al., 2014) or by increasing the frequency of payouts by insuring small losses (Carter, 2009).

b. Ambiguity aversion

Ambiguity aversion as per Bryan's (2010) analysis is best understood by considering the Ellsberg paradox. Ellsberg (1961) argued that faced with two gambles, one with known odds and one with unknown odds, many people strictly prefer the gamble with known odds, even if they can choose which side of the gamble to take. Subsequent studies have confirmed this intuition and show that a large portion of the population prefers known odds. An agent that behaves in this way is called "ambiguity averse", and his behavior is inconsistent with Subjective Expected Utility theory. The behavior is, however, consistent with a model in which agents entertain a set of possible priors and choose using the prior that maximizes their chance of winning. If the set of priors is large when probabilities are unknown, and a singleton when probabilities are known, these agents will prefer known odds. Thus, an ambiguity averse agent "worries" that the odds depend on her choice in such a way that her choices are always wrong. Bryan showed evidence that suggested that over 50% of the population prefers to bet on known odds.

In the context of the model, above an ambiguity averse agent may not know the probability distribution of the insurance return r of the WII, and this is quite likely for a new product that has no known (to the agent) history of application. In such a setting the ambiguity averse agent will prefer to not take up the contract rather than purchase one that is not clear when and how it will compensate.

c. Technology and institutional setup are difficult to explain and understand

This is a well-known practical problem in introducing a relatively complex and state contingent insurance product in an environment where farmers have low education, as is the case in most developing countries. Index insurance is particularly difficult to understand because, with presence of basis risk, payments are not linked to the individual farmer's losses. Studies by Cole et al (2013) for India, Giné and Yang (2009) for Malawi, and Cai et al. (2014) for China all give evidence of the importance of household financial literacy in insurance take-up. Financial education can be provided through games that simulate potential gains from insurance with groups of farmers (Lybbert et al., 2009). Knowledge of insurance obtained through financial education can in turn diffuse in the community through social networks. Because financial education is costly, optimizing the role of social networks in circulating knowledge about insurance is important. For this, the choice of entry points for the delivery of financial education can make a difference on the subsequent spread of knowledge.

4.6. Learning from stochastic experiences

a. Recency bias: Demand depends on recent experiences

The perceptions of many farmers seem to be conditioned by recent experiences. The experience of recent uncovered income shocks may make farmers more aware of the lack of insurance coverage for such shocks. In terms of the model above, the first term in brackets in equation (1) reflect this recency bias, and contributes positively to the demand for WII. Recent experiences may be directly yours or indirectly others in your social network.

b. Role of shocks (positive effect on the need for insurance) and role of payouts (negative effect of no payouts)

Knowledge about insurance is being updated as experience accumulates. There can be also recency bias, seen in how demand respond to recent shocks, while there is no reason for updating on weather distribution. Cai et al. (2014b) show that there is erosion of demand for insurance with successive good years: payment of a premium without experiencing payouts decreases perceptions about the importance of being insured.

4.7. Cost and price

A recognized advantage of index-based insurance is lower implementation costs compared to traditional loss adjustment-based insurance as it avoids the administrative costs of loss assessment and moral hazard, as well as the actuarial cost of adverse selection. Price however remains an issue for uptake. In spite of lower costs, prices may internalize a “data rent” (see below) as risks are initially poorly informed with existing data, translating into high insurance company loadings. Several studies have shown that demand for index insurance is very price sensitive. By randomly varying price for a rainfall index insurance offered by BASIX ICICI Lombard in India, Cole et al. (2013) estimated a high price elasticity of demand in the range of -0.66 to -0.88. Demand is also affected by farmers’ liquidity position. Giné and Yang (2009) found that demand for rainfall-indexed insurance in Malawi is positively correlated with smallholder maize producers’ wealth position. In India, unanticipated random positive liquidity shocks in the Cole et al. (2013) study induced large increases in insurance purchase. This raises the issue of subsidies to insurance premiums that we discuss below.

5. Designing better index insurance contracts: Technological innovations and behavioral insights

Figure 2, taken from Clarke *et al.* (2012), illustrates the weak correlation that exists between farmers’ losses and actual payouts under rainfall index insurance schemes in India. Using data for the 1999-2007 period, the horizontal axis displays average district crop yields as a fraction of their long-term average, while the vertical axis displays payouts that would have occurred under the rainfall index insurance contracts that have been in use in India since 2006. Note that payouts when yields are almost zero (12% of the sum insured) are only modestly higher to payouts when yields are at their long-term average (8% of the sum insured). This modest correlation between losses and payouts suggests that these index insurance contracts operate more like lottery tickets (payoffs under which would appear as a horizontal line in the figure) than like insurance contracts. More charitably, the weak correlation evident in the figure makes it clear that these index insurance contracts offer at best partial and/or probabilistic insurance coverage.[2]

[2] The partial or probabilistic coverage found in index insurance also applies to conventional agricultural insurance in which individual loss verification and adjustment takes place after a loss occurs. A recent study of a conventional insurance program in Ecuador shows that the magnitude of these problems can be as severe for conventional as for index insurance.

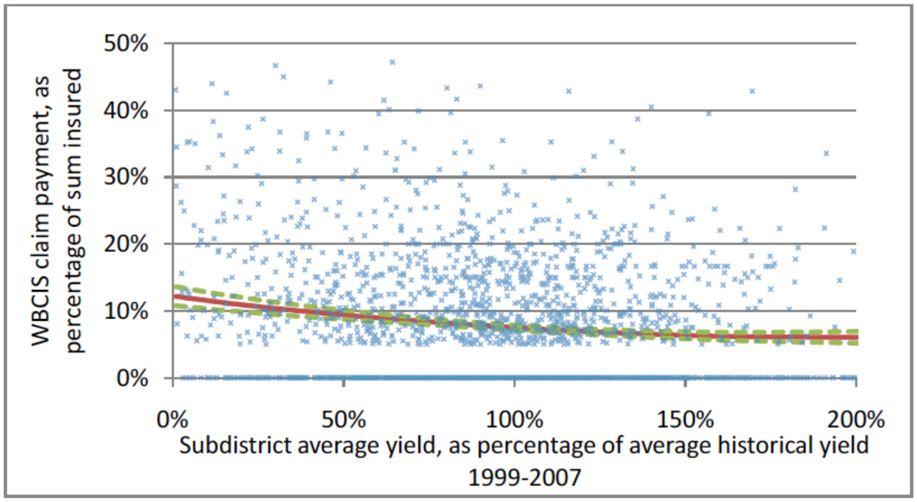

Figure 2. Weather Based Index Insurance Payments versus Yield Losses in India
Source: Clarke et al. (2012)

While a few authors have emphasized the importance of basis risk in index insurance (see Carter, 2009), the relative lack of attention to these issues (and to the measurement of basis risk) is perhaps an unfortunate side effect of the fact that many economists approach insurance from an explicitly or at least implicit expected utility perspective. As nearly every economics graduate student over the last 50 years has proven, an expected utility maximizing agent will purchase even partial or probabilistic insurance if the insurance is actuarially fair. From this perspective, incomplete insurance coverage might appear to be a modest or secondary issue. However, if insurance is actuarially unfair, if we expect insurance to crowd-in additional investment and risk-taking, or if individual behavior in the face of risk departs from the axioms of expected utility theory, then basis risk may become rather more important than the graduate school test questions would seem to imply.

After a brief review of basis risk and its sources, this section considers what we have learned from behavioral economics about behavior under risk and what it means for the importance of basis risk and more generally for the design of index insurance contracts. We then consider technological and institutional innovations that hold the promise of fundamentally reducing basis risk.

5.1 Insights from behavioral economics: Why basis risk and contract structure matter

Clarke (2011a) forcefully makes the point that even from a conventional expected utility perspective, index insurance contracts characterized by high basis risk may find low acceptance by highly risk averse agents. The basic insight is the simple but important one that, when a contract fails (premiums are paid, losses occur, but no indemnity payments are forthcoming), the individual is left worse off than if the insurance had not been purchased at all. Highly risk-averse individuals would be expected to be especially sensitive to this increase in tail-end risk that results from high basis risk insurance. In addition, when basis risk is high, index insurance will also fail in its basic development objective of crowding in additional investment in remunerative but risky technology, a point developed in detail by Carter *et al.* (2014).

This welcome emphasis on basis risk suggests a deeper consideration of the nature of index insurance. Figure 3, taken from Elabed and Carter (2014), illustrates how agricultural index insurance appears to the insured farm household as a compound lottery. In the first lottery, the household discovers its random crop yield (high or low in this simplified binary example). At the second stage, the household then faces a second lottery and discovers whether or not the insurance index triggers a payment. Significant basis risk means that there is a non-trivial probability that no payment is triggered, despite farm losses.

While a compound lottery structure like that in Figure 3 can be statistically reduced to a corresponding simple lottery over final outcomes (by multiplying probabilities as shown in the figure), an emerging body of behavioral economic research indicates that individuals are particularly averse to compound lotteries, effectively acting as if the final simple probabilities are unknown or ambiguous.

Drawing on the work on ambiguity aversion, Elabed and Carter (2014) measure ambiguity or compound risk aversion of a sample of cotton farmers in Mali. Roughly two-thirds of farmers are ambiguity averse. The implications of ambiguity aversion are two-fold. First, these farmers would in principle be willing to pay substantial amounts of money to reduce or completely eliminate basis risk (thereby eliminating the compound lottery or reducing its significance). Such willingness to pay could be thought of as a source of premium dollars needed to fund a more expensive to administer contract that offers reduced basis risk (e.g., the costs of a yield survey as the basis for an area yield as opposed to a rainfall-based index insurance contract).

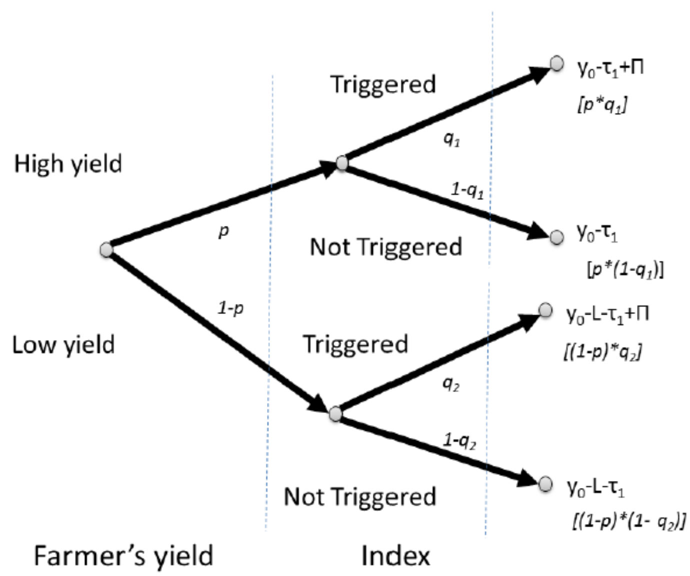

Figure 3. Index Insurance as a Compound Lottery

Second, compound risk or ambiguity aversion will substantially dampen demand for basis risk-laden index insurance contracts. Figure 4 from Elabed and Carter (2014) uses the distribution of preference characteristics (conventional risk and ambiguity aversion) from the sample of Malian cotton farmers to calculate how the predicted demand for index insurance would change with the severity of basis risk. The horizontal axis displays downside basis risk, measured as the probability that a farmer does NOT receive a payment conditional on having a loss. The dotted, green line shows what demand would be assuming risk, but no ambiguity aversion. The solid, red line displays demand given the measured distribution of ambiguity aversion. As can be seen, the gap between demand assuming that individuals maximize expected utility and demand taking account of ambiguity aversion increases as the level of basis risk increases. For basis risk in the range displayed in Figure 4, demand falls by almost half compared to what would be expected if we did not account for the level of ambiguity aversion in the population. From this perspective, it becomes even more important to reduce basis risk than is implied by the work of Clarke *et al.* (2012).

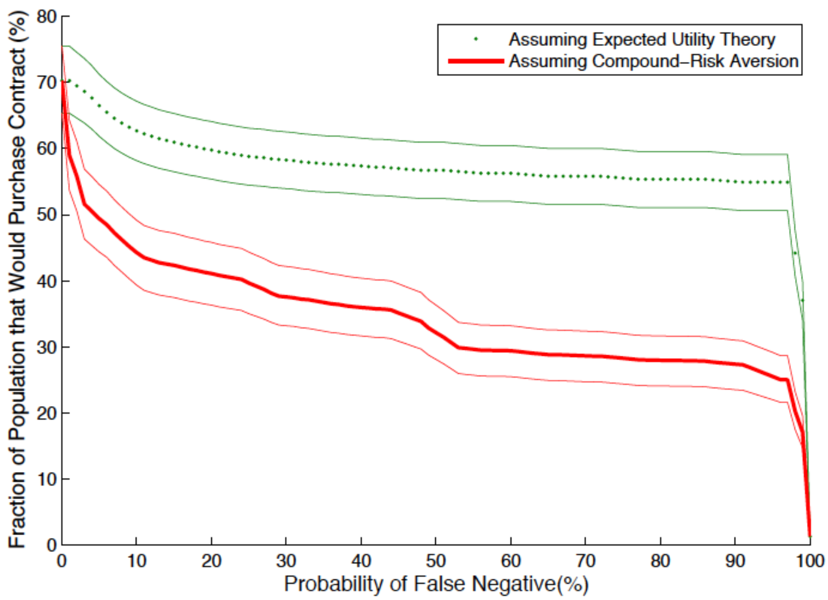

Figure 4. Impact of basis risk on index insurance demand

In addition to its insights on ambiguity aversion, behavioral economics has long found that people tend not to behave in conformity with the postulates of expected utility theory. Even ignoring the compound lottery aspect of index insurance, there is a large body of work that explores whether behavior in the face of risk is better described by expected utility theory or what has become to be known as cumulative prospect theory (Tversky and Kahneman, 1992). Cumulative prospect theory offers three basic insights that are relevant for the demand for, and design of, index insurance contracts:

1. *Probability Weighting* asserts that individuals may systematically misunderstand probabilities, overweighting low and high probability events relative to events with intermediate probabilities.
2. *Loss Aversion* captures the idea that individuals may think differently about gains and losses, perhaps being especially sensitive to marginal losses relative to marginal gains.
3. *Risk Seeking in Losses* captures the idea that beyond some level of losses, individuals may be less sensitive to large relative to small losses.

The implications of cumulative prospect theory for insurance design are potentially rich. If individuals overweight small probabilities, then they would be more likely to buy insurance for extreme events. If individuals are more sensitive to losses than gains, then they may be more likely to buy insurance that protects capital invested in a project than insures income gains. Finally, if individuals are risk seeking in losses, then they may be willing to insure only a relatively small amount, perhaps enough to protect the capital invested in a project and not beyond.

In a relatively early index insurance pilot (cotton insurance in Peru in 2008), demand was tepid until contracts were reformulated in 2009 to provide a simple lump sum payment[3] designed to protect the capital that a farmer had invested in the production process (see Petraud, 2014). Exploring these ideas further, following Tanaka *et al.* (2010), Petraud (2014) implemented a series of field experiments to measure individuals' probability weighting, loss aversion, and extent of risk seeking over gains. Individuals were then played an incentivized insurance game in which they revealed their preference for lump sum contracts versus a "linear" contract offering more continuous payouts that would be preferred from the perspective of conventional expected utility theory.

Figure 5 illustrates theoretical predictions for the demand for the conventional linear contract versus the lump sum contract, assuming that individuals exhibit a high degree of loss aversion. The figure shows that, conditional of risk aversion over gains, the demand for the lump sum contract is predicted to be especially strong for those individuals who systematically overweight small probabilities. In his work, Petraud (2014) goes on to see whether expected utility or cumulative prospect theory better explains demand for insurance as revealed in the incentivized insurance game. Somewhat surprisingly, neither the predictions of cumulative prospect theory nor expected utility theory proved to be especially powerful in terms of explaining choices in the game.

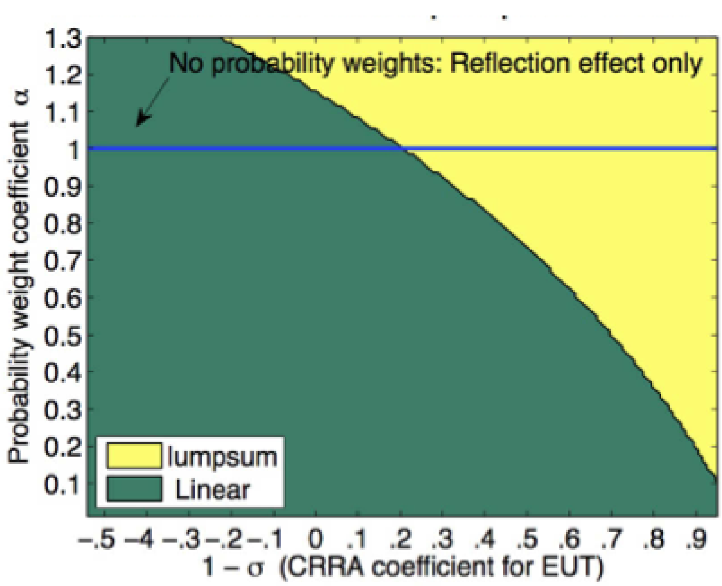

Figure 5. Demand for lump sum versus standard linear contract

While cumulative prospect theory attempts to account for a number of behavioral regularities that stand at odds with conventional expected utility theory, alternative explanations have been put forward by other analysts. Of particular interest here is the work of Andreoni and Sprenger (2010). These authors argue that a simpler explanation for the behavioral paradoxes that contradict expected utility theory can be found by simply assuming that individuals more highly value certain outcomes versus uncertain outcomes (i.e., a bird in the hand is worth two in the bush). To pick a particularly simple valuation or utility function, if an individual values a certain

[3] If the farmer invests an amount K in the production process, then the lump sum contract pays K when yields fall below a certain trigger level, but does not pay more than K as yields fall even lower and losses (in terms of foregone income) increase yet further.

outcome x as $u(x)=x^c$, then that same individual might undervalue a lottery with uncertain outcomes y_0 and y_1 using the function $v(y)=y^{c-a}$ ($a>0$), such that the expected utility associated with the risky lottery is given by:

$$Prob(y = y_0)v(y_0) + Prob(y = y_1)v(y_1).$$

Note that with $a>0$, this specification will apply a surprising undervaluation of uncertain versus certain alternatives. Andreoni and Sprenger show that his simple, one parameter specification (a) can account for many of the behavioral anomalies that motivate cumulative prospect theory. In lab experiments, they further show that when confronted only with uncertain alternatives (meaning all options would be evaluated with the function v), individual behavior corresponds closely to the predictions of expected utility theory. However, as soon as a certain alternative is added to the mix, behavior departs from the predictions of expected utility theory, exhibiting a strong preference for certainty.

Thinking about insurance contacts as conventionally designed, there is one element that is certain (the premium) and another that is uncertain (the indemnity payout). If different functions are used to value certain versus uncertain payouts as Andreoni and Sprenger's work suggests, then the certainty of the premium payment (a bad thing from the individual's perspective) should surprisingly suppress demand for insurance.

Building on these ideas, Serfilippi et al. (work in progress at UC Davis) played a series of games with cotton farmers in Burkina Faso to determine the extent to which individuals exhibit a preference for certainty. In addition, experimental participants were then randomly offered a contract which either offered a certain premium and an uncertain indemnity payment or an actuarially equivalent contract that offered a (lower) uncertain indemnity payment and an uncertain premium payment (i.e., farmers were told that the premium was forgiven in bad years).

The results of this experiment are striking. First, across the whole sample of farmers, willingness to pay for insurance was 10% higher when the uncertain premium framing was used (significant at the 10% level). However, breaking the sample up into those individuals that did and did not exhibit a preference for certainty, the Serfilippi et al. work reveals no significant difference in willingness to pay for those agents who exhibit no preference for certainty, but a 25% higher willingness to pay (significant at the 1% level) for those agents who revealed themselves to have a positive preference for certainty ($a>0$). Given that just over one-third of the population revealed themselves to have a preference for certainty, these results suggest that demand for index insurance could be boosted by simply reframing the standard contract. Importantly, the uncertain premium contract structure has no negative impact on the demand for standard expected utility agents.[4]

In summary, research results inspired by insights from behavioral economics suggest, first and foremost, that basis risk may be even more important than we would hypothesize from the perspective of standard expected utility theory. In addition, behavioral economics insights suggest several contract options (insuring capital and forgiving premium payments in bad years) that might be expected to boost insurance demand (and ultimately insurance impacts) beyond what would be expected from conventional expected utility perspectives.

[4] The empirical results show that demand increases for all agents with the uncertain premium framing, but the results are not significantly higher for standard expected utility maximizing agents.

5.2 Insurance indices to reduce basis risk and enhance uptake and impact

The ideas summarized in section 5.1 suggest that there could be potentially high returns to contracts that reduce basis risk. Solutions to the basis risk problem can be broadly grouped into three categories:

- *Technological solutions*—indices that are intrinsically better predictors of farmer losses either because the index (e.g., area yield) is an intrinsically better predictor of farmer losses (e.g., area yield versus rainfall-based indices), or because the scale or resolution of the index is more fine-grained and more closely related to farmer losses (e.g., satellite-based yield predictions at a resolution of 5 hectares) versus indices based on a terrestrial weather station where a single measure must predict the losses of all farmers within a 25 km radius of the weather station (approximately 2,000 hectares).
- *Contractual solutions*—complement the primary index-based contract with a secondary contract that can be index-based over a broader area or damage assessment-based.
- *Institutional solutions*—contracts that rely on a secondary index, audit rule, or within group redistribution.

In the end, these approaches are not independent, and the best solutions are likely to be found in contracts that use technologically better indices in conjunction with institutional rules that rely on information from multiple scales.

i. *Technological Solutions*

To fully appreciate the prospects for reducing basis risk, we need to first develop some notation for its different elements.

We first define an index insurance zone z as the geographic space that is covered by a single insurance index. For illustrative purposes, assume that there are H farm households in this zone (say 2,000 households) and we will denote a single representative household with the subscript h. Let yhzt denote the agricultural yield of household h in zone z in year t, and let $\bar{y}_{zt}$ denote the average yields of all households in the zone in year t. Similarly, let m_{hz} denote the long-term average yields of household h, and let m_z denote long-term average yields for farm households located in district z. Using these terms, we can decompose fluctuations in household yields in year t as:

$$[y_{hzt} - m_{hz}] = b[\bar{y}_{zt} - m_z] + [e_{hzt}],$$

where the parameter b indicates how closely yield fluctuations for household *h* track the average fluctuations for its neighbors. Note that if $b = 0$, then the household's yields do not track average neighbor yields at all. In contrast, if $b = 1$, then *h*'s yields closely follow those of neighbors in the zone. By definition, the average value of b must equal 1. To keep matters simple, we will focus on this typical household and set $b = 1$ in the discussion that follows.

Finally, the term e_{hzt} measures the idiosyncratic factors that further drive *h*'s yields above or below its long-term average. This idiosyncratic factor reflects things like localized animal or bird damage to crops suffered by household *h*, but not suffered by most households in the zone. Note also that the larger the area, the larger that idiosyncratic variance becomes relative to total variance.

To simplify the notation, define $y^*_{hzt} = y_{hzt} - m_{hz}$ and $\bar{y}^*_{zt} = y_{zt} - m_z$. Using this notation and the assumption that $b = 1$, the yield decomposition above can be written as:

$$y^*_{hzt} = \bar{y}^*_{zt} + e_{hzt}.$$

This expression captures the two sources of yield variation faced by households, the common or correlated sources of variation across households in the zone ($\bar{y}^*_{zt}$) and the idiosyncratic sources of variation (e_{hzt}). Complete insurance for the household would cover both of these sources of variation. However, as a myriad of experiences shows, trying to insure all sources of variation in agricultural outcomes for small farmers is beset by a host of problems rooted in the costs of obtaining information on small farm outcomes that renders such insurance infeasible. Index insurance is an explicitly second best attempt at creating an insurance that is both feasible and provides insurance value to the smallholder.

As a first step toward understanding the quality and design of index insurance, we need to further take apart average outcomes, $\bar{y}_{zt}$, in the insurance zone. Let S_{zt} denote the insurance index signal that is correlated with yields in the zone and can statistically explain some fraction of average outcomes in the insurance zone. Examples of S_{zt} include rainfall, remotely sensed measures of vegetative cover, or direct measures of average zone yields. We can then write deviations in average zone yields as:

$$\bar{y}^*_{zt} = f(S_{zt}) + u_{zt},$$

where f is a yield loss predictor function that maps the index signal into average zone outcomes and u_{zt} is the prediction or design error. If the signal predicts average outcomes well, then the design error will tend to be small. If the signal is a poor predictor, then this design error becomes large.

Assembling pieces, we can write yield fluctuations as:

$$y^*_{hzt} = f(S_{zt}) + [u_{zt} + e_{hzt}],$$

where the terms in the square brackets indicate, respectively, design risk and idiosyncratic risk.

Technological solutions to the basis risk problem can operate by either reducing the prediction error for a given insurance zone scale (reducing the variance of the design error u_{zt}), and or, by reducing the scale of the insurance zone and thereby reducing the variance of e_{izt}.

While terrestrial weather stations are sparse (implying a wide scale for the insurance zone) and satellite-based rainfall predictions are imperfect, there are substantial opportunities in exploiting new, remote sensing technologies to simultaneously reduce both the scale and the prediction error.

While the jury is still out on this, satellite measures that have proven to be reliable predictors of biomass growth (e.g., evapotranspiration measures) appear to be the most promising. The intrinsic resolution of the current generation of satellite sensors is as small as 3m x 3m. Publically available data allow calculation of evapotranspiration measures at a scale of 250m x 250m, a resolution well beyond that of terrestrial weather stations.

Drone aircrafts are another possible inexpensive source of high-resolution information that can be used to predict crop yields.

Preliminary results from WFP/IFAD for Senegal suggest that biomass-based measures perform better. New I4 work (about to be finalized) finds something similar in Tanzania. However, given instability of the relationship between biomass growth and grain yields, there are probably limits to the extent to which technological improvements per se can reduce basis risk.

ii. *Contractual solutions*

Given the likely limitations of any insurance index, no matter how technologically sophisticated, it makes sense to consider secondary, backup, or audit indices. The basic idea is that if insured farmers claim that the primary index failed, then the secondary or back-up audit index is implemented. This secondary index can be more expensive to implement (e.g., a crop cut), but as long as the primary index does not fail too frequently, then the cost implications can be manageable.

An IFPRI/I4 project in Ethiopia implemented this idea. While short-lived, the experience was promising. The idea is now being picked up to insure crops with large basis risk (e.g., mountain grown coffee in Colombia). The preliminary idea is promising, but practice and implementation have yet to be seen.

A variation on this theme has been utilized for West African cotton producers. As described in Elabed et al. (2013), the primary index is set at a level that is too low from a moral hazard perspective (village yields). However, low yields at the village level only release payments subject to a secondary audit. Specifically, payments are only made if yields at a broader geographical scale (surrounding villages) are consistent with low yields in the initial village being the result of natural causes as opposed to morally hazardous behavior. To date, this contract has been successful. Ex ante analysis reveals that it radically reduces basis risk. Initial uptake rates have been nearly 30% and a major expansion to an area of approximately 30,000 hectares is currently underway in Burkina Faso.

iii. Institutional solutions

A third and final approach to basis risk is to use local institutions to redistribute payments from farmers with less severe to those with more severe losses. The abstract logic of this institutional mechanism has been explored in a series of insurance games by de Janvry, McIntosh, and Sadoulet (2013). Two strong results emerge. First, in principle, this kind of secondary sharing can make insurance more valuable if there is an idiosyncratic component to weather shocks. However, at the same time, this kind of local redistribution puts tremendous pressure on local institutions (e.g., cooperatives). The Guatemala experiment reveals a limited willingness to pay for insurance under this kind of arrangement, presumably because individuals distrust the ability of local institutions to honestly implement the required redistribution. The institution would need put into place an enforceable commitment device that insures that intra-institution redistribution rules will be respected.

An informal version of this mechanism is found in the hilly areas of Nepal, where idiosyncratic risk is high. The public sector as well as farmers themselves both contribute to a local "assurance fund." A local committee decides which farmers are to be indemnified. Rules seem to allow alternative (end of season) use of funds, creating an incentive for the local committee to only reward true losses with an indemnity. This contrasts strongly with the FONKOZE experience in Haiti where a similar idea went bankrupt when the local committee had no incentive to deny any claims.

6. The Public Role in Private Index Insurance Markets: Public-Private Partnerships for insurance take-up

The previous section identified key dimensions of contract quality that will be important to sustained demand and to assuring that insurance has its desired behavioral effects on farm investments and income. That section also identified promising technological and institutional innovations that might deliver contract quality. While these quality 'recipes' are thus becoming clearer, this section argues that it is far from obvious that the private market will deliver quality contracts. If this argument is correct, realizing the development potential of agricultural index insurance may require a unique public-private partnership, with the public sector playing an important regulatory role in certifying contract quality and also in providing well-designed subsidies that will cost-effectively help the market reach scale and sustainability.

6.1. Index Insurance as a "Credence Good"

Agricultural index insurance is an intangible commodity whose quality (say the basis risk aspect) cannot be directly ascertained by the consumer. Making matters worse, learning over time about insurance faces two barriers. First, it is a stochastic technology whose effectiveness can only be directly observed in those few years in which the individual experiences a loss. Second, unlike insurance against idiosyncratic risks (e.g., health or automobile insurance), learning from the experience of others is also difficult. Because index insurance covers common or correlated risk, any year which in which the individual cannot learn from her own losses will be a year in which the individual also cannot learn from the experience of their neighbors.

These observations prompt Clarke and Wren-Lewis (2013) to characterize index insurance as a "credence good", meaning a commodity whose quality cannot be ascertained prior to purchase, and whose quality can at best be only partially inferred after purchase. In this information environment, these authors then develop a simple model to explore the incentives for an insurance company to invest in creating a high quality contract, which they assume is subject to fixed costs. Several key observations emerge from their analysis:

1. It may be more profitable for the insurance company to forego investing in a high quality design and instead offer low quality insurance knowing that it can probabilistically escape detection for some time.
2. Because consumers know that they cannot ascertain quality, insurance demand will be a function of perceived trust in the contract.
3. In a low trust environment, even if the public sector licenses only high quality contracts, demand may still be minimal and the insurance firm will refuse to supply any insurance contract as it will not be able to recoup the costs of investing in quality.
4. Putting these things together, public subsidy to help build the market (or at least recoup the cost of designing high quality contracts) may be necessary.

In this perspective, there are two roles for the public sector: quality assurance and subsidy or cost-sharing. Building off of current practice, the next section considers some ideas on how insurance subsidies might be cost-effectively designed for the largest impact.

6.2. Risk Layers and Uncertainty Premiums: Optimal public insurance subsidies

The observation that public subsidies may play a key role in agricultural index insurance markets raises the question of how best to design those subsidies. The typical response has been to offer an across the board subsidy. If the market premium for an index contract is $50 per-hectare for a given contractual structure, then the subsidy reduces the price to the farmer by some percentage (say 20%) so that the net price to the consumer falls to $40, with the government remitting $10 for every hectare of insurance sold.[5] This price decrease is expected to increase demand and the size of the insurance market. This approach to subsidy of course still depends on individual insurance demand, and its effectiveness at building market size depends on the private elasticity of demand given farmers' trust in the contract. As mentioned above, given the fixed costs of design and information systems, market size is important to achieve.

While this across-the-board subsidy approach has the advantage of simplicity, the remainder of this section will explore two inter-related ideas. The first is that subsidy funds might be better spent paying 100% of the cost of insurance for the "catastrophic risk layer," rather than paying a 20% subsidy of the cost for all risk layers. This 100% risk layer subsidy will provide all farmers a basic insurance coverage, building a broad market. Individuals can then privately top up this basic insurance by purchasing insurance coverage for other risk layers, perhaps doing so as trust and understanding in the insurance improves over time.

The second idea is that the cost of public subsidy (and of the insurance itself) will be reduced if the public sector reinsures directly at least a portion of the risk. Both of these ideas require further explanation.

Risk layers can be most easily explained with an example.[6] The solid line in Figure 6 displays the risks faced by small-scale rice farmers in the coastal Ecuadorian province of Palenque. National yield survey data were used to estimate the risk distribution faced by these farmers, and random draws from the estimated distribution were used to generate the figure, which then accurately represents the kind of risks a farmer might face over the next 20 years.

[5] This approach is typically use by both national governments as well as by international subsidy mechanisms such as the Global Index Insurance Facility program implemented by the IFC.
[6] This discussion draws on Carter et al. (2011).

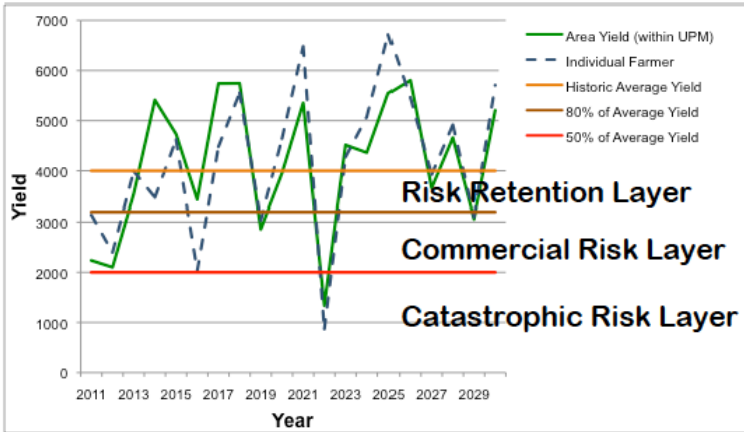

Figure 6. Risk Layers

As can be seen, average yields in this area are just over 4 metric tons per-hectare. When yields are at this level or above, farmers are happily able to preserve their working capital, pay any debts and make money. The first risk layer is defined by yields that fall between 3.2 and 4 tons (80% to 100% of the long-term average). While farmers make little if any money in these years, most can at least maintain their commercial viability for the next season. We refer to this first risk layer as the locally manageable *Risk Retention Layer*.

The second risk layer—the *Commercial Risk Layer*—occurs when yields are between 2 and 3.2 tons (50% to 80% of the long-term average). In Ecuador, we expect yield to dip to these levels once every five years or so. At these levels, local risk coping strategies become overwhelmed and farmers struggle to repay debts and maintain sufficient working capital to continue high yielding production in future years. Using insurance contracts to transfer this commercial risk layer out of the community can be highly advantageous, as we discuss below.

The third and final risk layer is the *Catastrophic Risk Layer*, when yields fall to less than half of their normal levels. For Ecuadorian rice farmers, yields are expected to collapse to these levels once every 10 or 15 years. In these catastrophic circumstances, farmers and their communities need external resources if they are to avoid long-term and irreversible consequences to their farming businesses and to the well-being of their children and other family members.

Using the concrete case of the coastal Ecuadorian rice farming, Figure 7 illustrates how catastrophic and commercial risks can be combined and covered with an area yield index insurance contract. The solid curve in the Figure is the estimated probability function used to simulate the yield outcomes in Figure 7. While a variety of insurance payoff structures are possible, we illustrate the case when farmers receive a single fixed payment of $200 per-hectare when yields fall between 50% and 80% of their long-term average (rectangle “B” in the figure). We assume that a payment of this amount would roughly allow farmers to recover their working capital (or creditworthiness) and continue production next year.

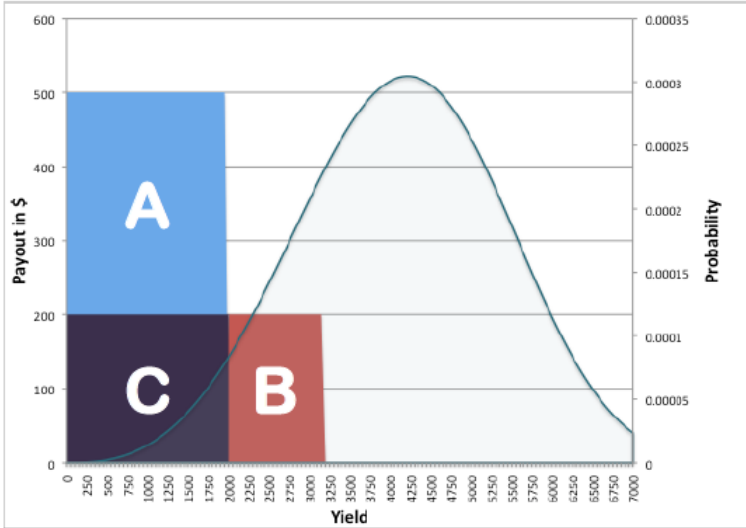

Figure 7. Index Insurance by Risk Layer

When yields fall further—to 50% of their long-term average or less—then this hypothetical contract would issue a total payment of $500 per-hectare insured: $200 to cover the business risk (Box 'C' in the figure) and the additional $300 to cover family and consumption liabilities (Box "A" in Figure 7).

How much would this insurance cost? In insurance analysis, it is typical to begin with the "actuarially fair price" or pure premium. This price or premium is equal to the value of expected payouts. The full market price of an insurance contract is some mark-up over the pure or actuarially fair premium. In US crop insurance, the mark-up is about 20% for index insurance contracts, with this extra charge used to cover administration and other costs of the insurance company.

Applying these standard principals to this Ecuadorian example, the pure premium for commercial coverage (Box "B") would be $12/hectare. The market price (with a 20% markup) would be $15/hectare. The pure premium for the full catastrophic layer (Boxes 'A' and 'C') would be $20/hectare, with a market price of about $24/hectare. Of this, the fair (marked-up) premium associated with box 'A' would be $12 (~$15) and that associated with Box 'C' would be $8 (~$9). The integrated contract offering both commercial and catastrophic protection with have pure (market) premium of $32 ($39) per-hectare.

How might public subsidy work in this context? The standard approach would provide an across the board subsidy of, say, 20%. The price to the farmer would fall from $39 to about $31, with $8 in subsidy paid by the government directly to the insurance company for each policy sold.

Alternatively, the government could subsidize fully part or all of the insurance costs for the catastrophic layer. If the public sector could pay the full price for the catastrophic risk layer (Boxes A and C at a price of $24/hectare) and the farmer could pay for the commercial risk layer (Box B at $15). Alternatively, the farmer could pay for the full cost of the first $200 in coverage designed to cover commercial risk (Boxes B and C in Figure 6) while the public sector could pay for the additional $300 indemnity that is paid when yields are catastrophically low. In this case, the farmer's share of the market premium would be $24/hectare and the public's social protection share would be $15. Under this scheme, the government could provision all farmers with $300 per-hectare coverage for catastrophic risk, while farmers could decide whether or not to purchase an optional commercial risk rider. In contrast to the across the board subsidy, this risk layer approach would guarantee a minimum market volume to the insurance provider. This approach to subsidy might be the smarter approach if the implied market volume was adequate to cover costs of innovation or a high quality insurance contract.

In addition to this risk layering approach, the public sector may in fact be able to save further public money by reinsuring the risk associated with the catastrophic layer. For reasons detailed in Carter (2013), the private reinsurance sector seems to be especially averse to the kind of risk and parameter uncertainty that emerges in what can be called "data sparse" environments. A data sparse environment is one typically found in low income rural environments in which the data available to design and price an index insurance contract are less than might otherwise be desirable. As a consequence, the probabilities used to price the hypothetical insurance contract illustrated in Figure 6 are known imprecisely. While standard statistical methods can give us an unbiased estimate of the probability that, say, a catastrophic loss occurs (4% in the example above), that estimate may be imprecise, perhaps a 95% probability that the true number is contained in the 1% to 7% interval. This parameter uncertainty tends to be reflected in high reinsurance premium, suggesting that an uncertainty neutral public re-insurance agency could reinsure the catastrophic risk layer at a price beneath that from the private sector. In this case, the price to the public sector of provisioning catastrophic insurance (for either Box A, C, or both) could be substantially less than the numbers above have indicated.

6.3 Towards a Public-Private Partnership for Agricultural Index Insurance

In summary, the unique characteristics of agricultural index insurance open the door for two inter-related tasks for government. The first is to provide a certification standard for contract quality, most importantly via an accepted measure of basis risk. The second is a "smart" subsidy scheme designed to get the sector off the ground and create a sustainable market that both provides an element of social protection as well as incentives investment in agricultural opportunity.

The bottom line is thus that there is a role for regulation. A first step might be to introduce a set of standards and require that new index insurance contracts meet some minimal basis risk norm, or at least require full disclosure of these measures. The new Global Action Network on Index Insurance in collaboration with the World Bank is currently working on such standards.

The second industrial organization problem comes from a mix of limited competition in the insurance and reinsurance markets and regulatory requirements that lead to penalty pricing when probability estimates for risk have high variance because of what Carter (2013) calls the "sparse data problem". As outlined in that paper, there would be appear to be a role for a novel public-private partnership in terms of reinsuring different layers of risk.

7. Policy implications to scaling-up

Index-based weather insurance thus has unusual promise as an institutional innovation, but faces the difficulty of low uptake. Successful uptakes have been few and generally confined to heavily subsidized local experiments, raising the issue of potential approaches to scaling up. We analyzed the determinants of low uptake, and explored ways of increasing uptake in a sustainable fashion. As a matter of conclusion, this survey paper leads us to advance five propositions toward successful scaling-up, with policy implications for governments and international development agencies.

1. **Reduce basis risk**: On the supply side, adoption of an index-based insurance hinges principally on ability to improve the quality of the product by reducing basis risk. We have seen that new advances in behavioral economics show that basis risk is even more important in the decision to demand index insurance than predicted by conventional expected utility theory. This is due to strong ambiguity aversion and a corresponding revealed preference for certainty in indemnity payments. We have seen that there are important advances with promise in reducing basis risk. They include multiple technological, contractual, and institutional innovations.
2. **Use risk layering**: Addressing risk reduction, shock coping, and risk management should go beyond index insurance and take a portfolio approach combining different instruments on a demand-driven basis. This will allow customization of the various instruments effective for this purpose, including insurance, savings, credit, technology, and infrastructure, where insurance serves as a complement to other instruments eventually also indexed on observable indicators. This requires risk layering where particular financial products and investments are used to cover particular sources of risk. Insurance will likely be used for larger covariate shocks (catastrophic and commercial risk layers), while credit is used for intermediate and less covariate shocks, and savings and technology for the more frequent and smaller shocks (risk retention layer). In that perspective, the delivery of index insurance products should be coordinated with the provision of other financial services and resilience-building investments.
3. **Give a role to the state in regulating and subsidizing**: Private sector providers need large markets to cover fixed costs. Data need to be accumulated over long periods of time over small areas for re-insurance to be competitively accessible. Learning needs to be achieved by users, principally by witnessing payouts to oneself or to trusted others, hence a role for social networks and for the circulation of information on payouts. This calls for state intervention. This starts with a regulatory role for the state in certifying standards with respect to maximum basis risk. Subsidies are also needed and can be delivered in the context of Public-Private Partnerships in a phase of demand creation. Subsidies for learning and scale can be for a few years, but likely more than one due to the credence nature of index insurance, with the need to learn about the distribution of covariate events. If loadings for reinsurance include a cost for data uncertainty, public subsidies to re-insurance can be provided in the transition to data accumulation. If insurance reduces the cost of social protection as a right, permanent subsidies are also justified, especially for catastrophic risks. The policy implication is thus for a careful design of "smart" subsidies in support of index insurance, with short-term subsidies to cover risk in the absence of re-insurance, learning, and economies of scale in a big push approach. And with long-term subsidies to insurance premiums in the face of social externalities, particularly for catastrophic risks.
4. **Use institutional-level and twin-track insurance**: While individual-level insurance has met with low uptake, there are good reasons why institutions may want to index-insure their portfolios at risk. This includes cooperatives with shared fixed costs, Fondos de Aseguramiento in Mexico, banks with outstanding loans, development agencies with a commitment to deliver expeditiously social protection at a time of crisis (WFP, Oxfam), and state governments with a legal obligation to provide relief to farmers (such as CADENA in Mexico). Index insurance payouts can be distributed internally to the institution to compensate for locally observable idiosyncratic risks, thus reducing basis risk and improving the quality of the index insurance product (Dercon et al., 2014). Policy questions should be directed at the way these institutions manage basis risk,

distribute premium payments to their membership (for instance reducing interest rates on insured loans), and add a layer of verifiable loss-based transfers to index insurance (thus following a twin-track approach of local-traditional insurance combined with regional/institutional-index insurance).

5. **Promote research on behavior toward risk and experiment with options**: Uptake depends on behavior toward risk, and products need to be designed in relation to behavior. While important advances have been made in applying theoretical concepts derived from behavioral economics, there remain particular aspects of the demand for insurance that need to be better understood, such as low willingness to pay at close to zero prices, fatalism, unrealistic trust in others, recency bias in assessing risk, time inconsistency, ambiguity aversion, compound risk aversion, and prospect theory. The policy implication is that customized financial products to handle risk must be correspondingly developed, requiring experimentation and impact analysis.

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