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Replanting Guarantee in Developing Countries

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Introduction

In this paper we address the risk management problems of the rural poor in the developing world whose livelihoods depend, directly or indirectly, on agriculture. The economic lives of such individuals are typically characterized by exposure to profound weather-related perils such as droughts, floods, and windstorms, and by lack access to formal insurance and financial services that forces them to employ risk-avoidance, risk-diversification, and informal risk-sharing practices that are either costly or offer inadequate risk protection (Coate and Ravallion, 1993; Townsend, 1994; Ligon, Thomas, et al., 2002; Dubois, Jullien, et al 2008; Gine 2009; Chantarat et al 2007).

This paper is devoted to the optimal design of weather index insurance, which over the past twenty years has received increasing attention from development economists and practitioners as offering a potential solution to the agricultural risk management problems of the developing world (Hazell, 1992; Miranda and Vedenov, 2001; Bryla and Syroka, 2007). Unlike more conventional forms of agricultural insurance, which provide payouts based on verifiable production losses, weather index insurance provides payouts based on the value of a publicly observed “index” or some other variable that is highly correlated with losses. Most weather index insurance contracts are designed to protect against drought, providing payouts when rainfall over a specified period of time falls below a prescribed threshold. However, weather index insurance contracts can also be fashioned to provide payouts when rainfall exceeds a prescribed threshold where excess rain, rather than drought, is the most pervasive risk, and can be based on other weather and weather-related indexes such as temperature, area yields, flood levels, satellite measured vegetation indices, and regional livestock mortality rates (Bardsley,

Abey, and Davenport 1984; Halcrow 1949; Miranda 1991; Skees, Hartell, and Murphy 2007; Khalil, Kwon, Lall, Miranda, and Skees 2007; Leiva and Skees 2008; Miranda and Farrin 2012).

Weather index insurance avoids many of the problems that undermine more conventional forms of agricultural insurance, including moral hazard, adverse selection, and high administrative costs. Because the insured cannot significantly influence the value of the index, and thus the indemnity paid by the contract, weather index insurance is essentially free of moral hazard.

Because a weather index insurance contract's premium rate is typically based on publicly available information, not privately held information, weather index insurance is largely free of adverse selection. And because weather index insurance does not require individually-tailored terms of indemnification or separate verification of individual loss claims, it is less expensive to administer. These features of weather index insurance substantially reduce its cost relative to conventional agricultural insurance, making it more affordable, particularly to the rural poor in the developing world (Miranda and Farrin, 2012).

A feature of weather index insurance that distinguishes it from conventional agricultural insurance, whose payouts must await verification of losses, is that weather index insurance indemnities can be paid at virtually any time, and, in particular, before losses are fully realized. Payment of indemnities prior to the realization of losses may well be desirable if provides the insured with financial resources in time to take measures to mitigate the losses effectively.

This paper explores alternate timing for index insurance payouts. In particular, we explore the potential benefits of replanting guarantee, the payouts of which arrive before losses are incurred, in time to be used to take measures to mitigate, that is, reduce, eventual losses. Crop yields are especially sensitive to the weather conditions that exist during the agronomic phase of

germination, which occurs shortly after planting. A poor smallholder who invests in high quality seed can quickly find that poor rainfalls shortly after planting have substantially reduced the maximum attainable yield at harvest. Given that it is still early in the planting season, the farmer can typically replant. However, if the farmer is poor and credit-constrained, he may lack the financial means to purchase new seeds, given that he spent what little cash he had on his original bag of seeds.

In 2014, in Tanzania, Acre Africa launched a mobile-enabled weather index insurance contract that is bundled by seed companies into the bags of certified seed they sell, known as "replanting guarantee". The insurance product provides payouts to the registered smallholder if a drought occurs during the first three weeks after planting, with the farmer receiving a mobile money transfer for the full cost of quality seed so they can replant with high quality seed within the same season.

In this paper we explore how replanting guarantee insurance affect farmers' seed choice and replanting decision using a infinite horizon, stochastic dynamic optimization model. We consider a subsistence farmer who plants a single crop on an annual cycle and who, a few weeks after planting, may choose to abandon his original crop and replant if poor weather during germination has severely diminished harvest yield expectations. Each production year is marked by three time points at which the farmer must undertake decisions. At time point 1, the farmer decides whether to plant traditional seed, or, at a greater cost, higher yielding certified seed. At time point 2, the farmer observes the condition of his emerging crop and decides whether to abandon it and replant, and, if so, whether to plant traditional or certified seed. And harvest is

realized at time point 3. At each time point, the farmer also decides how much to consume and how much of to store, in addition to any planting or replanting decision he may need to take.

We assess the values of replanting guarantee insurance by deriving the smallholders expected ex-ante welfare under two scenarios: farmers who must undertake decisions without replanting guarantee insurance and farmers who may purchasing hybrid seed coupled with a replanting guarantee insurance. The premium is included in the price of seed. If a drought occurs during the first three weeks of planting, the farmer is provided with a new bag of seed.

Farmer's Decision Problem

Consider a subsistence farmer who plants a single crop on an annual cycle and who, a few weeks after planting, may choose to abandon his original crop and replant if poor weather during germination has severely diminished harvest yield expectations. Each year t is marked by three time points τ at which the farmer must undertake decisions. At $\tau = 1$, the farmer decides whether to plant “traditional” seed, $i = 1$, or, at a greater cost, a higher yielding “hybrid” seed, $i = 2$. At $\tau = 2$, the farmer observes the condition of his emerging crop and may choose to not replant, $j=0$, replant traditional seed, $j=1$, or replant hybrid seed, $j=2$. At $\tau = 3$, the harvest is realized.

A crop planted to seed variety i at $\tau = 1$ possesses a maximum attainable harvest yield \bar{y}_i , where $\bar{y}_2 > \bar{y}_1 > 0$. A crop planted to seed variety i at $\tau = 2$ has its maximum attainable yield is reduced by a proportion $\gamma \in (0,1)$, due to diminished growing time. A drought can occur between $\tau = 1$ and $\tau = 2$ with probability p_1 and, if it occurs, diminishes the maximum attainable yield from a crop planted at $\tau = 1$ by a proportion $\beta_1 \in (0,1)$, regardless of seed variety. A

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drought can occur between $\tau = 2$ and $\tau = 3$ with probability p_2 and, if it occurs, diminishes the

maximum attainable yield by a proportion $\beta_2 \in (0,1)$, regardless of the seed variety or when it was planted. As such, the yield realized at harvest $\tau = 3$ will be

$$y_{ijkl} = \begin{cases} \overline{y}_i(1 - k\beta_1)(1 - k\beta_2) & j = 0 \\ \overline{y}_j(1 - \alpha)(1 - k\beta_2) & j = 1,2 \end{cases}$$

where i indicates the seed variety planted at $\tau = 1$, j indicates the replanting decision at $\tau = 2$, $k = 1$ indicates the occurrence of a drought between $\tau = 1$ and $\tau = 2$, and $l = 1$ indicates the occurrence of a drought between $\tau = 2$ and $\tau = 3$.

The cost of planting seed variety i , κ_i , is the same regardless of when the seed is planted. More specifically, $\kappa_1 = \kappa_p$ and $\kappa_2 = \kappa_p + \kappa_h$, where $\kappa_p > 0$ is the cost of planting and $\kappa_h > 0$ is the cost of purchasing hybrid seed. No additional cost is incurred, $\kappa_0 = 0$, if the farmer does not replant at $\tau = 2$.

The farmer subsists on the crop he grows and may store it over time. Thus, at each time point τ , the farmer begins with a prescribed “wealth” in the form of stocks plus, in $\tau = 3$, new production, and must decide how much of it to consume and how much of it to store, in addition to any planting or replanting decision he may need to take. Utility of consumption between time points is a function u of rate of consumption during the period; in particular, if a quantity c is consumed between time point τ and the subsequent time point, then the utility derived by the farmer during that period is given by $u_\tau(c) = u(c/\Delta\tau)$, where $\Delta\tau$ is the length of the period in years. The utility function is twice continuously differentiable with, $u' > 0$, $u'' < 0$, and $u'(0) = \infty$.

The farmer maximizes the present value of current and expected future utility of consumption over an infinite horizon, discounting the future at a continuous annual rate $\rho > 0$. Thus, at time

point τ , the farmer discounts value at the subsequent time point by a factor $\delta_\tau = \exp(-\rho\Delta_\tau)$. The farmer's optimization problem can be captured by three Bellman equations, one for each decision point τ :

$$V_1(w) = \max_{0 \leq x \leq w - \kappa_i} \max_{i=1,2} \{u_1(w - x - \kappa_i) + \delta_1 \sum_{k=0,1} p_{1k} V_{2ik}(x)\}.$$

$$V_{2ik}(w) = \max_{0 \leq x \leq w - \kappa_j} \max_{j=0,1,2} \{u_2(w - x - \kappa_j) + \delta_2 \sum_{l=0,1} p_{2l} V_3(x + y_{ijkl})\}.$$

$$V_3(w) = \max_{0 \leq x \leq w} \{u_3(w - x) + \delta_3 V_1(x)\}.$$

Here, $V_1(w)$ represents the maximum present value of current and expected future utility of consumption, given the farmer possesses wealth w at decision point $\tau = 1$; $V_{2ik}(w)$ represents the same, given the farmer possesses wealth w at decision point $\tau = 2$, having originally planted seed variety i , and having either experienced a drought since planting, $k = 1$, or not, $k = 0$; and $V_3(w)$ represents the same, given the farmer possesses wealth w at decision point $\tau = 3$. For notational brevity, we have let $p_{\tau 1} = p_\tau$ and $p_{\tau 0} = 1 - p_\tau$.

Replanting Guarantee Insurance

Suppose purchasing hybrid seed in period 1 carries a “replanting guarantee” that provides the farmer a bag of hybrid seed for no additional cost in period 2, if a drought occurs in period 1. Further assume that a premium $\pi = (1 + \theta)p_1\kappa_h$ is added to the purchase price of hybrid seed in period 1, where $\theta \geq -1$ is the loading factor. Then the farmer's optimization problem can be captured by three Bellman equations, one for each decision point τ :

$$V_1(w) = \max_{\substack{i=1,2 \\ 0 \leq x \leq w - \kappa_{1i}}} \{u_1(w - x - \kappa_{1i}) + \delta_1 \sum_{k=0,1} p_{1k} V_{2ik}(x)\}.$$

$$V_{2ik}(w) = \max_{\substack{j=0,1,2 \\ 0 \leq x \leq w - \kappa_{2ikj}}} \{u_2(w - x - \kappa_{2ikj}) + \delta_2 \sum_{l=0,1} p_{2l} V_3(x + y_{ijkl})\}.$$

$$V_3(w) = \max_{0 \leq x \leq w} \{u_3(w - x) + \delta_3 V_1(x)\}.$$

Here,

$$\kappa_{1i} = \begin{cases} \kappa_p, & i = 1 \\ \kappa_p + \kappa_h + \pi, & i = 2. \end{cases}$$

$$\kappa_{2ikj} = \begin{cases} 0, & j = 0 \\ \kappa_p, & j = 1 \\ \kappa_p, & i = 2 \text{ and both } k = 1 \\ \kappa_p + \kappa_h, & j = 2 \text{ and either } i \neq 2 \text{ or } k \neq 1 \end{cases}$$

Analysis

We now numerically solve and simulate the model in order to assess how replanting guarantee affect farmer's seed choice, with and without a premium subsidy. In our base-case simulation, we maintain the following assumptions: (a) the maximum attainable yield of hybrid seed planted at $\tau = 1$ is 40% higher than that of traditional seed planted at $\tau = 1$; (b) the probabilities of drought between $\tau = 1$ and $\tau = 2$, and drought between $\tau = 2$ and $\tau = 3$ are both 20%; (c) in case that the farmer replants, the yield loss due to late planting is 10% for both hybrid seed and traditional seed; (d) the yield loss due to drought during germination period and after germination period are 60% and 50 %, respectively; (e) the expected rate of return on hybrid seed planted at $\tau = 1$ is 15%. (f) the farmer exhibits a constant relative risk aversion of 2.0.

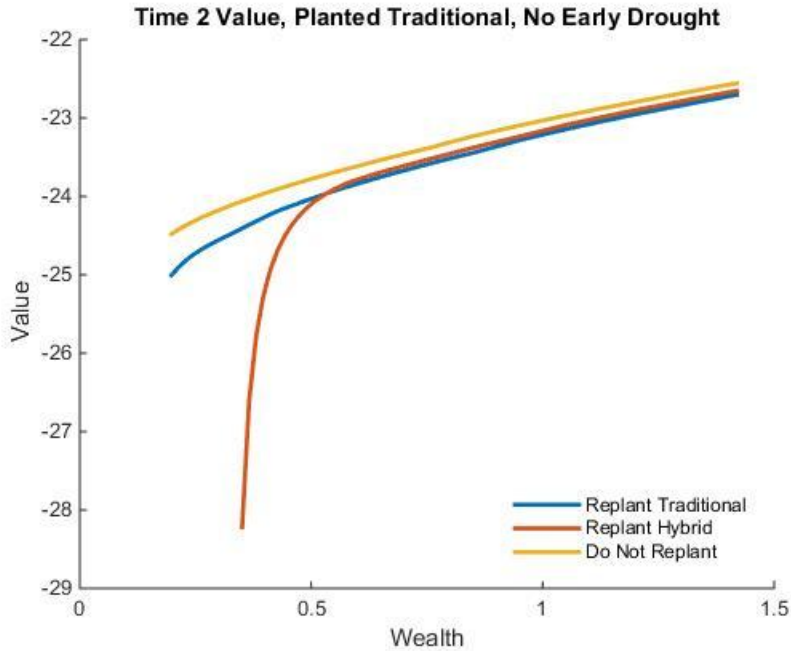


Figure 1. The maximum present value of current and expected future utility of consumption, given the farmer possesses wealth w at decision point $\tau = 2$, having originally planted traditional seed, and having not experienced a drought since planting.

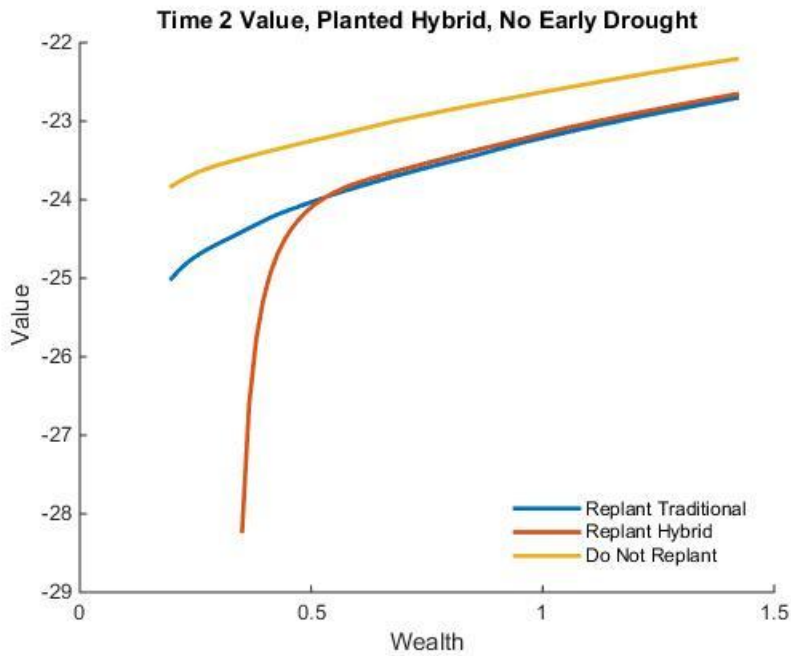


Figure 2. The maximum present value of current and expected future utility of consumption, given the farmer possesses wealth w at decision point $\tau = 2$, having originally planted hybrid seed, and having not experienced a drought since planting.

We start with the case without replanting guarantee. Figure 1-4 illustrate the maximum present value of current and expected future utility of consumption at decision point $\tau = 2$, V_{2ik} , as a function of wealth the farmer possesses at $\tau = 2$, in four different scenarios. Figure 1 and 2 show that "do not replant" is a dominating choice for the farmer if he has not experienced a drought since planting, regardless of whether he planted traditional seed or hybrid seed at $\tau = 2$. It is quite obvious since it is not necessary to replant if there is no drought during germination period at all.

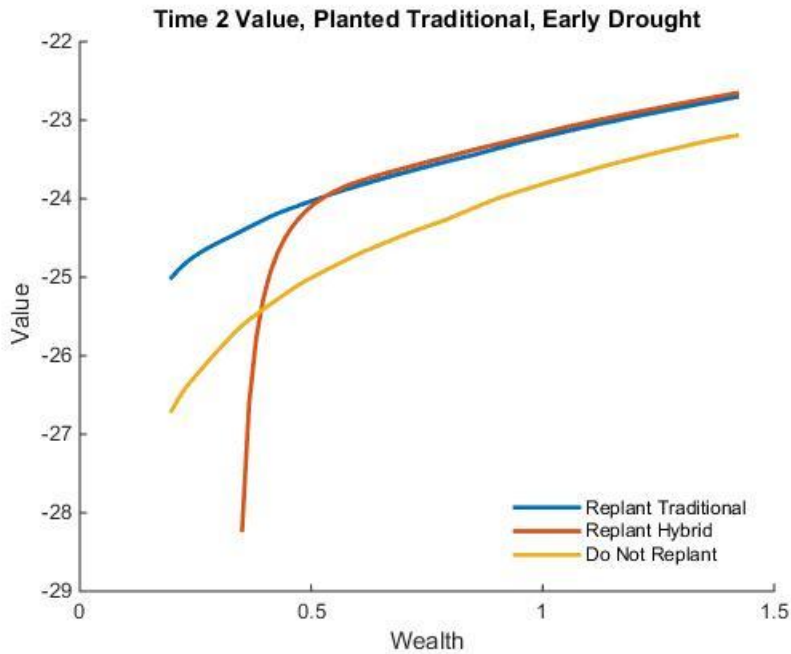


Figure 3. The maximum present value of current and expected future utility of consumption, given the farmer possesses wealth w at decision point $\tau = 2$, having originally planted seed variety i , and having experienced a drought since planting.

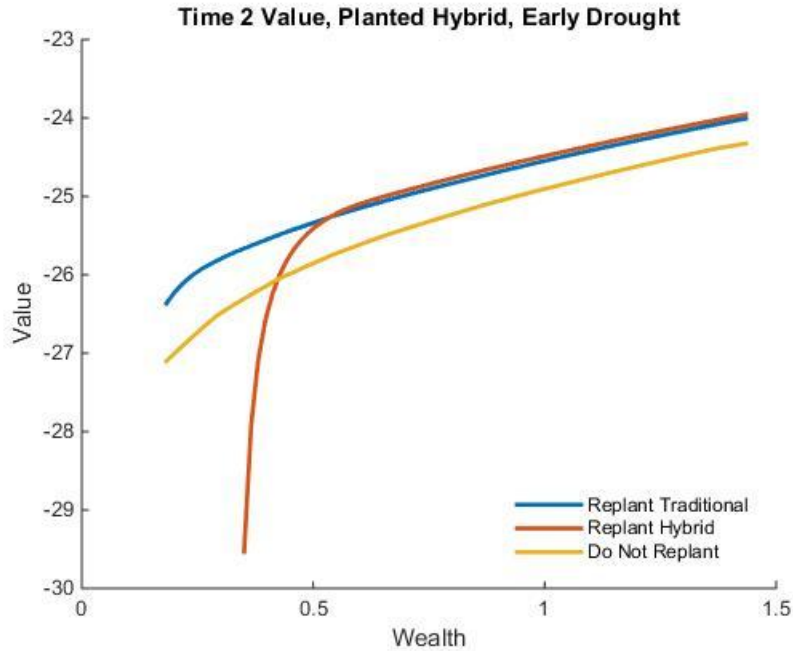


Figure 4. The maximum present value of current and expected future utility of consumption, given the farmer possesses wealth w at decision point $\tau = 2$, having originally planted hybrid seed, and having experienced a drought since planting.

However, in Figure 3 and 4, given that a drought has occurred during germination period, the optimal replanting decision now depends on the wealth level. The patterns in these two figures are similar despite of the farmer's initial seed choice: there exist a cut-off point in wealth, below that it is optimal to replant with traditional seed, and above that it is optimal to replant with hybrid seed. In other words, poor farmer chooses to replant traditional seed and rich farmer chooses hybrid seed, which is also intuitive.

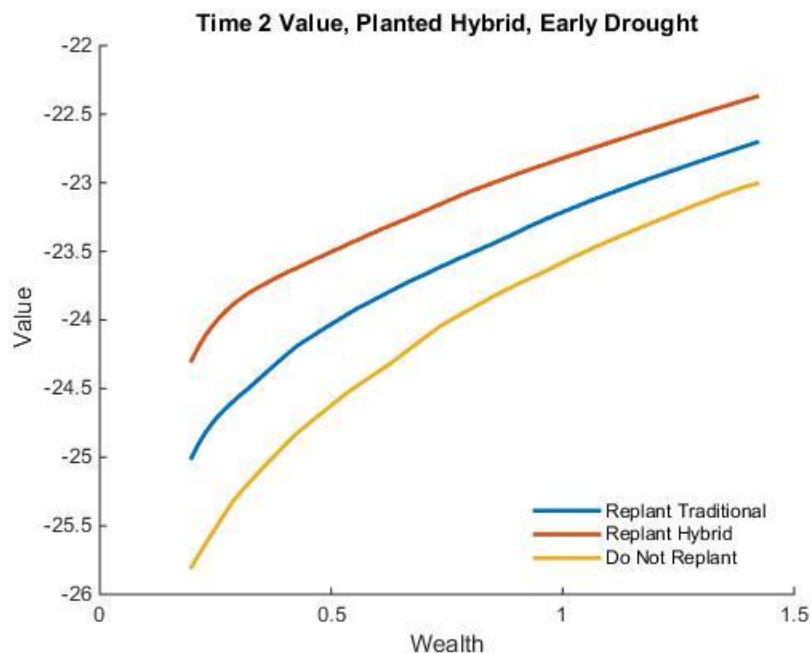


Figure 5. The maximum present value of current and expected future utility of consumption, given the farmer possesses wealth w at decision point $\tau = 2$, having originally planted hybrid seed, and having experienced a drought since planting, with replanting guarantee.

Now we move on to the case with replanting guarantee. The graphs are similar to those without replanting guarantee in the first three scenarios, but not in the last scenario. In Figure 5, given that the farmer purchased hybrid seed bundled with replanting guarantee $\tau = 1$ and a drought has occurred during germination period, "replant hybrid seed" becomes a dominating choice regardless of wealth level. Because in this case poor farmers can afford to replant hybrid seed with the help of replanting guarantee, which indemnifies the farmer with a new bag of hybrid seed due to the drought.

Having seen that replanting guarantee has an influence on farmer's replanting decision at $\tau = 2$, we are interested in studying its impact on the farmer's original seed choice decision at $\tau = 1$, with and without subsidy. How much is the farmer willing to pay for the replanting guarantee? By

simulating the model without replanting guarantee, we get the following ergodic probabilities of all the possible decisions. Table 1 shows that the probability that the farmer plants traditional seed at $\tau = 1$ is 55% . Within the 55%, the probability that he chooses not to replant at $\tau = 2$ is 45.1%, and the probabilities of replanting traditional seed and replanting hybrid seed at $\tau = 2$ are 3.3% and 6.6%, respectively. The probability that the farmer plants hybrid seed at $\tau = 1$ is 45% . Within the 45%, the probability that he chooses not to replant at $\tau = 2$ is 37.8%, and the probabilities of replanting traditional seed and replanting hybrid seed at $\tau = 2$ are 0% and 7.2%, respectively. The total probability of not replanting is 82.9%, which is pretty close to 80%. (We assumed the probability of a drought during germination is 20%, so the probability of not having drought is 80%.) It implies that the farmer does not replant if there is not drought.

Table 1. Ergodic Probabilities of Decisions (Percent)

	No Rep	Rep T	Rep H	TOTAL
Plant Traditional	45.1	3.3	6.6	55.0
Plant Hybrid	37.8	0.0	7.2	45.0
TOTAL	82.9	3.3	13.8	100.0

without replanting guarantee

Next we take replanting guarantee into consideration. The premium is $\pi = (1 + \theta)p_1\kappa_h$. We vary the value of the loading factor θ to see how it changes the farmer's choices. $\theta=0$ indicates actuarially fair insurance. $\theta<0$ indicate subsidized insurance. $\theta>0$ is expected if replanting guarantee is offered at market rate.

Table 2-5 show the Ergodic probabilities of farmer's decisions as we increase θ from 0.1 to 1. Compared with Table 1, we observe that the probability of purchasing hybrid seed at $\tau=1$ increases, if the replanting guarantee is offered at $\theta=0.1$. But as we increase θ , the probability decreases and drops to 0 if $\theta=1$. That is to say, when the premium is relatively low, the farmer is

willing to purchase the hybrid seed bundled with replanting guarantee. However, the farmer can no longer afford it if the premium gets too high. We find that Table 3 is quite similar to Table 1. Given a replanting guarantee with loading factor $\theta = 0.155$, the farmer's seed choices are almost the same as those he makes in the scenario without replanting guarantee. That is, the farmer is indifferent. Thus we can calculate the willingness-to-pay for replanting guarantee by plugging in $\theta = 0.155$.

Table 6 illustrates the case of actuarially fair insurance. Table 7 and 8 illustrate the case with partial subsidy and full subsidy, respectively. Comparing Table 6-8 with Table 1, we find that the farmer is encouraged to purchase hybrid seed in these three scenarios. The smaller θ is, the probability of purchasing hybrid gets higher. However, we do not see a big difference in the percentages as we vary θ from -0.5 to -1.

Table 2. Ergodic Probabilities of Decisions (Percent)

	No Rep	Rep T	Rep H	TOTAL
Plant Traditional	29.5	3.0	2.9	35.4
Plant Hybrid	53.4	0.0	11.2	64.6
TOTAL	82.9	3.0	14.1	100.0

$\theta = 0.1$

Table 3. Ergodic Probabilities of Decisions (Percent)

	No Rep	Rep T	Rep H	TOTAL
Plant Traditional	45.2	3.4	6.3	54.9
Plant Hybrid	37.7	0.0	7.4	45.1
TOTAL	82.9	3.4	13.7	100.0

$\theta = 0.155$

Table 4. Ergodic Probabilities of Decisions (Percent)

	No Rep	Rep T	Rep H	TOTAL

Plant Traditional	68.2	3.0	11.3	82.5
Plant Hybrid	14.7	0.0	2.8	17.5
TOTAL	82.9	3.0	14.1	100.0

$\theta = 0.2$

Table 5. Ergodic Probabilities of Decisions (Percent)

	No Rep	Rep T	Rep H	TOTAL
Plant Traditional	82.9	3.4	13.7	100.0
Plant Hybrid	0.0	0.0	0.0	0.0
TOTAL	82.9	3.4	13.7	100.0

$\theta = 1$

Table 6. Ergodic Probabilities of Decisions (Percent)

	No Rep	Rep T	Rep H	TOTAL
Plant Traditional	21.3	2.8	0.9	25.0
Plant Hybrid	61.6	0.0	13.4	75.0
TOTAL	82.9	2.8	14.3	100.0

$\theta = 0$ actuarially fair insurance

Table 7. Ergodic Probabilities of Decisions (Percent)

	No Rep	Rep T	Rep H	TOTAL
Plant Traditional	8.2	1.4	0.0	9.6
Plant Hybrid	74.7	0.0	15.7	90.4
TOTAL	82.9	1.4	15.7	100.0

$\theta = -0.5$ partially subsidized

Table 8. Ergodic Probabilities of Decisions (Percent)

	No Rep	Rep T	Rep H	TOTAL
Plant Traditional	6.0	0.7	0.0	6.7
Plant Hybrid	76.9	0.0	16.4	93.3
TOTAL	82.9	0.7	16.4	100.0

$\theta = -1$ fully subsidized

Conclusion

In this paper we explore how replanting guarantee insurance affect farmers' seed choice and replanting decision using a infinite horizon, stochastic dynamic optimization model. We assess the values of replanting guarantee insurance by deriving the smallholders expected ex-ante welfare under two scenarios: farmers who must undertake decisions without replanting guarantee insurance and farmers who may purchasing hybrid seed coupled with a replanting guarantee insurance. We find that replanting guarantee encourages farmers to purchase hybrid seed if the premium is set at a reasonable level, and government subsidy might not be necessary. Our model can be used to calculate farmer's willingness-to-pay to help the insurance to set the premium if we have real data. We also attempt to generalize our findings to address other risk management problems in the developing world, such as famine. Here, index insurance provides payouts on occurrence of a drought, prior to the onset of famine, which is typically delayed due to the availability of stocks of food that will eventually be exhausted.

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