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Index Insurance for Developing Country Agriculture: A Reassessment

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Abstract

With uninsured risk representing a major hurdle to investment, productivity growth, and poverty reduction in developing country smallholder agriculture, index-based agricultural insurance has offered the promise of overcoming the hurdles of traditional indemnity-based insurance for this context. In spite of extensive experimentation, take-up has been disappointingly low without large and sustained subsidies. We show that existing constraints on take-up can partially be overcome using revised contract designs, advanced technology for better measurement, improved marketing, and better policy support. However, because index insurance is likely to remain expensive in that context, we suggest that improved index insurance be combined with stress tolerant seed varieties and new risk-oriented savings and credit products that build on the complementarities between what can be offered by index insurance and these other instruments to cope with shocks and manage risk.

1. INTRODUCTION

Uninsured weather risks remain a major hurdle to both investment in developing country agriculture as well as to coping with shocks while avoiding decapitalization and rising poverty (Dercon & Christiaensen 2011, Rosenzweig & Binswanger 1993). Risk affects not only smallholder farmers, who are the main source of food supply in most developing countries and who account for some two-thirds of the poor, but it also affects agents in the whole local economy who depend on the fortunes of agriculture through intersectoral linkages and final demand effects. Inadequacies of the financial systems in these countries induce most households to self-insure against such risks. For these populations, self-insurance is both quite costly and ineffective for large weather shocks. Traditional forms of mutual insurance that are pervasive in village economies also have limited effectiveness, as they are exposed to the risk of default and do not help protect against covariate shocks (Ligon et al. 2002). Individual indemnity-based insurance products, where actual damages are objectively assessed by a certified loss adjuster, are well known to be prohibitively costly for millions of dispersed smallholder farmers, and as a consequence, they are generally not available for take-up or not used (Hazell 1992). Looking for ways of addressing this significant constraint to development has led to a widespread search for institutional and technological innovations that could help reduce exposure to risk and protect farmers from the remaining risks.

Although indemnity-based insurance products are largely dysfunctional for developing country smallholder agriculture due to the pervasive problems of adverse selection, moral hazard, and long delays in implementation, index-based insurance has appeared as a highly promising alternative that could potentially address these difficulties. By construction, index insurance is a second-best form of insurance that relies on an index that is correlated with individual farmer losses, but not identical to those losses. Despite this limitation, the theoretical appeal of index insurance has been enormous. This appeal has led to worldwide interest in the potential of this innovation to address the unresolved risk problem in smallholder agriculture. Implementation has, however, been generally disappointing, with many schemes ending up in failure or requiring heavy subsidies to induce and sustain adoption. Overall, take-up at market prices has been extremely low (Cole et al. 2013, Giné & Yang 2009). Nonetheless, this difficulty has induced the search for better designs and better implementation schemes.

In this article, we review constraints on the take-up of agricultural index insurance and then discuss innovations in its design and implementation. Our analysis complements other recent reviews, such as those by Miranda & Farrin (2012) and Jensen & Barrett (2016), in that we not only critically assess recent efforts (for a review of earlier efforts, see Carter et al. 2015) but also attempt to provide a perspective and a roadmap for the future.

Our review concludes that index insurance is a work in progress and that it is possible to redesign the product and how it is offered to increase take-up and contribute to overcoming the risk constraint in smallholder agriculture. We define index insurance in Section 2 and explain its theoretical appeal. In Section 3, we review what has been learned in identifying the causes of low take-up. We then proceed in Section 4 to discuss new directions to help index insurance progress toward achieving sustainable market-driven adoption. These new directions include (*a*) improvements in contract design, (*b*) better measurement of risk, (*c*) new approaches in offering index insurance, and (*d*) the use of complementary instruments in a risk portfolio perspective. Section 5 concludes and summarizes the most promising ways forward for addressing the age old problem of uninsured risk that inhibits the performance of smallholder agriculture.

2. AGRICULTURAL INDEX INSURANCE: DEFINITION AND THEORETICAL APPEAL

The appealing innovation in the design of an agricultural index insurance product is that it delinks payouts from the assessment of individual losses and links them instead to an index crossing a predetermined threshold. Payouts are based on triggers correlated to losses. Many index insurance contracts are based on weather events, but they can also cover price shocks, yield losses, and other relevant agricultural variables depending on data availability and correlation to farm losses. Most of the following discussion refers to weather-related events.

The index used for index insurance can be parametric in measuring weather events, such as drought, flooding, and excessive temperature, leaving no room for adverse selection and moral hazard. The index can also be an average in an outcome related to loss over a small area that aggregates farmer outcomes beyond potential adverse selection effects and collusive moral hazard behavior. The average production outcomes can be crop yield or livestock mortality rate. They can be estimated using statistical sampling (such as random crop cuttings) or average damage for the area based on satellite observations. In both cases, the index should be objectively and easily quantifiable, publicly verifiable, and not possibly manipulated by the insurer and the insured. Choice of the threshold and the level insured can be left to the provider and the client, with cost equal to the actuarially fair price of the risk involved plus a loading that should ideally be competitive.[1] Advantages are that the need for farm-level assessment of loss is avoided, which reduces cost, and payouts can proceed immediately upon measuring the impact of the weather event on the index. Thus, the expectation is that the insurance product could help deliver protection to millions of smallholder farmers at low cost and without delay.

Though expected to be cheap and fast, index insurance suffers from a major drawback under the form of basis risk. Basis risk results from discrepancies between the measured insurance index and the events and losses actually experienced by the insured. That is, basis risk results from the imperfect correlation between the insurance index and the shocks that it is meant to protect against. With an area average yield index, heterogeneity of damages within the area is not recognized. As a consequence, the index may be triggered when no negative event occurred for an individually insured. More nefariously, it may not be triggered when the insured incurred both a loss and paid the cost of insurance (Clarke 2016). With basis risk, payouts become an additional risky prospect. The extent of basis risk depends on the quality and granularity of the index in signaling a potential loss. Section 4 discusses new index insurance approaches designed to reduce basis risk and hopefully make the insurance reliable enough to induce technology adoption and credit risk-taking.

The promise of index insurance has been met with considerable interest and enthusiasm among governments and development agencies. It has been introduced at the individual, institutional, and geographical levels. More than 15 developing countries have offered individual-level index insurance schemes, sometimes at a massive scale, and some 20 have offered it at the institutional or geographical level. Rigorous studies have identified the impact, and experimental methods have been used to explore improved designs and implementation techniques. The product has been shown to work well where implemented, both for ex-post shock-coping and for ex-ante risk

[1]The actuarially fair price of an insurance contract is the price that equates the premium paid to the expected value of the payout received. The latter is equal to the product of the probability of the insured-against event occurring and the payout received in case of a loss. As discussed in Section 4.3.2, markups or loadings for index insurance in developing countries appear to be well above levels seen in developed country markets.

management. It helps pastoralists in northern Kenya cope with livestock mortality due to drought, as well as avoid consumption destabilization for the poorer households (who want to protect their asset endowments from falling below critical thresholds) and asset destabilization for the richer households (who want to protect their consumption levels) when they self-insure against losses (see Janzen & Carter 2017 for livestock in Kenya). Better ability to cope with shocks is seen in the reduced need for food aid. Improved risk management has been shown to induce investment in more risky and more profitable activities, such as growing various crops in India (Mobarak & Rosenzweig 2013), tobacco in China (Cai 2016), maize in Ghana (Karlan et al. 2014), and cotton in Mali (Elabed & Carter 2016). It has also been shown to work at the institutional level, such as for state-level insurance for drought in Mexico through the CADENA program, with both positive shock-coping (de Janvry et al. 2016) and risk management (Fuchs & Wolff 2011) effects. Yet, take-up and scalability have not matched theoretical promise. Although take-up can be high with high subsidies, not atypical of products demanded in developing country contexts, such as preventative health products and services (Banerjee & Duflo 2011, Dupas 2014), demand is highly price elastic and typically collapses before reaching market price (Schickele 2016). This gap between the promise and reality of index insurance may create one of the most important current opportunities to designing new institutions that can help developing countries achieve the goal of increased investment in agriculture, accelerated growth, and poverty reduction.

3. LOW TAKE-UP OBSERVED AND EXPLAINED: LESSONS FROM EXPERIENCE

Low take-up may come from defects of the product itself, most particularly as it only offers partial and probabilistic payouts. It may come from imperfect correspondence between the structure of risk and what it can cover. Moreover, it may come from other barriers such as high cost, liquidity constraints, lack of trust in the provider, difficulties in learning about a product that covers stochastic events, and behavioral specificities such as aversion to ambiguity and compound risks. We review each of these barriers below.

3.1. Basis Risk: Partial and Probabilistic Payouts

Basis risk originates in the fact that the index used to trigger payouts is imperfectly correlated with the risk it is expected to insure against, such as income or asset losses. It originates in two features of the insurance contract: coverage of income shocks that is only partial and payouts that are probabilistic when a shock occurs at the farm level.

The index insurance that helps hedge against weather events, such as a rainfall shortage, may only protect the farmer from a small share of the determinants of potential income and wealth losses. If markups and loadings are high, the insurance may also be offered at a market price that is too high relative to the farmer's reservation price, implying that the product does not meet safe minimum quality standards (see Section 4.3.1). When the price of the insurance is high, the farmer may prefer to self-insure. A specialized insurance, for example, on just a cash crop, may leave too much uncorrelated background risk to be worth taking. Using incentivized lab-in-the-field experimental games with smallholder coffee farmers in Guatemala, McIntosh et al. (2016) show that willingness to pay for insurance increases with the severity and variability of shocks covered by the index. An increase in small downside risks in particular induces prospect theory–type behavioral responses, with a strong increase in demand for insurance. However, the demand for insurance declines with the partial coverage of income shocks. A unidimensional index discourages demand all the more if the risks are multiple perils. Greater uncorrelated background risk is thus detrimental to demand for index insurance, suggesting the importance of adapting index insurance to cover multiperil risks to increase take-up. If background risk is positively correlated to the insured risk, the framer will increase demand for the index insurance to protect himself at the same time for some of these uninsured risks. Thus, whereas uncorrelated background risk decreases demand for the index insurance, correlated background risk may increase or decrease demand according to the sign of this correlation.

Basis risk also originates in the possibility that shocks occur without payment, in spite of weather events at the farm level that should have been insured, and reciprocally as well. In this case, premium payments may worsen income under adverse states of nature and transfer income from bad to good states of nature (Clarke 2016). Interestingly, given cooperative membership of the coffee farmers studied by McIntosh et al. (2016), basis risk could be reduced by contracting index insurance at the cooperative level and having the institution distribute the insurance payout across farmers based on observed losses on an indemnity basis. They find that while farmers are strongly attracted by the idea of risk pooling to reduce basis risk; they do not trust implementation, and aversion to risk pooling is worsened by the degree of heterogeneity across members. All together, the authors find that only 12% of farmers have a willingness to pay for index insurance at a price above the fair price.

3.2. Risk Structure

Any insurance covers specific risks, for which a probability distribution must be assessed by the provider of the insurance to price the product. Agricultural index insurance is no exception. It provides insurance based on an index of rainfall, flood, temperature, frost, or any other weather-related outcome. Given the specific weather variable for which an index is desired, the relevant probability distribution can be estimated from time-series meteorological data. Such data, for instance, could refer to the level of daily or weekly rainfall, as measured by a specific rain gauge installed by the national meteorological agency in or near the location for which the index is required. The risk measured by the probability distribution of the relevant index must translate to some extent to the probability distribution of the variable that is of interest to the individual household, such as the yield of specific crops and income. The difference between the two probability distributions is the basis risk, and it implies that the risk faced by the individual household may be different from the risk measured or represented by the index. This example also highlights that basis risk is different for each individual farmer because of both different production structures and the distance from the station that measures the relevant meteorological data.

3.3. Other Barriers

3.3.1. Cost. Similar to many beneficial products used by the poor (Dupas 2014), demand for index insurance tends to be highly price elastic. Using an experimental approach, Cole et al. (2013) find that the index insurance offered by BASIX ICICI in Gujarat, India has a price elasticity of −0.66 to −0.88. Cai et al. (2016) find that index insurance for rice in China offered by PICC (the People's Insurance Company of China) has a price elasticity of −0.44 at the fair price. Price itself tends to be high for several reasons. One is the loading charged by insurance companies, which is typically in the 50% range. The other reason is the difficulty of assessing a fair price in a context of data scarcity and climate change. These data imperfections translate into uncertainty loadings, which can further boost the price, as Carter (2013) discusses.

3.3.2. Liquidity constraints. Not only is insurance costly, but premiums often must be paid ahead of the cropping exercise, eventually with long periods of time between seasons. Savings instruments are necessary to maintain liquidity from harvest to the beginning of the next season. Credit may be needed as well. Both financial services are known to be highly deficient for smallholder farmers. Giné & Yang (2009) show that the wealth position of maize producers in Malawi is a determinant of index insurance demand, revealing the existence of liquidity constraints. Cole et al. (2013) find that unexpected positive liquidity shocks increase Indian farmers' purchase of index insurance. This liquidity constraint can be relaxed if farmers borrow to purchase other tangible inputs, as happens in contract farming schemes and other well-organized supply chains. Elabed et al. (2013) describe one such instance in which farmers borrow the premium amount as part of a loan package for growing cotton in Mali. The same approach has been used in cotton-growing regions in Peru (2008–2010) and Burkina Faso (2013 to the present). Although insurance take-up in those projects never exceeded 10–35%, Casaburi & Willis (2015) report that removing liquidity constraints by postponing payment of insurance premiums until harvest time (together with the potential intertemporal inconsistencies and lack of trust) increased take-up from 5 to 72% among sugarcane producers in Kenya. Yet liquidity may not be the major constraint on the adoption of insurance. Karlan et al. (2014) and Emerick et al. (2016) find that farmers can independently find the liquidity to adopt technological innovations for as long as they are profitable, and this would also apply to the take-up of index insurance that meets safe minimum quality standards.

3.3.3. Trust in provider. Similar to savings, where money flows from the clients to the financial institution, trust in the insurance provider is essential for take-up. Indexation removes a fundamental dimension of trust in the provider by not requiring damage assessment by the insurance company for payments to be made, which is a well-known source of conflict with indemnity insurance. In China, Cai et al. (2016) show that witnessing payouts to oneself or to others in one's social network is essential for trust building. Of the 11-percentage-point increase due to experiencing payouts, 36% comes from direct payouts, and 64% comes from network payouts. Cole et al. (2013) observe that endorsement of the insurance product by a trusted third party increases insurance take-up by 40%. Trust can also be increased by using a two-strike payout scheme, where small and frequent payouts help build trust, whereas large and low frequency payouts secure the value of the product (Carter 2009).

3.3.4. Learning difficulties. The concept of insurance is difficult to understand when it is newly introduced. Farmers frequently expect to get their money back from the provider if no adverse event has occurred during the year. Financial literacy is low among smallholder farmers, yet it has been shown to be important for adoption (Cai et al. 2015 for China; Cole et al. 2013 for India; Giné & Yang 2009 for Malawi). Index insurance is even more difficult to understand due to basis risk that makes the relationship between the insurance index and individual payouts probabilistic. Although simulation games can be used to help farmers understand basis risk and other aspects of index insurance (see Lybbert et al. 2010), demand in these games tends to overstate real demand. Learning through experiencing payouts typically suffers from two factors: a positive recency effect on take-up when an insured shock has occurred and a payout has been observed, and a negative attenuation effect when a premium has been paid and either no shock occurred or the shock was not met by a payout. There may be habit formation, with past purchase of the product influencing current demand. The use of subsidies to give incentives to adopt can create more opportunities to observe payouts to others, but it can also reduce attention to a product that has not been fully paid for (Ashraf et al. 2010) and create price anchoring effects that reduce future willingness to pay at full price when the subsidy is removed (Cohen & Dupas 2010). The main problem with learning about index insurance is that it involves learning about a new probability distribution of incomes, something that takes years of experiencing for farmers. Because learning is affected by both past prices and recent payouts, the optimum subsidy needed to achieve a given rate of take-up may have to be constantly adjusted to recent events (Cai et al. 2016).

3.3.5. Behavioral specificities. In the same way that farmers frequently have a time consistency problem in setting postharvest cash aside to purchase (profitable) fertilizers for the next planting season (Duflo et al. 2011), setting aside liquidity to purchase insurance may suffer from a procrastination constraint. The same nudges that have proved effective for fertilizer use can thus be effective for insurance take-up. As shown by Hellmuth et al. (2009), collecting insurance premiums immediately postharvest when farmers are most able to pay has increased take-up. Bundling the payment of index insurance premiums with fertilizer and seed purchases, as done by the Syngenta Foundation under their Kilimo Salama scheme in East Africa, has also proved successful in overcoming the time consistency problem.

Basis risk in index insurance creates a behavioral response due to ambiguity aversion that reduces take-up. Under expected utility theory, the high tail-end risks of an insurance product will reduce demand. This is the explanation for the low demand for index insurance proposed by Clarke (2016). If high basis risk makes it possible that no indemnity payment may come following payment of a premium and incurred losses (making the farmer worse off than with no insurance), then highly risk-averse individuals will avoid index insurance. This expected utility prediction of the role of basis risk on insurance take-up is worsened by prospect theory. Under prospect theory (Tversky & Kahneman 1992), individuals have an aversion to ambiguity in that they prefer gambles with known odds over those with unknown odds. Because the odds of payout of an index insurance product are not precisely known, an ambiguity-averse farmer would prefer a more costly indemnity-based insurance contract with known odds (Bryan 2010). Stochastic payouts under index insurance create a double lottery: The weather event is stochastic, and the payout for a given weather outcome is stochastic as well. It has been shown that compounded risk aversion contributes to reducing demand (Elabed & Carter 2015).

Finally, if there is strong preference for certain as opposed to uncertain outcomes, preferences may be discontinuous in the neighborhood of certainty (Serfilippi et al. 2015). Because indemnity payments are stochastic, whereas payment of a premium is not, the demand for index insurance is reduced by preference for certainty, a finding confirmed by field experiments with farmers in West Africa.

4. NEW DIRECTIONS FOR IMPROVED INDEX INSURANCE

In spite of the theoretical promise and demonstrated effectiveness of index insurance and a better understanding of the constraints involved, low take-up has spurred an active search for improving the offer of index insurance through (*a*) improvements in contract design, (*b*) better measurement of risk, (*c*) new approaches in offering the product, and (*d*) combining index insurance with other risk-reducing instruments in a portfolio management perspective. We review each of these approaches to improvement below.

4.1. Improvements in Contract Design

We infer from the observed low take-up outcomes that index insurance will only realize its potential for development impacts if contracts are designed to minimize exposure to contract failures and to basis risk events. In this section, we first consider the potential to combine existing index insurance tools with audit rules to create a fail-safe index insurance contract. We then consider the potential for institutional or mesolevel insurance contracts, which confront lower levels of basis risk, to realize the hypothesized benefits of agricultural insurance.

4.1.1. Fail-safe contract design. When indexing against production losses, directly measured small area yields would be the most reliable approach. However, these measurements are quite expensive. Instances in which area yield indices can be used without incurring high measurement expenses are limited to production in monopsonistic supply chains, as with cotton production in Mali, where the single buyer can easily measure output achieved over the area harvested.

To go beyond these rare cases, a pilot project in Ethiopia led by researchers at the International Food Policy Research Institute suggested backing up a failure-prone rainfall index with an area yield audit.[2] Specifically, insured farmers can petition the insurance company to have an agronomist measure average yields for their village in the event that they experience losses but the primary rainfall index failed to trigger insurance payouts. Although this audit rule–based contract should offer the same protection as an area yield index, to be cost effective, the underlying rainfall index must be relatively reliable so that audits are not triggered too frequently. Elaborating on this idea, Flatnes & Carter (2015) suggest a multiscale approach that combines area indexing using predicted yields based on satellite observations and direct audits, with a very low failure rate.

A new project in Tanzania is piloting this idea, combining a rainfall index, predicted zone-level yields, and a crop-cut audit that is initiated at the request of farmers. Flatnes & Carter (2016) illustrate the accuracy gains of this more comprehensive approach. Given the lack of preexisting data on farmer losses, the project solicited yield data going back 5–10 years from 40 farmers in each of the 36 insurance zones (an insurance zone is defined as 2–3 geographically proximate villages). These data in turn allow the construction of a (noisy) yield time series for each zone, from which average yields were calculated for a total of 143 zone–year combinations. **Figure 1** presents these yield data.

How well can insurance indices capture these losses and issue appropriate payments to indemnify farmers when losses occur? After exploration of the statistical properties of various potential indices, the project in Tanzania settled on two core indices. The first is based on estimated rainfall during the 40-day plant germination and establishment phases, with a payout being triggered if there is <80 mm of rainfall. The horizontal axis in **Figure 1** displays that index. Any zone-year combinations to the left of the vertical trigger line at 80 mm would have triggered payment under this index. Clearly, none of the years of extreme losses would have triggered the rainfall index, and two of the years of intermediate losses would have done so.

The second index is based on a yield estimate from a satellite measure of biomass growth and a full season cumulative rainfall measure. The vertical axis in **Figure 1** displays this index, which would trigger payments when estimated yields fall below 60% of their average level. As shown in the figure, this estimated yield index correctly captures all but two instances of severe loss (solid triangles). Although this performance is relatively strong, the two triangles in the northeast quadrant of the figure signal the presence of two instances of index failure. Given the likelihood that such failures will almost surely occur, the Tanzania project adopted an audit rule. Insured farmers are invited to send the insurance company a text message if the contract does not trigger and if they believe that yields in their zone are 60% or less of normal. If more than 30% of farmers register a complaint, the insurance company carries out a crop-cut audit, with payments to be issued if measured yields are less than 60% of the long-term average. Although this is relatively costly to implement, these data indicate that an audit should be necessary in only 13% of all severe loss events. This 13% failure rate of the core satellite-based indices highlights the continuing imperfection of

[2]The pilot project, which lasted only a year, is described briefly in I4 (2013).

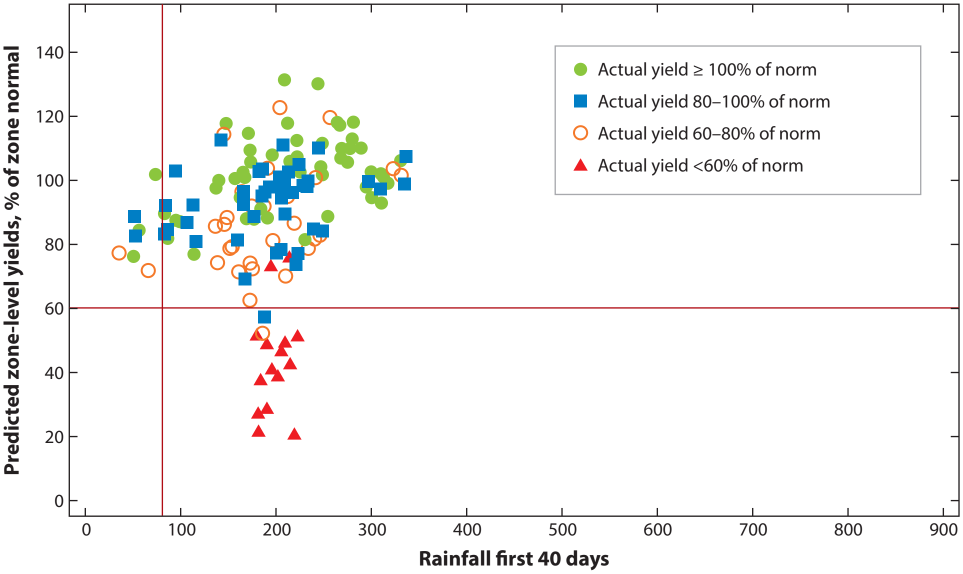

Figure 1

Filled (*green*) circles are instances in which yields were above average. Filled (*blue*) squares are instances with modest losses, with average yields of 80–100% of their long-term average. Open (*orange*) circles are instances with intermediate losses, whereas the solid (*red*) triangles signal severe losses with yields less than 60% of their long-term average. Rainfall measured in millimeters. Figure adapted from Flatnes & Carter (2016).

even this multi-index insurance contract and the importance of the fail-safe audit option if farmers are to sustain their confidence in the insurance and increase their investments on that basis.

4.1.2. Mesolevel insurance. With some exceptions discussed below, index insurance projects to date have targeted farmers, either individually or in groups, with the hope that insurance provision will encourage farmers to invest in profitable (in expectation) but risky technologies using either their own or borrowed funds. However, as already discussed, offering insurance protection to individual farmers poses a number of demand-side constraints (trust and understanding) and supply-side constraints (design of contracts that are sufficiently reliable to protect individual farmers). Offering insurance to a mesolevel institution—such as a bank that might offer agricultural loans, an administrative entity, or a producer organization—is a potentially attractive option. As stressed by Carter et al. (2016), banks are worried about large correlated shocks, which affect the performance of their entire portfolio of agricultural loans in a given region; idiosyncratic events are of less concern. This implies that basis risk is less of a problem for such a mesolevel institution, as an index with regional coverage is likely more correlated with an average production outcome for the region, compared with individual producer outcomes.

The ways in which mesolevel portfolio insurance would be expected to work depends on the liability and collateral rules that characterize loan contracts. In the extreme (and likely unrealistic) case that loans are fully collateralized, the bank bears no risk, and mesolevel insurance should have no impact on their lending operations. However, when loans are undercollateralized, bank exposure to risk and sensitivity to the covariant element of that risk can be substantial. In the likely case that liability and risk are carried by both borrower and lender, the operation of mesolevel insurance becomes somewhat more complex.

In this mixed context, lenders may be happy with an index-based portfolio insurance that protects them against large-scale covariant events (if and only if the contract has little design risk, i.e., the contract still has to predict average outcomes well, something that basic rainfall contracts do not do). However, farmers face three problems. First, what happens when there is a large-scale event and the bank receives an insurance payout? Is this payout shared with the farmer in terms of reduced loan liability? Uncertainty about this decision raises a trust issue for the farmer. Second, the farmer continues to bear the risk of idiosyncratic risks. If those risks are too large, he may be unwilling to borrow and remains risk rationed. Third, is the loan market sufficiently competitive that the cost of the insurance is compensated by a reduction in the loan interest rate?

Carter et al. (2016) examine these issues theoretically and note that mesolevel contracts (what they call interlinked index insurance) would be expected to induce farmer investment and technological change only in environments with low collateral requirements and modest idiosyncratic risks as a share of total farmer risk. Whereas theory is suggestive, empirical evidence is still needed on these difficult questions. Interlinked products have rarely been introduced, as their implementation requires the collaboration and coordination of several key actors, such as insurance companies, banks, agrometeorological services, and governments. A recent pilot project in Ethiopia (Ahmed et al. 2016) revealed the institutional and coordination difficulties of introducing credit interlinked with insurance, but it also demonstrated that there is considerable demand for such products at the farm level, despite their costs. More positively, Mishra et al. (2017) report that interlinking credit with loans significantly increased supply of loans to smallholder farmers in Ghana, and that the insured loans met with high demand from farmers themselves.

Mesolevel insurance can also be integrated as interlinked transactions in value chains. The Syngenta Foundation demonstrated the feasibility of interlinking seed and fertilizer sales with index insurance. In the Kenyan Kilimo Salama (safe farming in Swahili) scheme, index insurance is offered at a 5% premium over the seed price. A mobile phone camera is used to scan barcode symbols on labels attached to bags of inputs sold to farmers. Weather events are measured at automated weather stations, and payouts are made using mobile payments. In case of weather shocks in excess of predetermined thresholds, the cost of purchases is refunded to farmers.[3] When there are delivery contracts, such as with seed farmers and members of dairy cooperatives, the cost of premiums is deducted from payments for product deliveries. In these cases, it is the commercial company or the producer organization that insures its interlinked transactions in value chains, thus facilitating decision-making for individual farmers to benefit from index insurance and to enhance take-up.

4.2. Better Measurement of Risk

Much progress has been made using information technology to measure yields and infer weather events. The quality of index insurance greatly depends on the structure of the index that is used to determine payouts. The relationship of the weather event to the underlying product risk determines the appropriateness of the index, and hence a large part of the basis risk. There have been considerable advances in crop modeling that specify the water- and other climate-related requirements for crops to have full yield. Deviations from the optimum conditions result in declines from the optimal yield, and specific deviations lead to corresponding yield declines. This simple logic drives index construction. Behind this logic, however, there is an enormous amount of agrometeorological science that tries to specify the time intervals during growth and the

[3] However, the extent of basis risk under the Kilimo Salama contract has yet to be determined.

appropriate amounts of the weather variables that lead to optimal yields, as well as the relationship between the weather variable (such as rainfall deficits) and yields.

Although advanced estimation and interpolation techniques open the door to creation of indices that can employ terrestrial weather data to more precisely track farmer losses, the technological possibilities of what can be measured, and at what resolution, have been expanding rapidly. We gave in Section 4.1.1 an example of predicting crop yields using a satellite-based normalized difference vegetation index (NDVI) measure of crop biomass for maize in Tanzania. Those particular predictions were based on measures from the MODUS satellite, which provides NDVI readings on each 250-m^2 (or 6.25-hectares) pixel. The Climate Hazard Group InfraRed Precipitation (CHIRPS) rainfall data (estimated at a pixel size of 5 × 5 km) were used to estimate maize planting dates, and the actual yield prediction was based on cumulative growth of NDVI (area under the NDVI curve) for the 100-day period following the estimated planting date. Allowing for village fixed effects, the model captures just less than 80% of the variation in average village yields.[4]

Though fairly successful in this particular application, NDVI is a relatively early and perhaps somewhat crude measure of plant growth. Guan et al. (2016) describe a number of alternative measures of plant growth and crop yields based on other satellite measurements designed to more closely track the actual biology of photosynthesis and plant growth. Building on these ideas, Flatnes & Carter (2015) show that a satellite-based measure of gross primary production, combined with careful crop masking[5] and a planting date detection algorithm, outperforms a wide range of alternative measures when it comes to predicting irrigated rice yields in northern Tanzania. Lobell et al. (2015) describe a fascinating approach in which crop growth models are used to generate simulated data on what satellites should see under different conditions of plant health and yields. These simulated data can in turn be used to train a model to predict real crop yields based on actual satellite data.

Remote sensing techniques to predict crop yields are advancing rapidly, but their usefulness as the basis for index insurance depends on their predictive accuracy and the scale at which they are able to predict.[6] This latter problem of scale has inspired others to literally get closer to the ground. One such approach is to mount sensors on low-flying drones, allowing measurements at an extremely high spatial resolution. An alternative approach, which is even closer to the ground, is to employ what are essentially crowdsourcing techniques, which solicit time- and location-stamped photographs from a large number of individual farmers on a regular basis. The hope is that machine-learning techniques can be applied to the pictures to assess crop or forage damage. One challenge to making these techniques functional for insurance is to either discipline the crowd into taking regular pictures of the same, randomly selected fields, or incentivizing the crowd so that a random and representative picture of the relevant landscape is obtained. As with other aspects of index insurance, these techniques remain works in progress.

4.3. New Approaches in Offering Index Insurance

Developing a vibrant market for reliable index insurance that can induce development impacts faces a number of difficulties. We focus in this section on three such difficulties. First, because the

[4]That is, the satellite measure captures 80% of the variation that would be captured by a village-level area yield index.

[5]Crop masking is a technique whereby data from pixels that do not appear to contain much or any of the crop of interest are either ignored completely in the calculation of yield estimates or are probabilistically downweighted so that they contribute relatively little information to the ultimate estimated yield measure.

[6]For example, the measure explored by Guan et al. (2016) (solar-induced fluorescence) relies on pixels that cover 320 km^2. Although they can predict county-level crop yields in the United States with this measure, its usefulness as an insurance index is uncertain, especially in areas with high spatial heterogeneity, at least until higher resolution measures become available.

quality of protection obtained from a particular index insurance product is difficult to discern, and incentives are weak for private firms to provide quality contracts, minimum quality standards could be put in place and enforced by regulators. Second, despite the willingness of many governments to subsidize agricultural insurance, the pricing of index insurance in most developing countries markets appears to be high, perhaps because of sparse data problems reflecting past public good failures, suggesting that there may be more effective ways of deploying public subsidies to build the market. Finally, the supply of credit, similar to that of insurance, is subject to fixed costs, making it difficult to profitably offer contracts to smallholder farmers. Based on lessons from microfinance, new institutions are needed if insurance is to be cost-effectively offered to the smallholder sector.

4.3.1. Safe minimum quality standards for index insurance. Similar to many other agricultural inputs, the quality of index insurance is a hidden trait in the sense that the farmer cannot ascertain quality by simply examining the input at the time of purchase. But unlike some agricultural inputs, such as certified seeds that must pass germination and yield tests to which a government agency attests, quality certification standards neither exist, nor are enforced for index insurance in developing countries. As problems of counterfeit fertilizer and other chemical inputs mounting, it is becoming increasingly clear that without enforced quality standards, input use and agricultural productivity suffer.[7]

As discussed above, there is growing evidence that insurance can act as a productivity-enhancing input, and yet there is also growing evidence that exactly as in the case of adulterated fertilizer, low-quality, basis risk–laden contracts create distrust and undercut the market for index insurance. Development and enforcement of quality standards should thus be important for the future development of index insurance.

Standard economic tools offer ways of measuring index insurance quality. Intuitively, such a measure would be sensitive to the probability that a contract fails to pay any indemnity as a function of the farmer's loss, or it would be more generally sensitive to the distribution of payments conditional on loss levels. In addition, a quality measure would be sensitive to the shadow value of money when there is an insurance failure. A contract failure in an extremely bad state of the world, when yields are near zero, should lower the assessed quality of the insurance product more than a contract failure that happens when yields are only modestly below the contract strike point.

Define the reservation price for index insurance as the maximum amount that could be paid for the insurance without pushing the expected utility of the farmer below its expected utility absent insurance. Whereas the distributions of indemnity payments and stochastic agricultural income can be derived from the information needed to design a contract and calculate basis risk, the reservation price will depend on assumptions about the degree of risk aversion. Assuming constant relative risk-aversion preferences, the reservation price will typically increase as a function of risk aversion.[8] The actuarially fair price for the contract equals the reservation price for a risk neutral agent. A Safe Minimum Standard (SMS) for index insurance quality might then require that the market price not be above the reservation price for moderately risk-averse agents.

Although this reservation price–based measure derives from the perspective of economic theory and is a minimum quality standard, it is potentially informative. Analyzing the high-quality area yield contract discussed in Elabed et al. (2013), we find that the reservation price is 50% above the actuarially fair price for moderately risk-averse farmers. This finding is striking, given that

[7] Bold et al. (2015), for example, consider the case of fertilizer adulteration and low fertilizer use.

[8] Reservation price may not monotonically increase with risk aversion if the contract fails to pay out in extreme states of the world (to which more risk-averse people are more sensitive), a point that is consistent with that of Clarke (2016).

contracts with inferior statistical properties compared to an area yield contract are often priced with markups in excess of this 50% level. Although it is possible to imagine more elaborate measures of index insurance quality, this reservation price–based SMS might provide a useful starting point for defining contract quality.

Establishment and enforcement of this or other quality standards for index insurance would seem to be in the interest of the insurance industry itself, although some public regulation might well be necessary, as with the case of standards for certified seeds.[9]

4.3.2. Pricing and smart(er) subsidies. Though only indicative of one instance (of a relatively high-quality area yield contract), the reservation price–based SMS for index insurance should give pause in terms of the current state of index insurance and its pricing in developing countries. In US crop insurance markets, agricultural index insurance is sold at a markup that is approximately 20–30% above the actuarially fair price (Smith & Watts 2009). There is no systematic data on index insurance pricing, but experience across a half dozen index insurance pilot projects reveals markups that are typically well more than 50%, calling into question whether an SMS can be met under current pricing conditions.

Although the reasons behind these seemingly high price levels are hard to discern, the authors' experiences with pilot projects suggest that at least part of the problem lies with sparse or low-quality data and the tendency of insurance companies to impose uncertainty loadings in these cases. As discussed further in Carter (2013), these data problems reflect past failures to collect reliable agricultural statistics (a public good failure), and loading the cost of these past failures into the price of insurance threatens to undercut the market and perpetuate the low productivity levels that insurance is designed to alleviate. As Carter further discusses, this may suggest the need for some public underwriting of the tail risk, about which there seems to be the greatest uncertainty. Indeed, whereas most agricultural subsidy schemes provide a comprehensive discount for farmers, an alternative and potentially budget-neutral approach would be to simply have the government provide free insurance for the catastrophic risk layer (for example, when yields are less than 50% of their average value). Individuals or institutions would then have the option of purchasing top-up insurance to cover less catastrophic risk layers.[10] Providing free insurance for this layer will not only lower the overall cost of insurance (if the public sector can provide the insurance with a lower uncertainty loading than the private sector), but it will create a minimum market size.[11] Perhaps of equal importance, getting at least catastrophic insurance in the hands of a large number of participants gives them the opportunity to learn about the efficacy of insurance and how it works. More speculatively, this approach may also enhance trust in the insurance provider, as insured parties would know that the public sector was on their side should there be any dispute about whether payouts are due.

4.3.3. Lessons from the microcredit revolution to offer microinsurance. Institutional innovations used in microfinance to address issues of savings and lending to the rural poor can

[9] Clarke & Wren-Lewis (2013) argue that the market is likely to underprovide quality insurance contracts in the absence of regulation. This is because a low-quality equilibrium is a likely outcome when it is hard to ascertain the quality of insurance and costly to provide high-quality insurance.

[10] Although some Latin American countries issue payments to farmers in poor regions when triggered by an insurance-like index, they are not always structured so that farmers can purchase additional units of coverage for less catastrophic events.

[11] Note that in some political environments, the government is already responsible for paying the full cost of helping farmers in the event of catastrophic losses. This means that the government is already subsidizing protection against the catastrophic risk layer. If set up as scalable insurance, implementing this obligation through an insurance mechanism (in the spirit of Clarke & Dercon's 2016 "dull disasters") can provide the additional benefit of helping build the market.

be used to address the issue of low take-up of index insurance. Village savings groups, which in many instances are already linked to formal financial institutions, can offer an institutional foundation on which the information, liquidity, and time-consistency constraints on index insurance can be solved. For example, the Nirdhan Utthan Bank already regularly collects lockbox savings from savings groups across rural Nepal. These savings groups allow for named savings accounts, in particular, those dedicated to the purchase of health insurance. Establishing VISAs (Village Insurance Savings Accounts) would thus seem a small but potentially effective incremental step. Already established regular savings group meetings could serve not only as a way of disseminating information on insurance but also as a way of creating and enforcing savings plans that will assure that farmers have the cash on hand to buy index insurance when the purchase period arrives. The transfer of group funds to a formal financial institution would also offer a natural way of bundling insurance demand for villagers who presumably reside in the same insurance zone. Finally, combining this VISA approach with publicly provided catastrophic risk coverage (as discussed above) might further enhance learning about insurance. Though it has yet to be put in practice, these ideas are currently under consideration (Steinmetz & Carter 2016).

4.4. Use of Complementary Instruments in a Risk Portfolio Perspective

Under many current index contracts, every US$1 in expected benefit costs the insured in excess of $1.5, with a strong likelihood that the contract will fail the insured when losses occur. For the case of CADENA in Mexico, de Janvry et al. (2016) calculate that the implicit loading to reconcile premiums and payouts has been as high as 73%. These simple observations suggest that efforts to reduce the cost and improve the reliability of index insurance should be accompanied by efforts to integrate it with alternative financial and nonfinancial technologies. In this section, we discuss each of these observations in turn.

4.4.1. Dynamic relationships between insurance, savings, and contingent credit. Insurance moves money from the past and the future to the day when a shock occurs and additional resources are required. That is, a dollar in insurance payment is in principle covered by premiums paid both in the past and in the future. Savings and credit also move money through time, but unlike insurance, they are unidirectional transfers. Savings move money from the past to the present, and with a positive interest rate, the $1 received in the time of need costs the insured less than $1, say $0.95. Credit moves money from the future to the present and the $1 received at the time of the shock costs, for example, $1.25 in future income if the interest charges amount to 25%. Although these unidirectional transfers are much less costly than money received under current index insurance contracts, access to them requires the prior accumulation of particular kinds of assets. Managing risk through savings most obviously requires the prior accumulation of wealth. Similarly, the ability to access loans after a shock requires the accumulation of reputational assets, such that a lender is willing to offer credit precisely at the time when the farmer's repayment capacity has been weakened by the shock. In a promising new effort, the BRAC developmental organization in Bangladesh is experimenting with contingent emergency credit that mimics index insurance and is released in the event of a shock (de Janvry et al. 2016). These loans are not for everyone (only 40% of BRAC clients are approved for such loans), and the amount of credit is rationed (limited to 50% of the borrower's most recent regular loan from BRAC). With a 25% interest charge, it is cheaper money than that which comes from existing index insurance contracts.[12]

[12]There is still an analog with the basis risk problem of insurance if the individual has a loss but the index releasing the line of credit is not triggered. On the other hand, there are no false positives because the borrower decides whether or not to exercise the line of credit and need not pay for money that she does not need if the shock spared her.

Although both credit and savings can fill the role of insurance, the challenge is for low-asset smallholders caught in a low productivity trap to reach a point where they have accumulated sufficient financial or reputational assets to allow them to manage shocks with savings and, or credit. This observation suggests that the optimal risk management portfolio will necessarily evolve over time. Producers with few initial assets have no choice other than to rely heavily on relatively expensive insurance to manage risk. But, as stressed by Carter et al. (2016), insurance is effectively less expensive if it underwrites an increase in investment and expected income.[13] If such a virtuous circle can be broken, then the farmer can herself begin to accumulate financial and reputational resources that will allow her to rely less heavily on insurance and more on the cheaper unidirectional financial flows available from savings and contingent credit. Under this scenario, the fraction of risk that is managed by insurance would decline. How far it would drop would ultimately depend on limitations on the available lines of credit and the optimal amount of savings the household should hold given interest rates and other considerations. There is analytical work to be done to precisely envision how optimal risk management might evolve over time, but it is easy to imagine a longer-term state in which insurance is ultimately relied upon for the most catastrophic losses that can be covered by neither optimal savings nor contingent credit lines.

4.4.2. Index insurance and agronomic risk reduction technologies. Significant advances have recently been made in releasing seed varieties for major staple crops that have tolerance to abiotic shocks, such as flood, drought, and extreme temperatures. Flood-tolerant rice has been widely adopted in South Asia (Dar et al. 2013), and drought-tolerant and water-efficient maize varieties are being rolled out in sub-Saharan Africa. In a study for the state of Orissa, India, Emerick et al. (2016) show that farmers who were randomly allocated flood-tolerant rice varieties responded with increased investment in fertilizers and other risky inputs. These findings parallel those studies on the impacts of index insurance. Yet, as Lybbert & Bell (2010) show, these new stress-tolerant varieties offer protection over only a limited range. Flood-tolerant rice gives a yield advantage over nontolerant seeds for floods up to 16 days, but both seed varieties fail with longer floods that still have an 11% likelihood of happening in Orissa. Similarly, the new drought-tolerant maize varieties perform no better than other varieties when subjected to early season moisture stress that compromises plant germination and establishment.

The incomplete protection offered by stress-tolerant varieties suggests that index insurance can fill in where the built-in seed protection ends. For the case of flood-tolerant rice, this would imply index contracts that cover flood events that last longer than 16 days. For drought-tolerant maize, this might imply protection against early season drought or years of extreme drought stress. Conceptually, this complementarity should result in expected utility gains for farmers (Lybbert & Carter 2014). In practice, Carter et al. (2016) report on a new effort to bring these ideas to the field in the form of a randomized controlled trial in Tanzania and Mozambique that offers stress-tolerant seeds both with and without a matched insurance protection.

5. CONCLUSIONS

Uninsured weather risks remain a major hurdle to investment and the economic well-being of smallholder farmers in developing countries. The cost of risk in terms of foregone income and unnecessary poverty is potentially large. Recent studies show that removal of risk through insurance

[13] Financing for those increases can come from credit that is newly offered, from farmers willing to borrow more heavily from already available credit (as in Elabed & Carter 2015), or from farmers' own low-return buffer stock resources (as in Karlan et al. 2014).

can boost smallholder investment and income by 20 to 30%, indirectly identifying the huge, year-after-year cost that farmers pay when they manage the risks they face on their own. The challenge remains how to cost effectively and sustainably remove risk from smallholder systems. The failure of traditional indemnity-based insurance products in this context has led to an outpouring of experimentation with index insurance contracts. Despite its theoretical appeal, and that it has been shown to enable greater smallholder investments and incomes when deployed at either the individual or institutional level, take-up has proven disappointing without high and sustained subsidies.

Recent research and experimentation with index insurance has helped identify reasons for this low take-up. The main reasons identified are high basis risk, incomplete risk coverage, high cost, liquidity constraints and a lack of flexibility in making payments, lack of trust in the provider, difficulty in understanding the product, and ambiguity aversion derived from basis risk. It is likely that initial setbacks with the take-up of index insurance have been due to excessive haste in making the product available without sufficient understanding of its specificities and limitations. From this perspective, index insurance is still very much a work in progress.

This juxtaposition of low take-up with high promise has induced an active search for ways of improving the product and increasing take-up. Promising innovations include improved contract designs, use of advanced technology to obtain better data and achieve better measurement, definition and enforcement of index insurance quality standards, improved marketing, and smarter use of public subsidy dollars to leverage better insurance pricing. Uniting these efforts is the intention to improve the reliability of index insurance and to reduce its price. However, because index insurance is likely to remain expensive in the developing country context, we believe that the immediate challenge is to offer farmers a suite of risk management instruments, ranging from stress tolerant agricultural technology to contingent savings and indexed emergency credit lines. It is also important to give them the flexibility of moving between these instruments as experience, reputation, and wealth are accumulated.

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