# ONLINE APPENDIX

# Time vs. State in Insurance: Experimental Evidence from Contract Farming in Kenya

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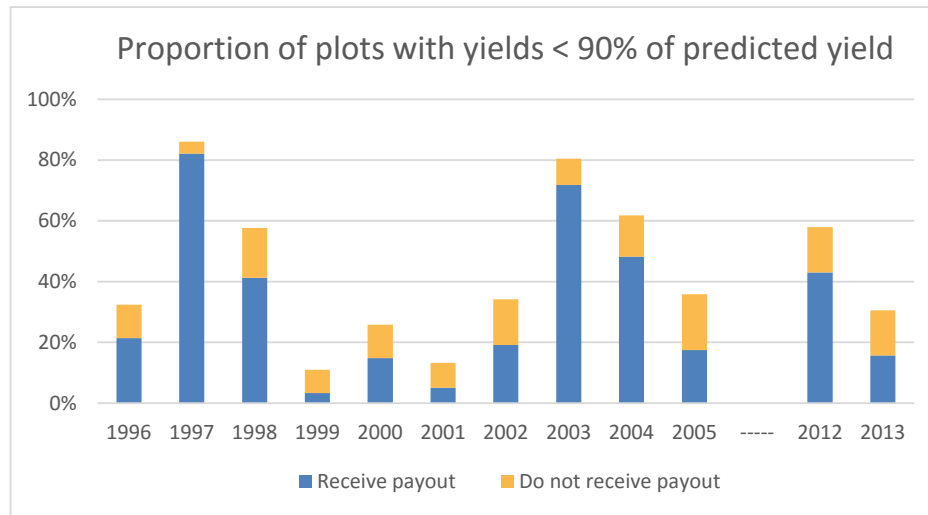## Contents

# A    Appendix figures and tables



Figure A.1: Simulation of Insurance Payouts Based on Historical Data

*Notes:* The diagram shows what proportion of farmers would have received a positive payout from the insurance in previous years, and gives a sense of the basis risk of the insurance product. The numbers are based on simulations using historical administrative data on yields. The total bar height is the proportion of people who would have received an insurance payout under a single trigger design. It is broken down into those who still receive a payout when the second, area yield based trigger is added, and those who do not. We do not have historical data for the years 2006-2011.

Table A.1: Main Experiment: Heterogeneous Treatment Effect by Required Rates of Return

| *Heterogeneity Variable* (X): | (1) RRR on inputs | (2) RRR 0 to 1 week | (3) RRR 0 to 1 week minus RRR 1 to 2 weeks |
|---|---|---|---|
| X *Pay At Harvest | -0.124 | 0.099 | 0.001 |
| | [0.141] | [0.114] | [0.152] |
| X | 0.073 | 0.035 | 0.121 |
| | [0.081] | [0.065] | [0.091] |
| Pay At Harvest | 0.761 | 0.685 | 0.716 |
| | [0.054] | [0.042] | [0.029] |
| Mean dep. var. (Pay Upfront group) | 0.052 | 0.052 | 0.052 |
| Mean heterogeneity var. (X) | 0.324 | 0.269 | -0.043 |
| S.D. heterogeneity var. (X) | 0.228 | 0.278 | 0.211 |
| Observations | 561 | 563 | 561 |

*Notes:* The table shows heterogeneities of the treatment effect of the pay-at-harvest premium on insurance take-up in the main experiment, by preferences in Money Earlier or Later experiments. The dependent variable is a binary indicator equal to one if the farmer took-up the insurance. *Upfront Payment* and *Upfront Payment with 30% discount* treatment groups are bundled together as baseline group, as outlined in the registered plan. The relevant heterogeneity variable is reported in the column title. *Mean dep. var. (Pay Upfront group)* reports the mean of the dependent variable in the *Pay Upfront* group. For each of the heterogeneity variables (X), we report their mean (*Mean heterogeneity var.*) and standard deviation (*S.D. heterogeneity var.*). These variables come from responses to hypothetical (Becker-DeGroot) choices over earlier or later cash transfers, from which we deduce three Required Rates of Returns. 'RRR for inputs' is the required rate of return which would (hypothetically) make farmers indifferent between paying for inputs upfront and having them deducted from harvest revenues. 'RRR 0 to 1 week' is the required rate of return to delay receipt of a cash transfer by one week. 'RRR 0 to 1 week - RRR 1 to 2 weeks' is the difference between the rates of return required to delay receipt of a cash transfer from today to one week from now, and from one week from now to two weeks from now. All columns include field fixed effects.

## Table A.2: Cash Drop Experiment: Balance Table

|  | Upfront [U] | Upfront + Cash [U + Cash] | Pay at Harvest [H] | Pay at Harvest + Cash [H + Cash] | P-value [H - U] | P-value [Cash - No cash] | N |
|---|---|---|---|---|---|---|---|
| Plot Size | .301 | .290 | .283 | .282 | .18 | .967 | 120 |
|  | (.107) | (.092) | (.121) | (.088) |  |  |  |
| Yield | 54.3 | 57.8 | 61.4 | 54.1 | .758 | .745 | 120 |
|  | (18.4) | (17.9) | (14.8) | (17.0) |  |  |  |

*Notes:* The table presents baseline balancing for the Cash Drop Experiment. *Previous Yield* is measured as tons of cane per hectare harvested in the cycle before the intervention. There are fewer covariates for this experiment as it did not have an accompanying survey, so we only have covariates from administrative data. P-values are based on specifications which include field fixed effects (since randomization was stratified at the field level).

## Table A.3: Intertemporal Preferences Experiment: Balance Table

| | Receive Now | Receive in One Month | p-value | N |
|---|---|---|---|---|
| Plot Size | .328 | .290 | .085 | 121 |
| | (.109) | (.106) | | |
| Yield | 58.0 | 57.8 | .571 | 121 |
| | (20.1) | (21.3) | | |
| Man | .793 | .590 | .009 | 119 |
| | (.408) | (.495) | | |
| Age | 48.3 | 47.7 | .573 | 119 |
| | (12.8) | (11.9) | | |
| Land Cultivated (Acres) | 3.81 | 2.67 | .02 | 118 |
| | (3.87) | (1.72) | | |
| Own Cow(s) | .844 | .852 | .987 | 119 |
| | (.365) | (.357) | | |
| Portion of Income from Cane | 3.62 | 3.32 | .193 | 119 |
| | (1.12) | (.943) | | |
| Savings for Sh1,000 | .327 | .295 | .526 | 119 |
| | (.473) | (.459) | | |
| Savings for Sh5,000 | .155 | .065 | .056 | 119 |
| | (.365) | (.249) | | |
| Expected Yield | 77.7 | 87.5 | .47 | 119 |
| | (65.3) | (38.4) | | |
| Expected Yield in Good Year | 95.1 | 109. | .322 | 119 |
| | (70.7) | (48.4) | | |
| Expected Yield in Bad Year | 63.0 | 69.4 | .682 | 119 |
| | (61.7) | (32.0) | | |
| Good Relationship with Company | .310 | .316 | .622 | 118 |
| | (.466) | (.469) | | |
| Trust Company Field Assistants | 3.10 | 2.83 | .315 | 119 |
| | (1.02) | (1.01) | | |
| Trust Company Managers | 2.15 | 2.11 | .32 | 119 |
| | (1.13) | (1.03) | | |

*Notes:* The table presents baseline balancing for the Intertemporal Preferences Experiment. *Plot Size* and *Previous Yield* are from the administrative data of the partner company and are available for each of the 605 farmers in our sample. The rest of the variables are from the baseline survey. These are missing for 2 farmers who denied consent to the survey. In addition, a handful of other values for specific variables is missing because of enumerator mistakes or because the respondent did not know the answer or refused to provide an answer. *Previous Yield* is measured as tons of cane per hectare harvested in the cycle before the intervention. *Man* is a binary indicator equal to one if the person in charge of the sugarcane plot is male. *Own Cow(s)* is a binary indicator equal to one if the household owns any cows. *Portion of Income from Cane* takes value between 1 ("None") to 6 ("All"). *Savings for Sh 1,000 (Sh 5,000)* is a binary indicator that equals one if the respondent says she would be able to use household savings to deal with an emergency requiring an expense of Sh 1,000 (Sh 5,000). 1 USD= 95 Sh. *Good Relationship with the Company* is a binary indicator that equals one if the respondent says she has a "good" or "very good" relationship with the company (as opposed to "bad" or "very bad"). *Trust Company Field Assistants* and *Trust Company Managers* are defined on a scale 1 ("Not at all") to 4 ("Completely"). P-values are based on specifications which include field fixed effects (since randomization was stratified at the field level).

# B Intertemporal model of insurance

In this section we develop formally the dynamic model of insurance that we presented in the main text. We begin by setting up a background intertemporal model, without insurance, into which we then introduce the two insurance products - pay-upfront, and pay at harvest.[1] We first consider the case where contracts are perfectly enforceable, and then allow for imperfect enforcement. The model shows how the channels interact to affect insurance demand (and for whom) and motivates our mechanism experiments and empirical tests to identify them.

## B.1 Background

The background model is a buffer-stock savings model, as in Deaton (1991), with the addition of present-biased preferences and cyclical income flows (representing agricultural seasonality).

**Time and state**  We use a stochastic discrete-time, infinite horizon model. Each period $t$, which we will typically think of as one month, has a set of states $S_t$, corresponding to different income realizations. The probability distribution over states is assumed to be memoryless and cyclical (of period $N$). Thus $P(s_t = s)$ may depend on $t$ but is independent of the history at time $t$, $(s_i)_{i<t}$, and $S_t = S_{t+N}$ and $P(s_t = s) = P(s_{t+N} = s) \; \forall t, s$.

**Utility**  Individuals have time-separable preferences and maximize present-biased expected utility $u(c_t) + \beta \Sigma_{i=1}^{\infty} \delta^i \mathbb{E}[u(c_{t+i})]$ as in Laibson (1997).[2] We assume that $u(.)$ satisfies $u' > 0$, $u'' < 0$, $\lim_{c \to 0} u'(c) = \infty$ and $u''' > 0$, and that $\beta \in (0, 1]$ and $\delta \in (0, 1)$.[3]

**Intertemporal transfers**  Households have access to a risk-free asset with constant rate of return $R$ and are subject to a borrowing constraint. As in Deaton (1991), we assume $R\delta < 1$.

**Income and wealth**  Households have state-dependent income in each period $y_t$. We assume $y_t > 0 \; \forall t \in \mathbb{R}^+$.[4] We denote cash-on-hand once income is received by $x_t$ and wealth at the beginning of each period by $w_t$, so that $x_t = w_t + y_t$.

**Household's problem**  The household faces the following maximization sequence problem in period t:

$$\max_{(c_{t+i})_{i \geq 0}} \quad u(c_t) + \beta \mathbb{E}[\Sigma_{i=1}^{\infty} \delta^i u(c_{t+i})] \tag{B.1}$$

$$\text{s.t. } \forall i \geq 0 \quad x_{t+i+1} = R(x_{t+i} - c_{t+i}) + y_{t+i+1}$$

$$x_{t+i} - c_{t+i} \geq 0$$

We assume that households are naive-$\beta\delta$ discounters: they believe that they will be exponential discounters in future periods (and so may have incorrect beliefs about future consumption). There is evidence for such naivete in other settings (DellaVigna and Malmendier 2006) and, with the

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[1] An alternative approach is to use observed investment behavior (in particular the potential returns of risk-free investments which farmers make or forgo) as a sufficient statistic for the cost of the transfer across time. In appendix section C we report basic quantitative bounds for the effect of the transfer across time on insurance demand using this approach.

[2] We note that time-separable preferences equate the elasticity of intertemporal substitution, $\psi$, and the inverse of the coefficient of relative risk aversion, $\frac{1}{\gamma}$. As such they imply a tight link between preferences over risk and consumption smoothing, both of which are relevant for insurance demand. Recursive preferences allow them to differ (Epstein and Zin 1989), which would provide an additional channel: if $\psi \ll \frac{1}{\gamma}$, then demand for upfront and at-harvest insurance may differ greatly, since the cost of variation in consumption over time would far exceed that of variation across state.

[3] We assume prudence, i.e. $u''' > 0$, as is common in the precautionary savings literature (and as holds for CRRA utility), to ensure that the value of risk reduction is decreasing in wealth, i.e. Lemma B.2, part 3. Liquidity constraints strengthen concavity of the value function, and thus the result, but our proof requires prudence.

[4] As a technical assumption we actually assume that $y_t$ is strictly bounded above zero $\forall t$.

exception of Proposition 2, all propositions hold with slight modification in the sophisticated-$\beta\delta$ case.[5]

Denote time-$t$ self's value function by $V_t$.[6] Then $V_t$ is a function of one state variable, cash-on-hand $x_t$, and is the solution to the following recursive dynamic programming problem:

$$V_t(x_t) = \max_{c_t} u(c_t) + \beta\delta\mathbb{E}_s[V_{t+1}^c(x_{t+1})] \tag{B.2}$$

subject to, for all $i \geq 0$,
$$x_{t+i+1} = R(x_{t+i} - c_{t+i}) + y_{t+i+1}$$
$$x_{t+i} - c_{t+i} \geq 0$$

where $V_t^c(x_t)$, the continuation value function, is the solution to equation B.2, but with $\beta = 1$, i.e.

$$V_t^c(x_t) = \max_{c_t} u(c_t) + \delta\mathbb{E}_s[V_{t+1}^c(x_{t+1})] \tag{B.3}$$

Because of the cyclicality of the setup, the functions $V_t(.) = V_{t+N}(.)$ and $V_t^c(.) = V_{t+N}^c(.)$ $\forall t$.

**Lemma B.1.** $\forall t \in \mathbb{R}^+$:

1. $V_t$, $V_t^c$ exist, are unique, and are concave.

2. $\frac{dc_t}{dx_t} < 1$, so investments (and wealth in the next period) are increasing in wealth.

*Proof.* **Part (1)**

Since $V^c$ is the solution to a recursive dynamic programming problem with convex flow payoffs, concave intertemporal technology, and convex choice space, theorem 9.6 and 9.8 in Stokey and Lucas (1989) tell us that $V^c$ exists and is strictly concave. To expand further, the proofs, which are similar in method to subsequent proofs below, are as follows.

**Existence & Uniqueness.** Blackwell's sufficient conditions hold for the Bellman operator mapping $V_{t+1}^c$ to $V_t^c$: monotinicity is clear; discounting follows by the assumption that $\delta R < 1$ - taking $a \in \mathbb{R}$, $V_{t+1}^c + a$ is mapped to $V_{t+1}^c + \delta Ra$; the flow payoff ($u(c_t)$) is bounded and continous by assumption; compactness of the state-space is problematic, but given $\delta R < 1$ the stock of cash-on-hand will not amass indefinitely, so we can bound the state space with little concern (Stokey and Lucas (1989) provide more formal, technical methods to deal with the problem. Since it is not the focus of the paper, we do not go into more details). Thus, the Bellman operator is a contraction mapping, and iterating this operator implies the mapping from $V_{t+N}^c$ to $V_t^c$ is a contraction mapping also. $V_t^c$ is a fixed point of this mapping, and thus exists and is unique by the contraction mapping theorem.

**Concavity.** Assume $V_{t+N}^c$ is concave. Then, $V_{t+N-1}^c$ is strictly concave, since the utility function is concave and the state space correspondence in convex, by standard argument (take $x_\theta = \theta x_a + (1-\theta)x_b$, expand out the definition of $V_{t+N-1}^c(x_\theta)$ and use the concavity of $V_{t+N-1}^c$ and the strict concavity of $u(.)$). Iterating this argument, we thus have that $V_t^c$ is concave. Therefore, since there is a unique fixed point of the contraction mapping from $V_{t+N}^c$ to $V_t^c$, that fixed point must be concave (since we will converge to the fixed point by iterating from any starting function; start from a concave function).

**Part (2)**

$$V_t(x_t) = max_c\ u(c) + \beta\delta\mathbb{E}[V_{t+1}^c(R(x_t - c) + y_{t+1})]$$

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[5]The required modification is replacing $\beta$ by a state-specific discount factor, which is a function of the marginal propensity to consume. Proposition 2 and Lemma B.2 may no longer hold, since concavity and uniqueness of the continuation value $V_t^c$ is no longer guaranteed, complicating matters significantly.

[6]Since preferences are not time-consistent, $V_t$ is different from the continuation value function, denoted $V_t^c$, which is the value function at time $t$, given time $t-1$ self's intertemporal preferences, i.e. without present bias.

Since $V_{t+1}^c$ is concave, this is a convex problem, and the solution satisfies:

$$u'(c_t) = \max\{\beta\delta R\mathbb{E}[V_{t+1}^{c'}(R(x_t - c_t) + y_{t+1})], u'(x_t)\}$$

Define $a(x_t) = x_t - c(x_t)$. Take $x_t' > x_t$, and suppose $a_t'(x_t') < a_t(x_t)$. Since $a_t' \geq 0$, we must have $a_t > 0$. Now, $a_t' < a_t$ implies $c_t' > c_t$, so $u'(c_t') < u'(c_t) = \beta\delta R\mathbb{E}[V^{c'}(Ra_t + y)] \leq \beta\delta R\mathbb{E}[V^{c'}(Ra_t' + y)] \leq u'(c_t')$. Contradiction. Thus $a_t'(x_t) \geq 0$. Since $V^{c'}(Ra_t + y_{t+1}) = u'(c_{t+1})$, the concavity of $V^c$ also implies that $c_{t+1}$ is increasing in $x_t$ in the sense of first order stochastic dominance.

$\square$

**Iterated Euler equation**   To consider the importance of the timing of premium payment, we will compare the marginal utility of consumption across time periods using the Euler equation:

$$u'(c_t) = \max\{\beta\delta R\mathbb{E}[u'(c_{t+1})], u'(x_t)\} \tag{B.4}$$
$$= \beta\delta R\mathbb{E}[u'(c_{t+1})] + \mu_t \tag{B.5}$$

where $\mu_t(x_t)$ is the Lagrange multiplier on the borrowing constraint, and $c_{t+1}$ is period $t$ self's belief about consumption in period $t + 1$. Iterating the Euler equation to span more periods gives:

$$u'(c_t) = \beta(R\delta)^H\mathbb{E}[u'(c_{t+H})] + \lambda_t^{t+H} \tag{B.6}$$

where $\lambda_t^{t+H}(x_t)$ represents distortions in transfers from $t$ to $t+H$ arising from (potential) borrowing constraints:

$$\lambda_t^{t+H} := \mu_t + \beta\mathbb{E}[\Sigma_{i=1}^{H-1}(R\delta)^i\mu_{t+i}] \tag{B.7}$$

The setup provides the following result, which we will use when considering insurance demand.

**Lemma B.2.** $\forall t \in \mathbb{R}^+$:

1. $\frac{d^3V_t}{dx_t^3}, \frac{d^3V_t^c}{dx_t^3} > 0$, so the value of risk reduction is decreasing in wealth.

2. $\frac{d\lambda_t^{t+H}}{dx_t} < 0$, i.e. the distortion arising from liquidity constraints is decreasing in wealth.

The intuition behind part 1 of the lemma is as follows. The value of risk reduction depends on how much the marginal utility of consumption varies across states of the world. Two things dictate this. First, how much marginal utility varies for a given change in consumption; this drives the comparative static through prudence (i.e. $u''' > 0$). Second, how much consumption varies for a given change in wealth (the marginal propensity to consume). Concavity of the consumption function, another consequence of prudence (Carroll and Kimball 1996), but further strengthened by the borrowing constraint (Zeldes 1989; Carroll and Kimball 2005), reinforces the result.[7]

*Proof of Lemma B.2.* **Part (1)**
The intuition for the result is that $V_t^{c'} = u'(c_t(x_t))$ (combining the first order condition with the envelope condition), and $u'$ and $c$ are convex by prudence (with the convexity of $c$ strenghtened by the borrowing constraint). The proof relies on showing that the mapping from $V_{t+1}^{c'}$ to $V_t^{c'}$ conserves convexity, $\forall t \in \mathbb{R}^+$. Then the proof follows as in 1 above: $V_t^c$ is the fixed point of a contraction mapping which conserves convexity of the first derivative, hence $V_t^{c'}$ must be convex.

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[7]Mathematically, the value of a marginal transfer from state $x + \Delta$ to state $x$, assuming both equally likely, is (one-half times) $V'(x + \Delta) - V'(x) = u'(c(x + \Delta)) - u'(c(x)) \simeq u''(c(x))c'(x)\Delta$. Its derivative w.r.t. $x$ is $\Delta(u'''(c(x))c'(x)^2 + u''(c(x))c''(x))$, which shows the role of both $u'''$ and $c''$.

We show that the mapping preserves convexity as follows, which is based on Deaton and Laroque (1992):

Suppose $V_{t+1}^{c'}$ is convex.

$$V_t^{c'}(x_t) = u'(c_t)$$
$$= \max\{\delta R \mathbb{E}[V_{t+1}^{c'}(R(x_t - c_t) + y_{t+1})], u'(x_t)\}$$

Define G by $G(q, x) = \delta R \mathbb{E}[V_{t+1}^{c'}(R(x_t - u'^{-1}(q) + y_{t+1})]$.

*G is convex in q and x*: $u'$ is convex and strictly decreasing, so $u'^{-1}$ is convex (and so $-u'^{-1}$ is concave); $V_{t+1}^{c'}$ is convex and decreasing, so $V_{t+1}^{c'}(R(x_t - u'^{-1}(q)) + y_{t+1})$ convex in q and x (since $f$ convex decreasing and $g$ concave $\Rightarrow f \circ g$ convex); expectation is a linear operator (and hence preserves convexity).

Now $V_t^{c'} = \max[G(V_t^{c'}(x_t), x_t), u'(x_t)]$, or, defining $H(q, x) = \max\{G(q, x) - q, u'(x) - q\}$, then $V_t^{c'}$ is the solution in q of $H(q, x) = 0$.

H is convex in q and x, since it is the max of two functions, each of which are convex in q and x. Take any two $x$ and $x'$ and $\lambda \in (0, 1)$. Then $H(V_t^{c'}(x), x) = H(V_t^{c'}(x'), x') = 0$. Thus, by the convexity of H, $H(\lambda V_t^{c'}(x) + (1 - \lambda)V_t^{c'}(x'), \lambda x + (1 - \lambda)x') \leq 0$. Now, since H is decreasing in q, that means that $V_t^{c'}(\lambda x + (1 - \lambda)x') < \lambda V_t^{c'}(x) + (1 - \lambda)V_t^{c'}(x')$, i.e. $V_t^{c'}$ is convex.

**Part (2)**

Clearly $\frac{d\mu_t}{dx_t} \leq 0$. Also, the distribution of $x_{t+1}$ is increasing in the distribution of $x_t$, is the sense of first order stochastic dominance, by iterating Lemma A.1 part (2). Hence the result holds by the law of iterated expectations.

□

## B.2 Insurance with perfect enforcement

We begin with the case where insurance contracts are perfectly enforceable.

**Timing** The decision to take up insurance is made in period 0. Any insurance payout is made in period $H$, the harvest period.

**Payouts** Farmers can buy one unit of the insurance, which gives state-dependent payout $I$ in period H, normalized so that $\mathbb{E}[I] = 1$. We assume that $y_H + I - 1$ second-order stochastically dominates $y_H$.[8]

**Premiums** We consider two timings for premium payment: upfront, at time 0, and at harvest, at time $H$. If paid at harvest the premium is 1, the expected payout (commonly referred to as the actuarially-fair price). If paid upfront, the premium is $R^{-H}$. Thus, at interest rate $R$, upfront and at-harvest payment are equivalent in net present value.

**Demand for insurance** Farmers buy insurance if the expected benefit of the payout is greater than the expected cost of the premium. Thus, to first order,[9] the take-up decisions are:

$$\text{Take up insurance iff} \begin{cases} \beta\delta^H \mathbb{E}[u'(c_H)] \leq \beta\delta^H \mathbb{E}[Iu'(c_H)] & \text{(pay-at-harvest insurance)} \\ R^{-H}u'(c_0) \leq \beta\delta^H \mathbb{E}[Iu'(c_H)] & \text{(pay-upfront insurance)} \end{cases} \tag{B.8}$$

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[8]Historical simulations using administrative data suggest this assumption is reasonable in our setting. While the second, area-yield based trigger, does lead to basis risk in the insurance product, it only prevents payouts in 26% of cases receiving payouts under the single trigger, as shown in Figure A.1.

[9]We use first order approximations at several points. They are reasonable in our setting for several reasons: the premium is small (3% of average revenues) and the insurance provides low coverage (a maximum payout of 20% of expected revenue); we care about differential take-up by premium timing, so second order effects which affect upfront and at-harvest insurance equally do not matter; both the double trigger insurance design, and the provision of inputs by the company, meant insurance was unlikely to affect input provision, in line with results in Section IV.D

For pay-at-harvest insurance, the decision is based on a comparison of the marginal utility of consumption across states (when insurance pays out vs. when it does not). For pay-upfront insurance, in contrast, the decision in based on a comparison across both states and time (when insurance pays out in the future vs. today). To relate the two decisions, we use the iterated Euler equation, Equation 3, which gives the following.

**Proposition 1.** *If farmers face a positive probability of being liquidity constrained before harvest, they prefer pay-at-harvest insurance to pay-upfront insurance; otherwise they are indifferent.*[10] *To first order, the difference is equivalent to a proportional price cut in the upfront premium of* $\frac{\lambda_0^H}{u'(c_0)}$ *($< 1$).*

Intuitively, paying the premium upfront, rather than at harvest, is akin to holding a unit of illiquid assets. The cost of doing so is given by the (shadow) interest rate, which depends on whether liquidity constraints may bind before harvest - if not, then asset holdings can simply adjust to offset the difference. As a corollary, intertemporal preferences only matter for the timing of premium payment indirectly, through their effect on liquidity constraints, reflecting the fact that preferences are defined over flows of utility rather than over flows of money.

*Proof of Proposition 1.* In the following, denote by $a_t$ the assets held at the end of period $t$, so that $a_t = x_t - c_t$.

Suppose farmers have zero probability of being liquidity constrained before the next harvest when they buy pay-upfront insurance. Denote their (state-dependent) path of assets until harvest by $(a_t^U)_{t<H}$, given that they have purchased pay-upfront insurance. By the assumption that the farmers will not be liquidity constrained before harvest, $a_t^U > 0 \ \forall t < H$ and for all histories $(s_i)_{i \leq t}$. Now, suppose instead of pay-upfront insurance, they had been offered pay-at-harvest insurance. If they invest the money they would have spent on pay-upfront insurance in assets instead, so $a_t^H(s) = a_t^U(s) + R^{-H-t}$, then they can pay the pay-at-harvest premium at harvest time and have the same consumption path as in the case of pay-upfront, so they must be at least as well off. Similarly, suppose they optimally hold $(a_t^P)_{t<H}$ in the pay-at-harvest case. If instead offered upfront insurance, they can use some of these assets to instead buy insurance, so that $a_t^U(s) = a_t^P(s) - R^{-H-t}$. Since, by assumption $a_t^U(s) > 0$, doing so they can again follow the same consumption path as in the case of pay-at-harvest insurance, so pay-upfront insurance is at least as good as at-harvest insurance. Thus the farmer is indifferent between pay-upfront and pay-at-harvest insurance. As an aside, we note that this holds true even in the sophisticated $\beta\delta$ case, since so long as the farmer is not liquidity constrained he is passing forward wealth, meaning that paying the insurance at harvest time doesn't give him any extra ability to constrain his choices at harvest time than what he already has.

To first order, at time 0 the net benefit of pay-at-harvest insurance is $\beta\delta^H\mathbb{E}(Iu'(c_H)) - \beta\delta^H\mathbb{E}(u'(c_H))$, and of pay-upfront is $\beta\delta^H\mathbb{E}(Iu'(c_H)) - \beta\delta^H\mathbb{E}(u'(c_H)) - R^{-H}\lambda_0^H$ (note that the envelope theorem applies because, in the sequence problem, the insurance payout $I$ does not enter any constraints before time $H$. This would no longer be the case if borrowing constraints were endogenous to next period's income). Thus the difference between the two is $R^{-H}\lambda_0^H$. Consider a pay-upfront insurance product which had premium $(1 - \frac{\lambda_0^H}{u'(c_0)})R^{-H}$. The net benefit would be

$$\beta\delta^H\mathbb{E}(Iu'(c_H)) - (1 - \frac{\lambda_0^H}{u'(c_0)})R^{-H}u'(c_0)$$
$$= \beta\delta^H\mathbb{E}(Iu'(c_H)) - (u'(c_0) - \lambda_0^H)R^{-H}$$
$$= \beta\delta^H\mathbb{E}(Iu'(c_H)) - \beta\delta^H\mathbb{E}(u'(c_H))$$

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[10]To be precise, being "almost" liquidity constrained is sufficient: the exact condition for preferring pay-at-harvest is that, upon purchasing pay-at-harvest insurance, $x_t - c_t \leq R^{-H+t}$ for some time $t < H$ and for some path.

This is the net benefit of pay-at-harvest insurance.

$\square$

Liquidity constraints are closely tied to wealth (specifically, to deviations from permanent income, rather than permanent income itself) in the model. Combining Proposition 1 and Lemma B.2 gives the following corollary, under the assumption that the product provides just a marginal unit of insurance (so that we can ignore second order effects).

**Proposition 2.** *The net benefit of pay-at-harvest insurance is decreasing in wealth. So too is the cost of paying upfront, rather than at harvest. Among farmers sure to be liquidity constrained before harvest, the latter dominates, so the benefit of pay-upfront insurance is increasing in wealth.*[11]

Thus, while the benefit of risk reduction (pay-at-harvest insurance) is higher among the poor, they may buy less (pay-upfront) insurance than the rich, because the inherent intertemporal transfer is more costly for them. Liquidity constraints drive both results: the poor are more likely to face liquidity constraints *after* harvest, meaning that they are less able to self-insure risks to harvest income (shocks in income lead to larger shocks in consumption), but they are also more likely to face liquidity constraints *before* harvest, making illiquid investments more costly.

*Proof of Proposition 2.* The net benefit of the pay-at-harvest insurance is $\beta\delta^H\mathbb{E}(V_H^c(w_H + y_H + I - 1)) - \beta\delta^H\mathbb{E}(V_H^c(w_H + y_H))$. How this changes wrt $x_0$ is given by:

$$\frac{d}{dx_0}[\beta\delta^H\mathbb{E}(V_H^c(w_H + y_H + I - 1)) - \beta\delta^H\mathbb{E}(V_H^c(w_H + y_H))]$$

$$=\frac{dw_H}{dx_0}\beta\delta^H[\mathbb{E}(V_H^{c'}(w_H + y_H + I - 1)) - \mathbb{E}(V_H^{c'}(w_H + y_H))]$$

Now, $\frac{dw_H}{dx_0} \geq 0$, by iterating lemma 1 back from period H to period 0. Also, $y_H + I - 1$ strictly second order stochastic dominates $y_H$ by assumption, and $V_H^{c'}$ is strictly convex ($V^{c'''} > 0$ by lemma 1), so $\mathbb{E}(V_H^{c'}(w_H + y_H + I - 1)) - \mathbb{E}(V_H^{c'}(w_H + y_H)) < 0$. Thus, the value of pay-at-harvest insurance is decreasing with wealth.

The reduction in net utility from insurance arising from upfront premium payment is $R^{-H}\lambda_0^H$, by proposition 1. By lemma B.2, this is also decreasing in wealth.

If the farmer is certain to be liquidity constrained before the next harvest, when starting with $x_0$, then his wealth at the start of the next harvest $w_H$ will be the same as if he started with $x_0'$, for any $x_0' < x_0$. This is because wealth in the next period is decreasing in wealth this period, so by the time the farmer has exhausted his wealth starting at $x_0$, he will also have exhausted his wealth starting at $x_0'$. Now, since the income process is memoryless, once the agent has exhausted his wealth, his distribution of wealth at the next harvest is the same, irrespective of his history. Thus the farmer has the same value of deductible insurance, regardless of whether he starts with $x_0$ or $x_0'$, but the extra cost of the intertemporal transfer in the upfront insurance starting from $x_0'$ means that the farmer has a lower value of upfront insurance.

$\square$

### B.2.1 Delaying premium payment by one month

Consider the same insurance product as above, but with the premium payment delayed by just one period (corresponding to our experiment in Section IV.C, where the delay is one month).

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[11]The general point that the gap between pay-upfront and pay-at-harvest insurance is decreasing in wealth follows from the shadow interest rate being decreasing in wealth. In our model that comes from a borrowing constraint (and wealth is the deviation from permanent income), but it could be motivated in other ways, and models sometimes take it as an assumption.

**Proposition 3.** *The gain in the expected net benefit of insurance from delaying premium payment by one month is, to first order, equivalent to a proportional price cut in the upfront premium of* $\frac{\mu_0}{u'(c_0)}$.

Delaying premium payment by one period only increases demand if the farmer is liquidity constrained. The effect on the expected net benefit of doing so is $R^{-H}\mu_0$, compared to $R^{-H}(\mu_0 + \beta\mathbb{E}[\Sigma_{i=1}^{H-1}(R\delta)^i\tilde{\mu}_i])$ from delaying until harvest time. Thus, when $H$ is large, a one month delay will have a small effect relative to a delay until harvest, unless either liquidity constraints are particularly strong at time 0, or there is present bias. Present bias closes the gap in two ways: first, the effect of future liquidity constraints are discounted by $\beta$, and second, the individual naively believes that he will be less likely to be liquidity constrained in the future.

*Proof of Proposition 3.* The proof is essentially the same as that of the second half of Proposition 1.

$\square$

## B.3 Insurance with imperfect enforcement

If either side breaks the contract before harvest time, then the farmer does not pay the at-harvest premium, while he would have already paid the upfront premium. Accordingly, imperfect enforcement has implications both for farmer demand for insurance and for the willingness of insurance companies to supply it.

**Default** We assume that both sides may default on the insurance contract. At the beginning of the harvest period, with probability $p$ (unrelated to yield) the insurer defaults on the contract, without reimbursing any upfront premiums.[12] The farmer then learns his yield and, if the insurer has not defaulted, can himself strategically default on any at-harvest premium, subject to some (possibly state dependent) utility cost $d$ and the loss of any insurance payouts due.[13]Denoting whether the farmer chooses to pay the at-harvest premium by the (state-dependent) indicator function $D_P$, then to first order:

$$D_P := \mathbb{I}[Iu'(c_H) + d \geq u'(c_H)] \tag{B.9}$$

**Demand for insurance** Given this defaulting behavior, imperfect contract enforcement drives an additional first-order difference between upfront and at-harvest insurance:

Difference in net benefit of at-harvest & upfront $\quad = \quad \underbrace{R^{-H}\lambda_0^H}_{\text{liquidity constraint term}} \quad + \quad \underbrace{\beta\delta^H pE[u'(c_H)]}_{\text{premium saved when insurer defaults before harvest}}$

$$\tag{B.10}$$

$+ \quad \underbrace{\beta\delta^H(1-p)\mathbb{E}[(1-D_P)(u'(c_H) - d - Iu'(c_H))]}_{\text{premium saved, minus cost of default and loss in insurance payouts, when farmer defaults}}$

---

[12]Such default could represent, for example, the insurer going bankrupt or deciding not to honor contracts. The assumption that it is unrelated to yield is reasonable in our setting, as strategic default by the insurer would be highly costly for the farming company, both legally and in terms of reputational costs. We ignore any insurer default after the farmer's decision to pay the harvest time premium, since it would not have a differential effect by the timing of premium payment.

[13]In practice the farmer may face considerable uncertainty about both yields and insurance payouts when deciding to default, which shrinks the difference between pay-upfront and pay-at-harvest. In our setting, for example, the company harvests the crop, at which point its weight is unknown to the farmer, and the area yield trigger further increases uncertainty.

The size of the difference caused by imperfect enforcement is clearly decreasing in the cost of default, $d$. If the cost of default is high enough, $d > \max_s u'(c_H(s))$, the farmer never strategically defaults.

**Supply of insurance**  While the farmer is better off with the pay-at-harvest insurance, the possibility for strategic default means that the insurer may be worse off, which is the most likely reason why pay-upfront insurance is the norm. Whether there exists prices at which either of the two insurance products could be traded in a given setting depends on both $d$ and $p$, as well as liquidity constraints and preferences as discussed earlier.[14]

**Proposition B.1.** *If the cost of defaulting for the farmer, d, is too low, pay-at-harvest insurance will not be traded. If the probability of insurer default, p, is too high, pay-upfront insurance will not be traded.*

*Proof of Proposition B.1.* If the cost of farmer default is low enough, then the farmer effectively defaults whenever the net payout of pay-at-harvest insurance is negative, hence the insurer makes a loss regardless of the price. If the probability of insurer default is too high, then the market for pay-upfront insurance unravels: in a pooled equilibrium, the risk of insurer default means farmers are only willing to buy pay-upfront insurance at a significantly reduced price; but the only insurers willing to offer significantly reduced premiums are those who are certain to default. □

### B.3.1 Interlinked insurance

Interlinking the insurance contract with the production contract has implications for contractual risk, as it means that default on one entails default on the other.

**Outside option $o(s_H, w_H)$**

If the farmer chooses to sell to the company he receives profits $y(s)$ (comprising revenues minus a deduction for inputs provided on credit) plus any insurance payout $I(s)$, minus the insurance premium in the case of pay-at-harvest insurance. He also receives continuation value $r_C(s)$ from the relationship with the company, which is possibly state dependent. If he chooses to side sell, he receives outside option $o(s)$ [15], and saves the deductions for inputs provided on credit and for the deductible insurance premium, but loses the continuation value and any insurance payout. We abstract from any impact of insurance on the choice of input supply, since, as argued before, the choice set is limited, the double trigger design of the insurance was chosen to minimize moral hazard, and, as reported below, we see no evidence of moral hazard in the experimental data.

**Default**  Now the farmer has one default decision to make: whether to default on both the insurance and production contracts. We will solve the farmer's problem backwards, starting with the decision of whether to side-sell conditional on the company not having defaulted on the farming contract. All decisions are as anticipated at time 0. To translate this into the above framework, we

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[14]The cost of strategic default is also key in another type of purely cross-state insurance: risk sharing (Ligon, Thomas and Worrall 2002; Kocherlakota 1996). Related to the discussion here, Gauthier, Poitevin and Gonzalez (1997) show that enlarging the risk-sharing contracting space so as to allow for ex-ante transfers makes the first-best outcome easier to achieve.

[15]We don't have detailed information on payments under side selling, but anecdotal evidence suggests that side sellers pay significantly less than the contract company, so a natural assumption would be that $o(s) = \alpha y(s)$, where $\alpha < 1$

define the (now endogenous) cost of farmer default, $d$, to be the value of the production relationship to the farmer relative to his outside option of selling to another buyer (side-selling):

$$d = \mathbb{E}[V_H^c(w_H + o(w_H))] - \mathbb{E}[V_H^c(w_H + y_H)] \tag{B.11}$$

This cost will typically be positive, in which case interlinking helps to enforce the pay-at-harvest premium (this is why credit is often interlinked). However, if the farmer wishes to side-sell for some other reason, for example if the company defaults on aspects of the production contract, then $d$ will be negative, in which case interlinking encourages default on the premium. Importantly, selective default by the farmer in order to avoid the pay-at-harvest premium is unlikely with under the interlinked contract, since the premium is only marginal if $d$ is close to zero, and so expected default can be priced into the premium.

While unlikely, if pay-at-harvest insurance does affect side-selling, then the following (simple) proposition tells us how. Intuitively, for those with low yields, insurance payouts increase income from the contract, and so decrease the incentive to side-sell, whereas for those with high yields, pay-at-harvest premiums decrease income, and so increase the incentive to side-sell.

**Proposition 4.** *If pay-at-harvest insurance affects side-selling, it makes those with high yields more likely to side-sell, and those with low yields less likely to side-sell.*

*Proof of Proposition 4.* Consider the decisions to sell to the company (i.e. not to side-sell). Denote the indicator functions for these decisions by D, with a subscript representing whether or not the insurer has already defaulted on the insurance contract, and a supercript denoting whether the farmer holds insurance, and if so the type of the insurace.

If the insurer has not already defaulted, they are:

$$D_I = \mathbb{I}[d \geq 0] \qquad\qquad \text{without insurance}$$
$$D_I^U = \mathbb{I}[Iu'(c_H) + d \geq 0] \qquad\qquad \text{with pay-upfront insurance}$$
$$D_I^D = \mathbb{I}[Iu'(c_H) + d \geq u'(c_H)] \qquad\qquad \text{with pay-at-harvest insurance}$$

If the insurer has already defaulted, they are:

$$D_D = \mathbb{I}[d \geq 0] \qquad\qquad \text{without insurance}$$
$$D_D^U = \mathbb{I}[d \geq 0] \qquad\qquad \text{with pay-upfront insurance}$$
$$D_D^D = \mathbb{I}[d \geq u'(c_H)] \qquad\qquad \text{with pay-at-harvest insurance}$$

Since $I(s)u'(c_H(s))$ and $u'(c_H(s))$ are non-negative, and $Iu'(c_H)$ and $(I-1)u'(c_H)$ are larger when yields are low, the results follow.

$\square$

As for the effect on imperfect enforcement on insurance demand, we have the following result, which enables us to relate the impact of ex-ante expectations of default to the impact of a price cut in the upfront premium, a point we return to in Section IV.D:

**Proposition 5.** *The option to side-sell in the interlinked contract drives a wedge between pay-at-harvest and pay-upfront insurance, bound above by a price cut in the upfront premium of:*

$$\mathbb{P}(\textit{side-sell with pay-at-harvest}) \frac{\mathbb{E}[u'(c_H)|\textit{side-sell with pay-at-harvest}]}{\mathbb{E}[u'(c_H)]}$$

*Further, in so far as default is non-selective (i.e. independent of yield), it does not affect demand for pay-at-harvest insurance (to first order).*

14

*Proof of Proposition 5.* The basic intuition is that the extra loss from paying upfront is at most the premium when the farmer side-sells - if insurance did not change the decision to side-sell, then it is exactly the premium, if it did change the decision to side-sell, then by revealed preference the farmer loses at most the premium.

Formally, consider the net benefit of insurance, which is the benefit of the payout minus the cost of the premium payment. With perfect enforcement, we know that pay-at-harvest insurance is equivalent to upfront insurance with a percentage price cut of $\frac{\lambda_0^H}{u'(c_0)}$. With imperfect enforcement, denote the net benefit of pay-upfront insurance product by $S_U$, and the net benefit of pay-at-harvest insurance by $S_D$. Then:

$$\mathbb{E}[S_D - S_U] = (1-p)(\Sigma_{d^D, d^U \in \{0,1\}} \mathbb{P}[D_I^U = d^U, D_I^D = d^D] \mathbb{E}[S_D - S_U | D_I^U = d^U, D_I^D = d^D])$$
$$+ p(\Sigma_{d^D, d^U \in \{0,1\}} \mathbb{P}[D_D^U = d^U, D_D^D = d^D] \mathbb{E}[S_D - S_U | D_D^U = d^U, D_D^D = d^D])$$

Now, $D_D^U \geq D_D^D$ and $D_I^U \geq D_I^D$. Also

$$\mathbb{E}[S_D - S_U | D_I^U = 1, D_I^D = 1] = \mathbb{E}[S_D - S_U | D_D^U = 1, D_D^D = 1] = 0$$

This leaves the cases where both default, or where pay-at-harvest defaults and pay-upfront doesn't. Conditional on $D_I^U = 0$, $D_I^D = 0$, or $D_D^U = 0$, $D_D^D = 0$, we have

$$S_D - S_U = \beta \delta^H u'(c_H)$$

When $D_I^U = 1, D_I^D = 0$, then

$$S_D - S_U = \beta \delta^H (u'(c_H) - (1-p)Iu'(c_H) - d) \leq \beta \delta^H u'(c_H)$$

Thus:

$$\mathbb{E}[S_D - S_U] \leq (1-p)(\mathbb{P}[D_I^U = D_I^D = 0] + P[D_I^U = 1, D_I^D = 0]) \beta \delta^H \mathbb{E}[u'(c_H) | D_I^D = 0]$$
$$+ p(\mathbb{P}[D_D^U = D_D^D = 0] + \mathbb{P}[D_D^U = 1, D_D^D = 0]) \beta \delta^H E[u'(c_H) | D_D^D = 0]$$

with strict inequality iff $\mathbb{P}[D_I^U = 1, D_I^D = 0] > 0$. The right hand side can be rewritten to give:

$$\Leftrightarrow \mathbb{E}[S_D - S_U] \leq (1-p)\mathbb{P}[D_I^D = 0] \beta \delta^H \mathbb{E}[u'(c_H) | D_I^D = 0]$$
$$+ p\mathbb{P}[D_D^D = 0] \beta \delta^H \mathbb{E}[u'(c_H) | D_D^D = 0]$$
$$\Leftrightarrow \mathbb{E}[S_D - S_U] \leq \mathbb{P}(\text{side-sell with at-harvest}) \beta \delta^H \mathbb{E}(u'(c_H) | \text{side-sell with at-harvest})$$

We compare this to the surplus effect on the net benefit of upfront insurance of a further proportional price reduction of $\mathbb{P}(\text{side-sell with at-harvest}) \frac{\mathbb{E}(u'(c_H) | \text{side-sell with at-harvest})}{\mathbb{E}(u'(c_H))}$, which is:

$$\mathbb{P}(\text{side-sell with at-harvest}) \frac{\mathbb{E}(u'(c_H) | \text{side-sell with at-harvest})}{\mathbb{E}(u'(c_H))} \mathbb{E}(u'(c_H))$$
$$= \mathbb{P}(\text{side-sell with at-harvest}) \mathbb{E}(u'(c_H) | \text{side-sell with at-harvest})$$

$\square$

# C Bounding the effect of the transfer across time

Households are both consumers and producers. The implications of this dual role have long been considered in development economics. In particular, in the presence of market frictions, separation may no longer hold, so that production and consumption decisions can no longer be considered separately (Rosenzweig and Wolpin 1993; Fafchamps, Udry and Czukas 1998). Above we considered the household's full dynamic problem, which incorporates discount factors and stochastic consumption paths. Often, however, we can apply a sufficient-statistic style approach, where we rely on observed behavior to tell us what we need to know, without having to estimate all of the parameters of the full optimization problem. In the case of intertemporal decisions, an individual's investment behavior, and in particular the interest rates of investments they do and do not make, can serve this role.

In this section we consider what observed investment behavior can tell us about hypothetical insurance take-up decisions, given the intertemporal transfer in insurance. Empirically, investment decisions may be easier to observe than discount factors and beliefs about consumption distributions (which are needed if we consider the full dynamic problem), and other studies provide evidence on interest rates in similar settings - both for investments made and for investments forgone. Using a simplified version of the model developed above, we consider under which conditions farmers would and would not take up insurance, given information on their other investment behavior.

To simplify, we now assume that at harvest time there are just two states of the world, the standard state $h$ and the low state $l$, with the low state happening with probability $p$.[16] We assume that insurance is perfect - it only pays out in the low state (at time $H$), and that it is again actuarially fair. To simplify notation, in this section we denote by $R$ the interest rate on the insurance *covering the whole period from the purchase decision until harvest time*. We also assume CRRA utility, so that $u(c) = c^{1-\gamma}/(1-\gamma)$.

Under this setup, the expected net benefit of a marginal unit of standard, upfront insurance is:

$$\beta \delta^H R \mathbb{E}[c_H(y_l)^{-\gamma}] - c_0^{-\gamma}$$

Consider first the case that the farmer forgoes a risk-free investment over the same time period which has rate of return $R'$. Then, first we know that paying upfront is at least as costly as a price increase in pay-at-harvest insurance of $\frac{R'}{R}$, and second we know that:

$$\beta \delta^H R'(p\mathbb{E}[c_H(y_l)^{-\gamma}] + (1-p)\mathbb{E}[c_H(y_h)^{-\gamma}]) - c_0^{-\gamma} < 0$$

Substituting this into the expected benefit of upfront insurance, we can deduce that farmers will not purchase standard insurance if:

$$R\mathbb{E}[c_H(y_l)^{-\gamma}] < R'(p\mathbb{E}[c_H(y_l)^{-\gamma}] + (1-p)\mathbb{E}[c_H(y_h)^{-\gamma}])$$
$$\Leftrightarrow \frac{\mathbb{E}[c_H(y_l)^{-\gamma}]}{\mathbb{E}[c_H(y_h)^{-\gamma}]} < \frac{1-p}{\frac{R}{R'} - p}$$

So, the farmer will not purchase insurance if under all consumption paths:

$$c_H(y_h) < A c_H(y_l)$$

with A given by:

$$A = \left( \frac{1-p}{\frac{R}{R'} - p} \right)^{\frac{1}{\gamma}}$$

---

[16]Note that the following can be easily generalized so that these two states represent average outcomes when insurance does not and does pay out respectively.

Unsurprisingly, $A$ is increasing in the (relative) forgone interest rate $R/R'$, and decreasing in the CRRA $\gamma$. Also, $A$ is increasing in the probability of the low state, $p$, suggesting that the intertemporal transfer is less of a constraint on insuring rarer events.

Similarly, we can consider the case where the farmer *makes* an investment over the period with risk-free interest rate $R'$. Under the same logic, we first know that a price raise of pay-at-harvest insurance of $\frac{R'}{R}$ is at least as costly as paying upfront, and second we also know the farmer will purchase insurance if, for all consumption paths:

$$c_H(y_h) > Ac_H(y_l)$$

The following tables report $A$ for various values of $R'/R$, $p$, and $\gamma$. The tables thus reports how much consumption must vary between good and bad harvests in order to be sure about farmers' decisions to buy perfect insurance, given their investment decisions. In the case of forgone investments, it tells us the largest variation in consumption for which we can be sure that the farmer will still not buy perfect insurance; in the case of made investments, it tells us the smallest variation in consumption for which we can be sure that the farmer will buy perfect insurance. We note that $A$ represents variation in *consumption* between states at harvest time - not variation in income, which is likely to be significantly larger. The effect can be sizeable. For example, for a risk which has a 20% chance of occurring, if the forgone investment has risk-free rate of return 50% higher than the interest rate charged on the insurance, then farmers with CRRA of 1 will forgo a perfect insurance product even when the consumption in the good state is 71.4% higher than consumption in the bad state.

$\gamma = 1$

|  |  | $p$ | | | | |
|---|---|---|---|---|---|---|
|  |  | 0.01 | 0.05 | 0.1 | 0.2 | 0.4 |
|  | 1 | 1 | 1 | 1 | 1 | 1 |
|  | 1.1 | 1.101 | 1.106 | 1.112 | 1.128 | 1.179 |
| $\frac{R'}{R}$ | 1.2 | 1.202 | 1.213 | 1.227 | 1.263 | 1.385 |
|  | 1.5 | 1.508 | 1.541 | 1.588 | 1.714 | 2.250 |
|  | 2 | 2.020 | 2.111 | 2.250 | 2.667 | 6.000 |
|  | 3 | 3.062 | 3.353 | 3.857 | 6.000 | $\infty$ |

$\gamma = 2$

|  |  | $p$ | | | | |
|---|---|---|---|---|---|---|
|  |  | 0.01 | 0.05 | 0.1 | 0.2 | 0.4 |
|  | 1 | 1 | 1 | 1 | 1 | 1 |
|  | 1.1 | 1.049 | 1.052 | 1.055 | 1.062 | 1.086 |
| $\frac{R'}{R}$ | 1.2 | 1.097 | 1.101 | 1.108 | 1.124 | 1.177 |
|  | 1.5 | 1.228 | 1.241 | 1.260 | 1.309 | 1.500 |
|  | 2 | 1.421 | 1.453 | 1.500 | 1.633 | 2.449 |
|  | 3 | 1.750 | 1.831 | 1.964 | 2.449 | $\infty$ |

$\gamma = 5$

|  | | $p$ | | | | |
| --- | --- | --- | --- | --- | --- | --- |
|  | | 0.01 | 0.05 | 0.1 | 0.2 | 0.4 |
|  | 1 | 1 | 1 | 1 | 1 | 1 |
|  | 1.1 | 1.019 | 1.020 | 1.022 | 1.024 | 1.033 |
| $\frac{R'}{R}$ | 1.2 | 1.038 | 1.039 | 1.042 | 1.048 | 1.067 |
|  | 1.5 | 1.086 | 1.090 | 1.097 | 1.114 | 1.176 |
|  | 2 | 1.151 | 1.161 | 1.176 | 1.217 | 1.431 |
|  | 3 | 1.251 | 1.274 | 1.310 | 1.431 | $\infty$ |

# D   Other channels

In this section we briefly discuss several additional potential channels, several of which are interesting and warrant future work.

The at-harvest premium is a deduction, while the upfront premium is a payment; this difference suggests several (behavioral) channels which are not directly about timing. First, according to prospect theory (Kahneman and Tversky 1979; Kőszegi and Rabin 2007), farmers may be more sensitive to losses than gains. While a thorough application of the theory is beyond the scope of this paper (and would require detailing how reference points are set), intuitively upfront payments may fall in the loss domain, while at-harvest payments, being deductions, may be perceived as lower gains. Second, according to relative thinking (Tversky and Kahneman 1981, Azar 2007), farmers may make choices based on relative quantities, rather than absolute quantities. Being small relative to harvest revenues, the at-harvest premium could appear smaller than the upfront premium (we thank Nathan Nunn for pointing out this explanation). Salience Theory offers a similar argument: under a multiple time period interpretation of Bordalo, Gennaioli and Shleifer (2012), diminishing sensitivity means that the upfront period may be more salient than harvest period, since income will be higher in the latter. Finally, inputs were already charged as deductions from harvest revenues in our setting, so pay-at-harvest could have seemed like the default (although we note that the high take-up of pay-at-harvest insurance, not the low take-up of pay-upfront insurance, is the outlier in our results compared to other studies).

The large effect of just a one month delay in premium payment, however, does point to the direct importance of timing, which could arise in several ways beyond those captured in our model. First, numerous empirical studies find a jump in demand at zero prices (Cohen and Dupas 2010); a similar, zero-price *today* effect could help explain our results. Such an effect would be an alternative explanation for the finding in Tarozzi et al. (2014) that offering anti-malarial bednets through loans has results in a large increase in take-up, and would also explain the prevalence of zero down-payment financing options for many consumer purchases, such as cars and furniture. Second, Andreoni and Sprenger (2012) report expected utility violations when certain and uncertain outcomes are combined  pay-upfront insurance combines a certain payment with an uncertain payout, whereas both are uncertain in pay-at-harvest insurance. Third, at-harvest and upfront payments may have different implications for bargaining in other interactions within the household or within informal risk sharing networks (Jakiela and Ozier 2016; Kinnan 2017). Finally, while unlikely in our setting, allowing farmers to pay at harvest rather than upfront for insurance may provide a positive signal of the quality of the insurance.

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