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Underwriting Area-based Yield Insurance to Eliminate 'Risk Rationing' and Crowd-in Credit Supply and Demand

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This paper was chosen through an open call for research in rural finance, whereby the selected individuals were invited to Rome, Italy, to share their results during the conference and to discuss key issues in shaping the rural finance research agenda as well as ways of strengthening the ties between research, policy and practice.

UNDERWRITING AREA-BASED YIELD INSURANCE TO ELIMINATE 'RISK RATIONING' AND CROWD-IN CREDIT SUPPLY AND DEMAND*

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Abstract

Recent theoretical and empirical evidence suggests that risk (especially covariant risk that is correlated across producers) may discourage both the supply of agricultural credit and the willingness of small holders to utilize available credit and enjoy the higher expected incomes credit could make available to them. One possible resolution to this problem is to remove risk from the system by independently insuring it. However, conventional (all hazard) crop insurance has in almost every instance been rendered financially unsustainable by moral hazard and adverse selection problems. This parameter instead analyzes an area-based yield insurance scheme (where area yields are estimated using readily available weather information). While such insurance does not protect the farmer from all risks, our econometric analysis shows that it could have substantial value to the producer and could also crowd-in credit supply from lenders reluctant to carry too carry too much covariant risk in their loan portfolios. We close by arguing that present and past public good failures justify public intervention in this area and analyze the feasiability of a publicly funded scheme to underwrite the costs and uncertainties associated with area-based yield insurance.

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Underwriting Area-Based Yield Insurance to Eliminate 'Risk Rationing' and Crowd-in Credit Supply and Demand

Recent theoretical and empirical evidence[1] suggests that:

(i) A subset of agricultural producers will be discouraged from taking productive loans because they fear the loss of collateral that could occur under the available set of highly collateralized loan contracts;

(ii) That the producers so affected are likely to enjoy lower levels of productive wealth than other producers; and,

(iii) That the cost of wealth-biased risk rationing is lower and less equally distributed income. If these observations are correct, then improving the financial performance of low wealth agricultural producers is going to require more than land titling and other supply-side efforts. It is also going to require efforts to address risk constraints that limit effective demand.

One possible resolution to this problem is to remove risk from the system by independently insuring it.[2] However, conventional (all hazard) crop insurance has in almost every instance been rendered financially unsustainable by moral hazard and adverse selection problems. Index-based insurance (*e.g.*, area-based yield insurance or insurance based on rainfall or other weather indices[3]) has the virtue of being moral hazard proof in the sense that it preserves effort incentives for producers as no individual farmer can influence the probability of an insurance pay-off. It is also immune to problems of adverse selection.

However, despite these advantages index-based insurance by construction only covers a fraction of the risks faced by farming households, leaving households exposed to residual uninsured or basis risk. A key empirical question then is whether the provision

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[1] See Boucher, Carter and Guirkinger (2007) and Boucher and Guirkinger (2006).

[2] Other possible solutions include lending methodologies which do not depend on tangible collateral, such as group-based lending and lending based on reputation (see McIntosh, 2006).

[3] In area-based yield insurance, insurance payoffs are based on the payoffs of all producers in a region, irrespective of whether or not they purchase insurance. Weather index-based insurance can be viewed as a sub-set of area-based yield insurance in which predictors of average yields (e.g., rainfall and temperature) are measured instead of realized average yields.

of this partial index based insurance will suffice to relax demand constraints to borrowing and empower small holders to pursue more entrepreneurial strategies. Similarly, we might ask whether index insurance suffices to relax the reluctance of rural microfinance lenders to carry a larger agricultural portfolio (see Trivelli 2006).

Using data from coastal Peru, we estimate the parameters for an actuarially fair area-based yield insurance scheme (where area based yields are imperfectly predicted using weather information). We then simulate the value of such insurance to smallholder producers. This preliminary *ex ante* analysis confirms that index-based insurance would be of significant value to producers. In addition, under reasonable assumptions about default behavior, index based insurance radically reduces the probability of default (and the probability that the insured borrower will forfeit their collateral. Together these observations suggest that area-based insurance can crowd-in both supply and demand and supply of credit. Finally, we consider the reasons for the general absence of privately provided area-based insurance in low-income economies. Public goods, and past failures to provide informational public goods are the most likely explations for the absence of area-based insurance. We then analyze the possibilities for using a public gurantee scheme (over a five year period) in order to solve these two public good issues.

1. Statistical Foundations for Area-based Yield Insurance using Weather Information

In this section, we define and estimate the probability distributions needed to simulate the value to farm households of an area based yield insurance (ARBY) scheme. For illustrative purposes, we use information on irrigated rice production in the Peruvian coastal valley of Lambeyeque. As is the case in all of Peru's coastal valleys, agricultural production is completely dependent on water that flows down from the Andes Mountains. While an upstream reservoir provides some degree of water management in the Lambeyeqye valley, its limited capacity leaves producers vulnerable to year-to-year fluctuations in the river flows that feed into the reservoir.[4] A year of scarce water results has two impacts on farmers. First, it leads to a reduction in the area sown, and second it results in reduced yields on those areas which are sown. The empirical analysis reported in this section looks at these dual effects both at the valley and individual household levels.

In order to analyze the prospects for ARBY based on weather information, we need to estimate the probability distributions for four basic components: Valley wide water availability, average valley yields, average valley area sown, and individual yields. To do this, we have time series data for the first three variables (1969-2004) and panel data (2002-2004) for a sample of rice producers in Lambayeque (northern Peru) for the individual and valley average yields.

Estimation of the needed distributions followed four steps. First, we model outflows of water in year *t*, ω_t, as follows:

$$f(\omega) = \frac{(\omega - a)^{p-1}(b-\omega)^{q-1}}{\mathrm{B}(p,q)(b-a)^{p+q-1}} \; for\; a \le \omega \le b; p,q > 0$$
$$and\; \mathrm{B}(p,q) = \int_0^1 t^{p-1}(1-t)^{q-1}dt \qquad (1)$$

That is, we assume that water outflows follow a generalized *beta* distribution, *Beta (p,q;a,b)*, with density given by $f(\omega)$. The parameters of this density function were

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[4] A better candidate for an ARBY insurance scheme would be a valley in which there is no water management system that can carry water forward from non-drought to drought years. Of the 52 valleys on the Peruvian coast, only five have dams with sufficient capacity to allow significant degree inter-year water storage and transfer.

estimated maximum likelihood using the 35-year time series data on water outflows from the Tinajones reservoir that supplies the water for Lambeyeque rice producers. Results are given in the appendix below.

Second, again using the 35 years of time series data, average valley yields ($\bar{y}_t$) and area sown ($\bar{s}_t$) were estimated as functions of water outflows:

$$\begin{aligned} \bar{y}_t &= y(\omega_t) + \varepsilon_t^y \\ \bar{s}_t &= s(\omega_t) + \varepsilon_t^s \end{aligned} \qquad (2)$$

Once these functions are estimated, we can use realized information on water flows to create an estimated average yields and area sown for the Lambeyeque valley. Denote these estimated values as $\hat{\bar{y}}_t$ and $\hat{\bar{s}}_t$. These transformed weather indices, or estimated average yields, will be combined to write the insurance contract. Results are again given in the appendix below.

As a third step, we use the three year panel of data on individual producers and following a specification suggested by Miranda (1991), we estimated individual yields, y_{it}, and individual sown areas, s_{it}, using the following specifications:

$$\begin{aligned} y_{it} &= \mu_i^y + \beta_i^y(\bar{y}_t - \mu^y) + \varepsilon_{it}^y \\ s_{it} &= \mu_i^s + \beta_i^s(\bar{s}_t - \mu^s) + \varepsilon_{it}^s \end{aligned}, \qquad (3)$$

where the terms μ_i^y and μ_i^s are household-level fixed effects,

$\mu_i^y = E(y_{it}),\ \mu^y = E(\bar{y}_t),\ \mu_i^s = E(s_{it}),\ \mu^s = E(\bar{s}_t).$, and we assume that the error terms are distributed normally with mean zero. This exercise allows us to estimate the $\beta's$ from the above equations, which measure the sensitivity of individual yields (sown area) to valley average yields (average sown area). Note that while the distribution of the

$\beta's$ will be centered on one by construction, we can anticipate that some farmers will be hypersensitive to average outcomes with the $\beta > 1$ (perhaps the 'tail-enders' in the irrigation system), while others will have yields and sown area that are more insulated from average outcomes with the $\beta < 1$ (perhaps those located at the head of irrigation canals). ARBY will of course be less valuable for producers with lower values of the β, as we will explore later. Finally, note that the distribution of the error terms, ε_{it}^{y} and ε_{it}^{s}, permit us to recover the residual or basis risk faced by individual producers. The appendix below gives the results from estimating (3) using the Labmeyeque panel data.

As a basis for an area-based yield product, define adjusted valley yields ($\tilde{y}_t$) as $\tilde{y}_t = \overline{y}_t\left(\frac{\overline{s}_t}{s^{\max}}\right)$ and the corresponding estimated adjusted valley yields as $\hat{\tilde{y}}_t = \hat{\overline{y}}_t\left(\frac{\hat{\overline{s}}_t}{s^{\max}}\right)$.[5] We are not in a position to define an ARBY insurance contract will be written as a function of $\hat{\tilde{y}}_t$. In particular define the contractually predetermined "strike point" that determines when the insurance pays off as $\tilde{y}^c$. If normalized valley yields fall below this amount, the insurance pays out a per-hectare indemnity, ρ_t, equivalent to the shortfall:

$$\rho_t = \max[0, \tilde{y}^c - \tilde{y}_t] \qquad (4)$$

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[5] Using this same idea of an adjusted yield, we can define a farmers' output per cultivable hectare, Q_{it}, as: $Q_{it} = y_{it}\left(\frac{s_{it}}{s^{\max}}\right)$ and is expressed in kilos. In the simulation analysis of the value of insurance to farmers, we assume that the typical farmer has access to five hectares (*i.e.*, s^{max}=5). The value of an ARBY contract written on $\hat{\tilde{y}}_t$ will depend on how closely the farmer's adjust yields track $\hat{\tilde{y}}_t$ (as shaped by β^y and β^s and also on the individual (farmer specific) realizations of the idiosyncratic shocks (ε_{it}^{y} and ε_{it}^{s});.

We will consider the case of an actuarially fair insurance, which requires that per-hectare annual insurance premium, π, be equal to the average indemnity across time—*i.e.*, $\pi = E[\rho_t]$. In other words, ignoring the fixed and other administrative costs of designing and delivering the insurance, actuarially fairness implies that the insurer will break-even in the long run: average premiums will equal average payouts.

2. Benefits to Borrowers of Area-based Yield Insurance

The expression linking individual farmer *i*'s yields and sown area to valley averages is given in equation (3). Note that the insurance is written on valley averages, not individual outcomes. While this resolves moral hazard and adverse selection problems, it also limits the value of the insurance to the individual. The actual value of insurance to borrower will depend on the variance of idiosyncratic risk (the ε_{it}), and on the β_i^y *and* β_i^s which determine how closely the individual's yields track the valley averages. In addition, it depends on the accuracy with which average valley yields can be predicted with weather information (*i.e.*, on the variances of $\bar{\varepsilon}_t^y$ and $\bar{\varepsilon}_t^s$). If all the variance terms were zero, and $\beta_i^y, \beta_i^s = 1$, then the ARBY insurance would be perfectly cover all borrower risk. As those variances increase, or as the β decline, the insurance becomes less valuable to the borrower.

How valuable ARBY will be is this an empirical question and context specific. Note also that policy that permits the collection of reliable collection of average yield yield data (so that insurance can be written on actual average yields rather than on a weather index that imperfectly predicts average yield) will improve the value of insurance to producers. Using the econometric results summarized in the prior section, we will now simulate the value of various ARBY contracts to agricultural producers in Lambeyeque. Later sections will return to consider some of the limitations of this sort of *ex ante* analysis.

To get an idea of the benefits to borrowers from an ARBY scheme, we simulated water flows for 100 years (using the estimated distribution Beta distribution) and calculated the implied simulated time series of yields and plantings for the valley using the expressions in (2) above. Using that simulated time series, we then simulated the individual performance of a portfolio of 500 individual farmers (using estimates on the variance of ε_{it}). Using empirical information on the actual distribution of the β_i, we then used expressions (3) and (4) to calculate a time series of outcomes for each individual, with and without ARBY.

Farmers' net income is defined as the residual income, after repaying a loan of L at a nominal interest rate, r. Note that, since insurance is actually fair, the average net income of insured farmers will equal that of uninsured farmers. The loan amount is fixed for every farmer. Similarly, lenders' income is simply the amount of debt that is repaid.

For purposes of the simulation, we set the loan amount to be equal to 40 percent of the expected value of production (that is, we assume that financed inputs constitute 40% of the value of production). Matching the reality of agricultural microfinance lending in Peru, the interest rate was set to 21.7 percent (in Soles, non-annualized) for a five-month loan.[6] We further assumed the following insurance contract bundled with a typical input loan for a rice farmer in Lambayeque:

[6] This interest rate corresponds to current interest rates charged for agricultural loans by microfinance lenders (the Cajas) in Peru.

$$\tilde{y}^c = \mu^y$$
$$Farmers\ insure\ all\ 5\ hectares \qquad (5)$$

That is, we consider a contract in which the strike point equals the long-run average normalized valley yields. Later, we also consider contracts with other strike points (*e.g.*, $\tilde{y}_c = 0.8\mu_y$).

To value the insurance to the producer, we need to make some assumptions about repayment behavior. Initially, we will assume that borrower always pays back as much as is feasible after satisfying a subsistence consumption level, $\underline{c}$ (set at a some fraction of the long-run average production). Under these assumptions, the net income available for the farmer's consumption will thus be:

$$c_{it}^{ARBY} = 5 \times (\max[\underline{c}, (y_{it} - \pi_t - (1-r)L) + \rho_t]) \qquad (6a)$$

if a farmer buys insurance. Similarly, farmer's net income without insurance will be:

$$c_{it}^{NI} = 5 \times (\max[\underline{c}, (y_{it} - (1-r)L)]) \qquad (6b)$$

Note that if there is not full repayment of loans (for instance, if borrower has an income greater than $\underline{c}$ but less *(1+r)L*, the amount repaid will differ from*(1+r)L*), average consumption across farmers with insurance will not equal average farmer's consumption under the no insurance state. In the simulation results reported in Table 2, we set the consumption minimum to zero. To convert the consumption in the previous equations (expressed in kilos of rice) to $, we used a price of $0.16 per kilo.

Finally, to explore the value of insurance, we need to assume something about farmer's sensitivity to risk. In the analysis to follow, we assume that farmer preferences are given by the following Constant Relative Risk Aversion (CRRA) utility function:

$$U(c_{it}) = \frac{C_{it}^{1-g}}{1-g}, \quad \text{for } g > 0, g \neq 1., \qquad (7)$$

where g is the coefficient of relative risk aversion. The higher the parameter *g*, the more risk averse the individual. The analysis below will consider various degrees of risk aversion. Finally, it will be sometimes convenient to express the value of a given risky prospect (e.g., a risky income stream without insurance, or with imperfect ARBY insurance) in certainty equivalence terms. In particular, the certainty equivalent of the risky consumption stream $c_{it}(\omega_t, \beta^j, \varepsilon_{it}^j)(j = y, s)$ is defined as the value of consumption that if received with certainty would yield the same level of well-being as the expected utility of the risky income stream. The certainty equivalent of contract *k*, c_{ce}^k, is thus defined as:

$$c_{ce}^k = \{c \mid U(c_{ce}^k) = E[U(c_{it}(\omega_t, \beta^j, \varepsilon_{it}^j)]\}$$

Table 1 reports the certainty equivalence values for various degree of risk aversion. For a highly risk averse person, the uninsured consumption stream (which yields an expected consumption level of \$2584) has a certainty equivalence value of \$2197. This person would in principal be indifferent between the risky consumption stream, or giving up average \$387 in consumtpion (or 15% of expected annual consumption) in order to eliminate the risk. The certainty equivalence of ARBY insurance (AFTER payment of the actuarially fair premium) is \$2342. This figure indicates that the highly risk averse person would be willing to pay up to \$145 (beyond the total annual premium of \$405) in order to buy the ARBY insurance. These willingness to pay figures of course diminish as risk aversion diminishes, as shown in the table.

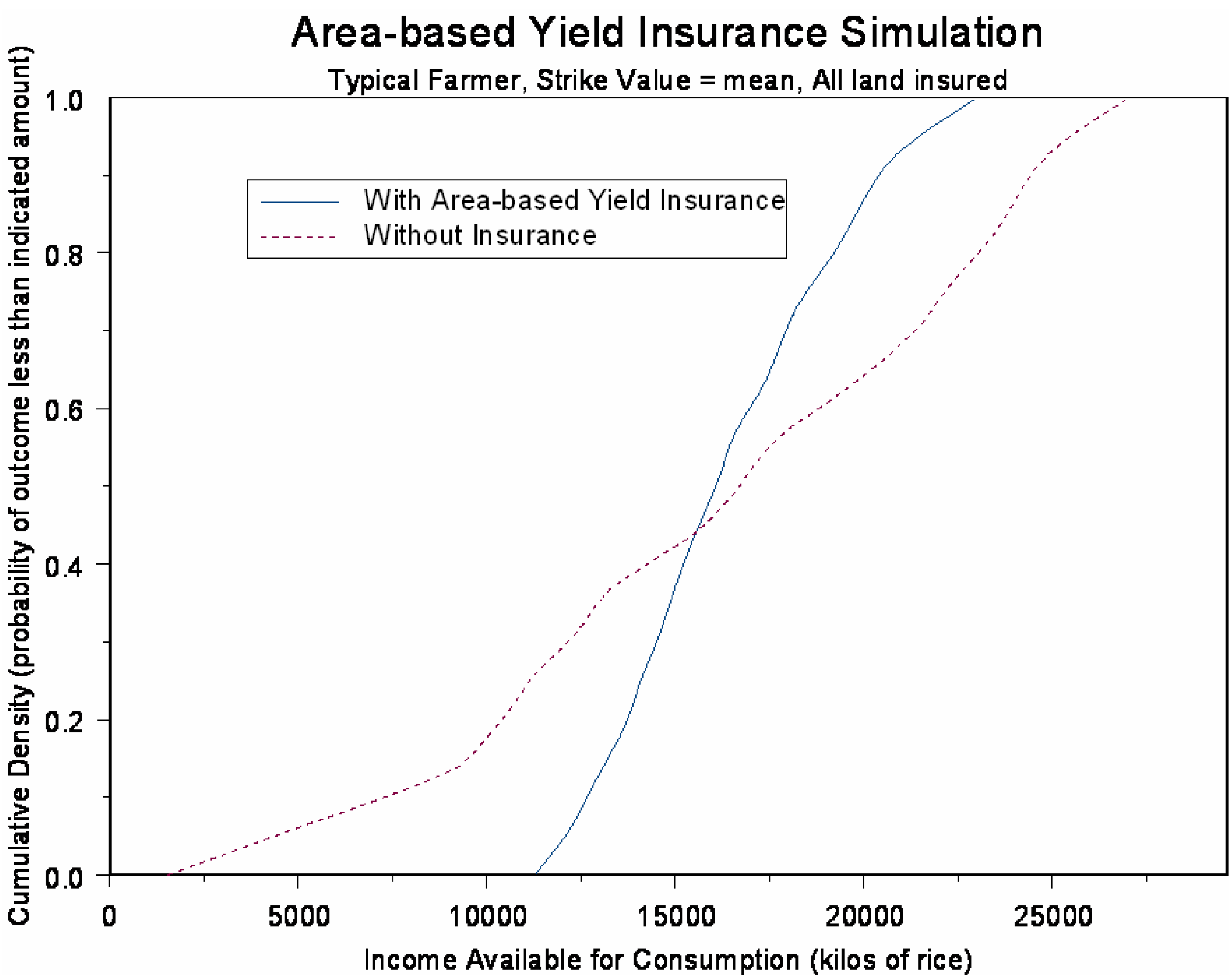
Results for the simulation are shown in Tables 1 assuming a strike point of 100% ($\tilde{y}_t = \mu^y$). As shown in Table 1, benefits to borrowers from ARBY come from smoothing borrowers' utilities (less variability). Note that the insurance is valuable (smoothes consumption and improves expected utility) for both high and low risk aversion farmers. However, the analysis here is for the favorable case in which $\beta_i = 1$. Further analysis could identify farmer types for which the insurance would cease to be valuable.

Table 1
Typical Farmer and Lender: Payoffs
(Coverage = 100% acreage & $\beta_i = 1$)

Variable		With ARBY		Without ARBY	
		Mean	**Std Dev**	**Mean**	**Std Dev**
Individual Yield		6,542	551	6,542	551
Total Output (5 has)		24,758	7,654	24,758	7,654
Net income		3,961	1,120	3,961	1,224
Insurance payment		$405	0	--	--
Expected Indemnity		$405	Xx	--	--
Consumption		$2,584	1,121	2,584	1,224
Loan repayment		$1,376.9	0.0	1,376.7	2.3
Utility [certainty equivalence, $'s] under different degrees of Risk Aversion:	Low risk aversion	660 [$2531]	240	656 [$2511]	267
	Mid-low risk aversion	276 [$2418]	86	274 [$2392]	97
	Middle risk aversion	99 [$2450]	24	98 [$2401]	28
	Mid-high risk aversion	40.1 [$2365]	6.8	39.6 [$2278]	8.5
	High risk aversion	23.6 [$2342]	2.5	23.3 [$2197]	3.6

Notes: Simulation over 100 years. Average loan: $ 1,223.
* Units: Yields and outputs are expressed in Kg per Ha; the remaining variables, in $.

The figure below presents the same information, showing the cumulative distribution of consumption (as defined in 6a and 6b). As can be seen, the ARBY insurance cuts off the probability of low outcomes. Without insurance, there is a 20% probability that the producer's net income falls below 11,000 kilos of rice (or $1760). Under the ARBY insurance, this probability drops to zero. Because of insurance premium, the probability of high outcomes are of course also reduced under ARBY. But as the expected utility values in Table 1 show, the risk averse borrower prefers this swap. A risk neutral borrower would of course be indifferent between the two distributions.



Finally, Table 2 explores the impact of lowering the strike point. As can be seen, the actuarially fair premium drops quickly as the strike price declines. While expected utility is strictly increasing in the strike price for the typical farmer being analyzed, this will not necessarily be true for farmers with different values of β_i. The analysis above can be easily extended different values of the β_i. Using information on the valley-wide distribution of the β_i,[7] it would then be possible to estimate the potential demand for any particular ARBY scheme.

Table 2
Typical Farmer and Lender: Value to Borrower by Strike Point
(Coverage = 100% acreage & $\beta_i = 1$*)*

Insurance Strike Point, $\tilde{y}_t$	Borrower Expected Utility [Certainty Equivalent, $'s]	Insurance Payment Per-Hectare, π_t ($)
0 (No ARBY)	**39.6 [2278]**	**0**
0.40	39.6 [2278]	$0.16
0.50	39.7 [2295]	$1.60
0.75	39.9 [2330]	$27
0.90	40.0 [2348]	$56
1.00	40.1 [2365]	$82

Notes: Average loan: $ 1,131; Normalized valley yield: 4,758. Subsistence consumption level: 0. Simulation over 100 years.
CRRA Utility: $U(c)= c^{1-g} / (1-g)$, with g=0.66; Farmer has mid-to-high Risk Aversion.

3. Area-based Yield Insurance and the Reduction of Default Probabilities: Crowding-in Demand and Supply in the Credit Market

The simulation results analyzed in the prior section make the strong assumption that individuals will always pay back as much as is financially possible. Under this assumption, default is not an issue, even without ARBY. However, if we relax this

[7] Econometric estimation of (3) yields the distribution of the β_i.

assumption and more realistically assume that farmers will always retain enough income to at least feed their families ($\underline{c}>0$), then this no default scenario will of course change.

Under less draconian repayment assumption, some of the benefit of ARBY will pass to the lender in the form of lower default rates and higher earnings. Simulation that sets $\underline{c}$ to 20% of long-term expected income shows that ARBY eliminates default and increases realized returns on the lenders loan portfolio by about 10 percent. This shift of benefits to the lender means, however, that the insurance is less valuable to borrowers in the short term sense. However, additional value would accrue to borrowers once we take into account their gain in future utility from not having defaulted in the present. Additional analysis can further explore these points.

The likelihood that ARBY insurance can reduce default suggests that it could have impacts on both the demand and supply sides of the credit market. From the demand side, the elimination of the probability of default eliminates the risk that borrowers will loose their collateral. As discussed by Bucher *et al.* (2007), studies in Guatemala, Honduras, Nicaragua and Peru suggest that between 15% and 30% of all potential borrowers are "risk rationed," refusing available loan contracts (and retreat to safer, lower return activities) in order to avoid the risk of default and collateral loss. The returns to ARBY insurance that brings these individuals into the market are potentially quite high (see Boucher and Guirkinger, 2006).

In addition, as documented by Trivelli (2006) for the case of the north coast of Peru, local ag lenders (the *Cajas*) are extremely reluctant to carry a large loan portfolio. At the root of this reluctance is a two-sided fear of covariant risk. Directly, locally based lenders clearly do not want to carry a large fraction of their portfolio in loans where the likelihood of default is highly correlated (as would happen in a drought year). In addition, covariant risk of this sort also generates a secondary political risk. When a large number of producers face default, they have obvious political incentives to demand a bail-out or other form of debt forgiveness. Precisely this scenario took place following the 1998 El Niño event. The resulting governmentally mandated *Rescate Financiero* (debt forgiveness) further reduced lenders willingness to lend to agriculture (see Trivelli, 2006). But here is precisely where ARBY insurance can reduce both the direct risk of correlated default, as well as the risk of political default, which is also produced by covariant shocks.

4. Implementation Issues for Area-based Yield Insurance: From Theory to Practice

The *ex ante* analysis above indicates large private and social gains to area-based yield insurance. ARBY would appear to be an attractive option precisely because it promises to crowd-in supply and demand in rural credit markets, enhancing the productivity of the sector.

These observations raise the question as to why the private insurance market (in Peru and elsewhere) generally fails to offer ARBY insurance products.[8] There are at least three reasons for the failure of the private market to provide this insurance:

1. The novelty of the product and the costs associated with its innovation;
2. Scarcity of reliable, long-term data on area yields or the weather indices needed to estimate them (meaning that potential insurance providers face parameter uncertainty as they try to write insurance contracts); and,

[8] In the context of the US, it is often that government subsidized conventional insurance products crowd-out market supply of ARBY insurance contracts. Such crowding out is not the issue in Peru and most other areas in the developing world.

3. Costs of marketing the product, especially to the smallholder sector (where returns are likely to be highest.

Following the example of other micro-insurance products, problem 3 can probably be addressed by bundling ARBY contracts with microfinance (for an example of this bundling in the case of micro health insurance, see xxx).

The other two problems have a public good character. Problem 2 in a very direct sense reflects past public good failures in the form of a public sector that has not maintained credible long-term yield and, or weather information. Problem 1 also presents an important obstacle since no individual insurance provider may have incentives to pay innovation costs, especially given problems 2 and 3.

These observations suggest that there may be a public role in underwriting innovation costs, creating reliable long-term information,[9] and sharing some of the excess risk (that results from parameter uncertainty) until experience and more reliable long-term information come on-line. But how costly, would it be for a public sector entity to underwrite the risk of an ARBY insurance scheme over a short term period until sufficient learning had occurred to permit the private sector to bear the full risk of the program?

Over the long-term, the expected cost of an underwriting guarantee is of course zero. That is, if the program were run for a long-time, then the premium would almost surely cover the indemnity payments. In the short term, it is of course possible that accumulated premiums would be insufficient to cover indemnity payouts. To get a handle on the magnitude of this risk, the Table 3 shows the probability of losses of different magnitudes (for purposes of this analysis, administrative costs are assumed to be

[9] As discussed above, ARBY insurance will become more valuable to farmers as direct reliable yield measurement can replace the reliance on weather indices and estimated average yields.

zero). The table is based on the simulation analysis Lambeyeque rice producers used above. Two alternative insurance contracts are illustrated. The first offers a payoff if yields fall below 80% of their long-run average. Under this plan, a farmer receives $1 in indemnity for every dollar that yields fall below 80% of their long-run average. The actuarially fair premium for this insurance is $37 per-planted hectare. This amount is 4.6% of the production loan taken by a typical rice farmer. Rolling this cost into the interest rate would increase the annual interest on the loan by approximately 10 percentage points.

Also illustrated is a more complete coverage scheme that pays off whenever yields fall below their long-term average ($1 in indemnity for every dollar below the long-term average). This insurance is more costly ($105 per cultivated hectare). The rows of the table display the probabilities that per-hectare *insurance* losses could take on certain amounts. Gains and losses over a *T*-year time horizon are calculated as follows:

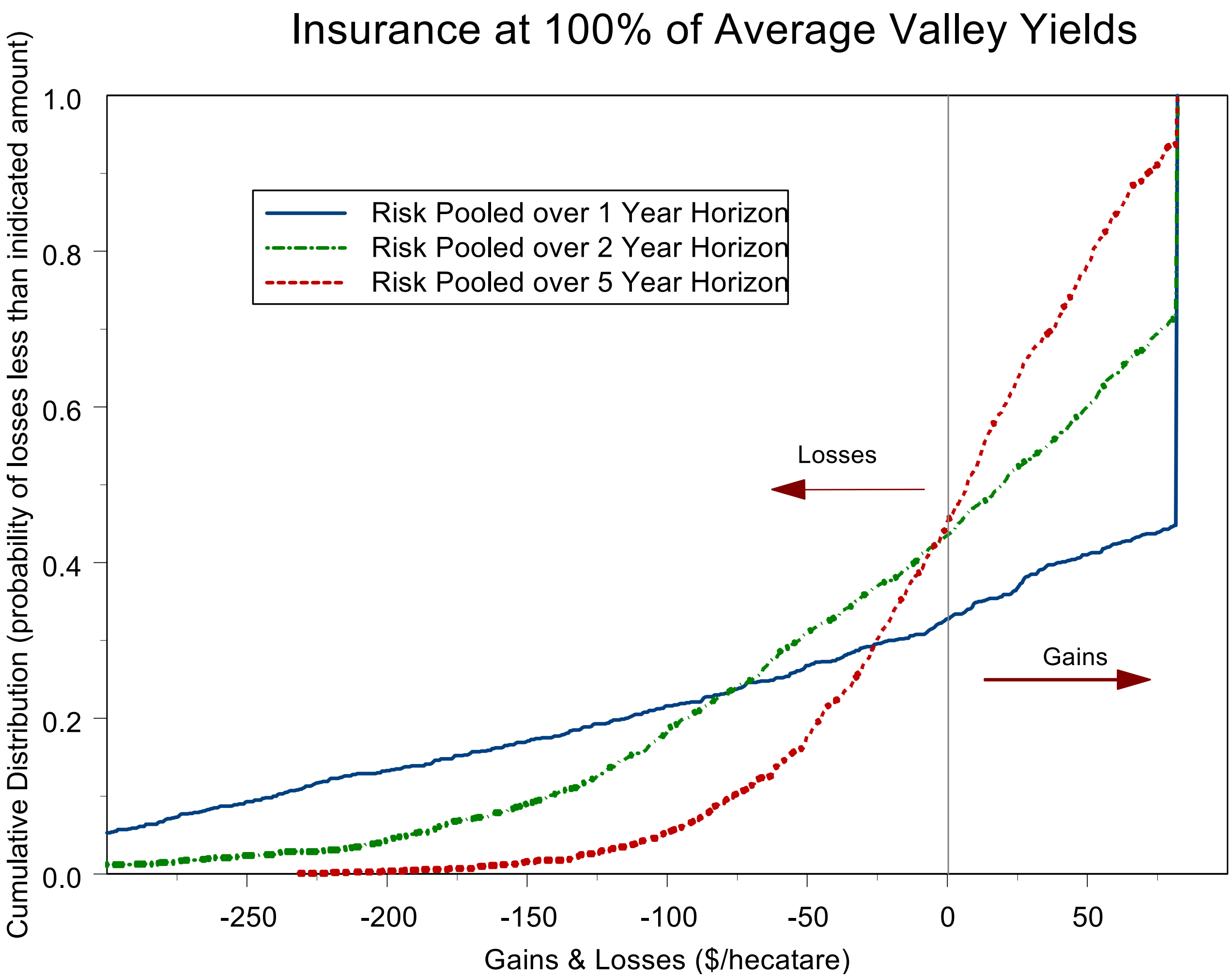
$$T\pi - \sum_{t=1}^{T}(\rho_t),$$

where π is the per-hectare premium and ρ_t is the random indemnity payment for year t. Note that premiums are pooled over the T years, and under this definition, losses appear as negative values. As can be seen in Table 3, over a single year time horizon, there is a 1% probability that insurance losses could be more than $300 per-hectare financed (recall however, that the farmer's debt obligation is $800 per-hectare). Pooling risks over even just two years, drops that risk to almost zero. Pooling risk (and premium) over a five year period makes it extremely unlikely that losses will be more than $100 per-hectare (there is only a 1% probability that losses will be over $100), and there is only a 20%

probability of losses less than $100 per-hectare. Put differently, premiums collected are sufficient to cover losses 80% of the time even when risk is pooled only over a five year horizon. The full estimated cumulative distribution function for losses (on which the figures in the risk table are based) is included below in the case of the 100% ARBY plan. As can be seen, the risk of losses over a one-year horizon are not trivial. Howver, this risk diminishes rapidly if the underwriter takes on a long-term commitment. Note also that this risk exposure could be reduced further by raising the premium to farmers, or by charging a usage fee to participating lenders (who would benefit from diminished default risk).

Table 3
Short-term Costs and Risks of Underwriting ARBY Insurance

	80% Plan (Payoffs occur when Valley productivity falls below 80% of Long-term Average)			*100% Plan* (Payoffs occur when Valley productivity falls below Long-term Average)		
Expected Yield per Cultivable Hectare ($US)	$802			$802		
Actuarially Fair Annual Premium per Planted Hectare	$37			$82		
Premium as % of Typical of Loan*	4.6%			13%		
Time Horizon Over which Loss Probabilities Calculated (years)	1	2	5	1	2	5
Expected Loss	0	0	0	0	0	0
Probability of loss worse than $300/hectare	1%	~0%	~0%	6%	1%	~0%
Probability of loss between $200 and $300/hectare	4%	1%	~0%	9%	4%	0%
Probability of loss between $100 and $200/hectare	10%	8%	1%	8%	15%	5%
Probability of loss between $50 and $100/hectare	3%	10%	7%	5%	7%	9%
Probability of loss between $0 and $50/hectare	3%	12%	13%	4%	15%	19%



4. Conclusions

The analysis here has used real data to illustrate the potential for area-based yield insurance to crowd-in supply and demand for agricultural finance.[10] While this potential has been recognized at least in part by a number of other authors, the actual implementation of area-based yield insurance has often floundered over the lack of

[10] It should be stressed that the valuation of insurance presented here assumes that producers behave in accordance with the axioms of the expected utility hypotheses. Behavioral research indicates that in reality individuals may depart from a number of these axioms. In an effort to get a sharper insight into the real world value of ARBY insurance, the authors of this study are planning field experiments to explore individuals' willingness to pay for ARBY insurance.

credible long-term statistical information needed to make area-based yield insurance immediately attractive to the private sector. But as argued here, this lack of information reflects a past history of public good failures. An appropriate response would thus seem to be a dual approach in which (1) needed informational infrastructure is created and (2) short term parameter uncertainty is resolved by public sharing of risk. The returns to such a dual approach would seem to be large, both in terms of rural income generation, but also in terms of underwriting the income growth of the small farm sector that suffers most from risk and incomplete financial markets.

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Appendix: Econometric Results

(available from the authors)