Do farmers prefer to insure against catastrophic risks or frequent risks in presence of basis risk?

A. Leblois[*] T. Le Cotty[†] E. Maitre d'Hotel[‡§]

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Abstract

This paper analyzes the role of drought frequency in farmers demand for index insurance in developing countries. In a model derived from Doherty and Schlesinger (1990), we show that the demand for insurance is an inverted U curve function of drought frequency. We further show that loading factor and basis risk hinders adoption for high drought frequency insurance. We led a field experiment in Burkina Faso to analyze farmers' insurance demand for different frequencies of insured drought, different levels of basis risks and different loading factors. This experiment confirms that the demand decreases with frequency for sufficiently frequent events.

Keywords: Index insurance, Extreme events, Basis risk

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[*]INRA, Nancy - France. Email: antoine.leblois@gmail.com

[†]CIRAD, Ouagadougou-Burkina Faso

[‡]CIRAD, Ouagadougou-Burkina Faso

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1 Introduction

In developing countries, index insurance projects are developing rapidly. Yet, and despite recent evidence of the role of uninsured risk in input use (Donovan, 2014; Emerick, de Janvry, Sadoulet, and Dar, 2015) combined to the interest of donors, insurers and banks, there is a low take up rate of index insurance products among farmers (Cole, Giné, Tobacman, Topalova, Townsend, and Vickery, 2013; Giné and Yang, 2009). Substantive progress has been made in the economic literature to understand the factors that may prevent farmers from purchasing index insurance in developing countries (De Bock and Gelade, 2012).

A first set of factors are related to the lack of interest or capacity of farmers to buy index insurance products. Farmers may be liquidity constrained, especially in the absence of credit markets, and unable to afford insurance premiums (Cole, Giné, Tobacman, Topalova, Townsend, and Vickery, 2013; Carter, Cheng, and Sarris, 2016). Because of low financial literacy (Cai, De Janvry, and Sadoulet, 2015), farmers may find index insurance too complex to understand (Gaurav, Cole, and Tobacman, 2011). They may not trust the insurance seller to provide the promised pay-outs (Patt, Suarez, and Hess, 2010; Cai, Chen, Fang, and Zhou, 2009; Dercon, Gunning, and Zeitlin, 2015). They also may be already insured through informal networks, through non agricultural activities or through limited liability credit contracts, which in turn limits their demand for a formal insurance product (Mobarak and Rosenzweig, 2013).

A second set of factors are related to the limitations of index insurance products, that may be too expensive. Recent experiments made with different subsidization levels argue in favor of a high elasticity of insurance demand to insurance price (Mobarak and Rosenzweig, 2012; Karlan, Osei, Osei-Akoto, and Udry, 2014).

Yet, a strong empirical body of evidence shows low average take up of formal insurance products, even when subsidized, suggesting that farmers may have other reasons for not buying those products (Cole, Giné, Tobacman, Topalova, Townsend, and Vickery, 2013; Tadesse, Shiferaw, and Erenstein, 2015; Jensen, Mude, and Barrett, 2014).

Contract nonperformance is another potential source of insurance product rejection by farmers (Doherty and Schlesinger, 1990). Although this is of general concern in insurance, it is particularly striking for index insurance contracts which are nonperforming contracts by nature because an imperfect correlation between the index and farmers yields. This potential discrepancy between insurance payouts and agricultural output has been coined as basis risk and may deter farmers demand for index insurance (Giné, Townsend, and Vickery, 2008; Giné and Yang, 2009; Cole, Giné, Tobacman, Topalova, Townsend, and Vickery, 2013; Clarke, 2016). This is especially the case for so called type II (false positive) basis risk: a situation of a yield shock with no payout triggered by the index. It leads to situations where the farmer may not receive any payout in case a yield shock occurs, i.e. he finds himself in a worse situation with insurance after paying a premium than without insurance. Type II basis risk exactly corresponds to insurer's default risk in the model of Doherty and Schlesinger (1990).

The effect of basis risk on insurance demand is widely acknowledged to be a major determinant of low index insurance take up (Tadesse, Shiferaw, and Erenstein, 2015; Dercon, Hill, Clarke, Outes-Leon, and Taffesse, 2014; Clarke, 2016), but few papers have dealt with the empirical measurement of the effect of basis risk on insurance demand (Jensen, Barrett, and Mude, 2015). In India, where index insurance is the most developed market, Mobarak and Rosenzweig (2012) used the perceived distance to the station used to insure Indian farmers as a proxy for basis risk and established that basis risk impact on demand is high. Further analysis on basis risk is needed, in particular to correctly capture empirically basis risk.

In this paper we look at another explanation of low demand for index insurance in Sub Saharan Africa. In countries like Burkina Faso where the dry season is always a limiting factor to agriculture, the definition of a climate shock is critical for farmers' interest into insurance. The insurer can choose the degree of drought to build an insurance product, typically a threshold, and doing so he also chooses a drought frequency in a given location, i.e. with a given distribution of historical events. The impact of this parameter on insurance demand has not been has not been analyzed in the literature. Intuitively, it is reasonable to expect that insurance against very frequent drought is of little interest for farmers because the risk vanishes as the variance of drought decreases; and one can also expect that insurance against very rare drought is of little interest for farmers because the average expected gain is weak.

In this paper, we study how the frequency of insured events may hinder the demand for insurance, depending on the level of basis risk. We build a discrete choice model of insurance upon the conceptual model by Doherty and Schlesinger (1990) to derive the effect of shock frequency on insurance demand. We establish that (1) the demand for insurance is an inverted U curve function of events frequency indicating that there is an optimal frequency for farmers to get insurance and that (2) high frequency risks get out of the range of insurable risks as basis risk increases

To confirm empirically this result, we led an insurance field experiment in Burkina Faso to analyze 205 farmers' demand for drought insurance with different drought frequencies and indemnification rates, different levels of basis risks and different loading factors. Farmers were asked to choose between insurance and no insurance, in 9 bets with different insurance policies.

- Three different basis risk levels are tested: absence of basis risk indicating that there is no discrepancy between the index and the yield (the insurance is perfect); a moderate basis risk, discrepancy between the index and the yield occurring in one case over 5, conditional of the occurrence of a yield shock; and an important basis risk, discrepancy between the index and the yield occurring in 2 cases over 5, conditional of the occurrence of a yield shock.

- Three frequencies of shocks are tested: rare shocks that occur on average once over a 20 years period; moderate shocks that occur on average twice over a 20 years period; and frequent shocks that statistically occur seven times over a 20 years period.

We find that an increase in drought frequency or in basis risk significantly hinder insurance demand, this result being robust to different specifications. This empirical result confirms our second theoretical result, about frequencies beyond the optimal level of frequency.

The paper is organized as follows. In section 2, a conceptual model accounts for the effect of shock frequency on insurance demand. In section 3, we present our field experiment in Burkina Faso. In section 4, we deliver our empirical results.

2 Model

Type I basis risk is the probability for an agent to get an indemnification while his production has not been impacted by random shock. Type II basis risk is the probability for an agent to get no i ndemnification while his production has been impacted by a random shock that is theoretically included in the contract. These two risks potentially have contradictory effects on insurance subscription. To keep the analysis simple, we will only consider type II basis risk. This basis risk is very close to what Doherty and Schlesinger (1990) call non performing contract, be it an imperfection in the insurance scheme or a default from the insurer.

2.1 Insurance framework probability set up

We adapt the formal framework by Doherty and Schlesinger (1990) to a binary descision to get full insurance or no insurance. We note r the probability for a farmer who has contracted an insurance to get no indemnity conditional on the drought occurrence. The type II basis risk is simply the probability, for a farmer who has contracted an insurance, to endure a drought and not be paid an indemnity (i.e. $r.p$ if p is the frequency of drought).

Let L denote the loss in case of a drought. If y is the farmer's income in a normal year, $y - L$ is the income in case of a dry year. In case of drought, the insurer pays an indemnity L with probability $1 - r$. Let P denote the yearly premium, and $m \geq 1$ the loading factor applied by the insurer. The premium is then the average loss $p.L$ miltiplied by the probability of indemnification $1 - r$ multiplied by the loading factor, $P = m.p(1 - r).L$.

The insurance framework probability set up is summarized in table 1.

Table 1: Insurance framework probability set-up

	Payout (1-r)	No payout (r)
No yield shock (1-p)	0	$1 - p$
Yield shock (p)	$(1 - r).p$	$r.p$

2.2 Effect of drought frequency on contract subscription

The farmer's expected utility gain from getting the insurance is the difference between his expected utility with insurance and the expected utility without insurance. This supposes that the decision to get insurance is a binary decision, which is a simplification with regard to Doherty and Schlesinger (1990) in order to be consistent with our experimental framework.

$$\begin{aligned} \Delta EU = (1 - p).u(y - P) + (1 - r).p.u(y - P) + r.p.u(y - P - L) \\ - [(1 - p).u(y) + p.u(y - L)] \end{aligned} \tag{1}$$

We are particularly interested in the effect of drought frequency on the sign and magnitude of the above expression. We replace P by $m.p(1 - r).L$, and derivate with regard to p to understand how propension to get insured varies with the frequency of damage.

$$\begin{aligned} &\tfrac{\partial \Delta EU}{\partial p} = -r.u(y - m.p.(1 - r).L) - (1 - p.r)m.(1 - r)L.u'(y - m.p.(1 - r).L) \\ &+r.u(y - m.p.(1 - r).L - L) - p.r.m.(1 - r)L.u'(y - m.p.(1 - r).L - L) \\ &+u(y) - u(y - L) \end{aligned} \tag{2}$$

The sign and variation of above expression are not constant on $[0,1]$ and notably depend on basis risk and the loading factor.

2.2.1 Moderate loading factor

We show in this section that moderate loading factor, compatible with insurance subscription, is $m < \frac{u(y)-u(y-L)}{L.u'(y)}$.

Indeed, for $p = 0, \Delta EU = 0$ and $\frac{\partial \Delta EU(p=0)}{\partial p} = (1-r)\left[u(y) - u(y-L) - m.L.u'(y)\right]$, which is positive if and only if $m < \frac{u(y)-u(y-L)}{L.u'(y)}$.

Furthermore, $\forall\, p \in\ [0;1] \quad \frac{\partial^2 \Delta EU}{\partial p^2} < 0$. This proves that $m < \frac{u(y)-u(y-l)}{l.u'(y)}$ is a necessary condition for $\delta EU > 0$.

For $p = 1$, $\frac{\partial \Delta EU}{\partial p} < 0$ (see proof in annex).

These elements alltogether guarantee that if $m < \frac{u(y)-u(y-l)}{lu'(y)}$, expected gain ΔEU is positive and increasing with p in zero, reaches a maximum at $p^* \in]0;1[$ and decreases until $p = 1$. There exists a critical value of drought frequency for which the incentive to take insurance is maximal. This is true for all values of basis risk $r \in [0,1[$ ($\Delta EU = 0$ if $r = 1$).

Proposition 1. *If* $m < \frac{u(y)-u(y-L)}{L.u'(y)}$*, there exists a unique* $p^* \in\ ]0;1[$ *such that* $p^* = argmax(\Delta EU)$.

In other words, if droughts are too rare, gains from insurance are low and if droughts are too frequent, gains are low or negative. Paragraph below tries to provide some intuition of this result. Starting from a virtual climate where drought is very very rare, the premium is cheap, but the indemnity is rare, so that only the most risk adverse farmers want to get insurance. When p increases, the premium and indemnity increase in a fixed proportion, but the gain of insurance increases simply because the ponderation of the worst case $u(y-L)$ increases.

But when p gets higher and the premium gets higher, the second worst case $u(y - m.p.L)$ gets closer to the worst case $u(y-L)$. The role of risk aversion on insurance tends to disapear as the insured payoff gets closer to the non-insured payoff. The bad situation without insurance is not bad enough any more in comparison with the case with insurance.

The incentive to get insurance is first increasing and then decreasing with p.

The question we want to adress is until what drought frequency p^{**} (the maximal insurable drought frequency) does insurance provides utility gain ?

In the particular well known case with actuarialy fair rate $m = 1$ and no basis risk $r = 0$, ΔEU remains positive for all values of $p \in]0;1[$ ($\Delta EU = 0$ for $p = 0$ or $p = 1$).

The existence of p^{**} is certain if $\Delta EU(p = 1) < 0$, because u is concave on p on $[0;1]$, increasing in p for $p = 0$ and decreasing in p for $p = 1$. Since $\Delta EU(p = 1) < 0$ is equivalent to $r > \frac{u(y-m.(1-r)L-u(y-L)}{u(y-m.(1-r).L-u(y-m.(1-r).L-L}$, and since this fraction is negative, the existence of p^{**} is certain.

The variation of p^{**} with r however is non trivial. But for our empirical purpose, we can approximate our problem with a Taylor development series, noting that in our experimental framework, as well as in reality in Burkina, the insurance premium is much lower than the income in case of good weather ($P << y$). In reality indeed, the average premium in Burkina Faso is around 10 000Fcfa per hectare who gets an insurance on maize and the average income from maize production in the area where insurance exists is around 300 000Fcfa per hectare. The average ratio P/y is around one on thirty, which allows the following approximation : $u(y-P) = u(y) - Pu'(y)$. The aim is to provide a handable expression of p^{**}, for ordinary values of P.

Under these conditions, we can rewrite ΔEU as

$$\Delta EU \approx p.(1-r).u(y) - P.(1-r.p).u'(y) - p.(1-r)u(y-L) - P.r.p.u'(y-L) \tag{3}$$

Which we can use to solve $\Delta EU = 0$ in terms of p, after replacing P by $mpL(1-r)$. This defines the maximal value $p^{**} \in]0;1[$ such that if $p \geq p^{**}$ then $\Delta EU \leq 0$. Everybody subscripts to insurance for $p \in]0;p^{**}[$ and nobody gets insurance for $p \geq p^{**}$

$$p^{**} \approx \frac{u(y) - u(y-L) - m.L.u'(y)}{m.L.r\left[u'(y-L) - u'(y)\right]} \tag{4}$$

It is clear from this expression that $0 < p^{**} < 1$ and that $\frac{\partial p^{**}}{\partial r} < 0$. This means that the maximal insurable drought frequency decreases as basis risk increases. In other words, when basis risk increases, insurance adoption decreases. Also note that r and p are substitute in expression (6) and a maximal admissible basis risk can be defined for each drought frequency for insurance to be interesting.

In practical terms, farmers get insurance if the loading factor is not too great and if the drought frequency is not too great.

Proposition 2. *If* $m < \frac{u(y)-u(y-L)}{L.u'(y)}$, *there exists a unique* $p^{**} \in]0;1[$ *such that* $\forall p \in]0;p^{**}[\quad \Delta EU > 0$ *and* $\forall p \in [p^{**};1] \quad \Delta EU \leq\leq 0$

The decision to take an insurance or not is a binary decision that directly derives from the continuous variable ΔEU. But because there is some unobserved heterogeneity among farmers we define a decision variable $x = 1$, iff $\Delta EU > 0$ and $x = 0$, iff $\Delta EU \leq 0$. Including inobservable heterogeneity among agents, we create an individual adoption variable $\tilde{x_i} = x + \epsilon_i$, and get the expected effects:

Proposition 3. *If* $m < \frac{u(y)-u(y-L)}{L.u'(y)}$ *and if* $P << y$,

$\frac{\partial prob(\tilde{x_i}=1)}{\partial m} < 0$

$\frac{\partial prob(\tilde{x_i}=1)}{\partial r} < 0$

$\frac{\partial prob(\tilde{x_i}=1)}{\partial p} < 0 \quad iff \quad p > p^*$

$\frac{\partial^2 prob(\tilde{x_i}=1)}{\partial rp} < 0$

$\frac{\partial^2 prob(\tilde{x_i}=1)}{\partial mp} < 0$
$\frac{\partial^2 prob(\tilde{x_i}=1)}{\partial rm} < 0$

2.2.2 Basis risk, heavy loading factor

If the insurance company imposes a heavy loading factor in comparison to the farmers' risk aversion $m \geq \frac{u(y)-u(y-l)}{lu'(y)}$, gains from insurance are always negative and farmers never get insurance, whatever basis risk and whatever drought frequency.

To see this, we first note that in $p = 0$, $\Delta EU = 0$ and expression (2) is negative if and only if $m \geq \frac{u(y)-u(y-l)}{lu'(y)}$.

Furthermore, we can show that ΔEU is concave in p on $[0;1]$:

$$\begin{aligned} &\frac{\partial^2 \Delta EU}{\partial p^2} = rm(1-r)Lu'(y-mp(1-r)L)+ \\ &rm(1-r)Lu'(y-mp(1-r)L) + (1-rp)m^2(1-r)^2L^2u''(y-mp(1-r)L) \\ &-m(1-r)Lru'(y-mp(1-r)l-l) - rm(1-r)Lu'(y-mp(1-r)l-l) \\ &+rpm^2(1-r)^2l^2u''(y-mp(1-r)l-l) \end{aligned} \tag{5}$$

Or after rearranging,

$$\begin{aligned} &\frac{\partial^2 \Delta EU}{\partial p^2} = 2rm(1-r)L\left[u'(y-mp(1-r)L) - u'(y-mp(1-r)l-l)\right] + \\ &+(1-rp)m^2(1-r)^2L^2u''(y-mp(1-r)L) \\ &+rpm^2(1-r)^2l^2u''(y-mp(1-r)l-l) \end{aligned} \tag{6}$$

Concavity of u ensures that $u'(y-mp(1-r)L) < u'(y-mp(1-r)l-l)$ and that $u'' < 0$. We thus have $\frac{\partial^2 \Delta EU}{\partial p^2} < 0$.

Since $\Delta EU = 0$ when $p = 0$, ΔEU is decreasing in p for $p = 0$ and $\frac{\partial^2 \Delta EU}{\partial p^2} < 0$, this proves that $\forall p \in [0;1], \Delta EU \leq 0$, and nobody gets insurance, no matter the drougth frequency or the basis risk.

3 Experimental design and empirical estimation

9 villages were randomly selected in two different departments of Burkina, Yako and Komsilga, located respectively in the Northern and Southern parts of Ouagadougou, the capital city. A total of 205 producers were surveyed into those 9 villages and participated to the insurance field experiment.

3.1 The insurance field experiment

After a description of drought index insurance, farmers were proposed a training session of contextualized games of insurance contracts. In each example, they are presented an insurance contract that is calibrated with existing insurance contracts in Burkina Faso, and they have to decide if they want to subscribe to the contract or not. During the training no draw nor paiment are performed. After the training session, they are successively presented 18 contracts that are similar to the training session contracts. Farmers have to make a discrete choice for each of the 18 different insurance products, and they get the payment, with a x100 down scaling factor, at the end of the session.

3.1.1 Training session

The simplified insurance products proposed are all based on a fixed surface of 0.5 ha of maize, and the outcome is based on fixed maize production of 800 kg in a normal year, yielding an income of 80 000 Fcfa, and zero production in a dry year, yielding a nil income.

The drought occurrence is the result of a lottery outcome, materialized by a transparent bowl with table tennis balls of two different colors. The proportion of balls of each color reflects the drought frequency. The drought frequency varies from 1/20 to 7/20, and the number of "drought-balls" (orange balls) in the bowl varies from 1 to 7 and the number of "rain-balls" varies from 19 to 13. The examples with no basis risk are played first. The climate random selection is made by a child with banded eyes who picks one ball in the bowl. For each choice, we offer the farmer a contract defined by the drought probability, the premium, the basis risk, and the payoffs.

Examples with basis risk

In examples without basis risk, the decision scheme is straightforward. Once the contract is defined, each farmer decides if he subscribes to the insurance, if so he notes down if he pays the premium, then the lottery is played. If a drought-ball is picked, the farmer is told he would receives an indemnification of 80 000F to compensate for his outcome loss. He is told his net income (80 000Fcfa minus the premium). If the rain-ball is selected, he also receives 80 000Fcfa. If he decides not to pay the insurance, if the drought ball is selected, he receives nothing and if the rain-ball is selected, he receives 80 000Fcfa.

In examples with basis risk, two sequential lotteries are used. The first lottery is the climate lottery, as described above. If the result is "rain", no other lottery is used and payments are validated. If the result is "drought", a second lottery is used, the indemnification lottery, which decides whether the insured farmers actually get indemnified or not. The probability of getting indemnified, conditional on a drought, is $(1 - r)$. This second lottery is made in a different transparent bowl (the indemnification bowl) filled with 5 balls in total, out of which the number of black balls indicating the level of basis risk (0, 1 or 2 black balls).

The insurance premium differs for each one of the 18 questions, with a minimum of 2000 Fcfa (rare drought, high basis risk, no loading factor) and a maximum of 56000 Fcfa (frequent drought, no basis risk and high loading factor). Table 10 in annex summarizes these 18 products. Insurance premium mechanically increases with the loading factor, the frequency of the insured drought and the lowering of the basis risk.

The first set of nine choices is based on actuary fair rate (loading factor =1). The second set of nine questions is based on a loading factor of 2 was then played.

3.1.2 Incentivized session

Farmers are explained that the 18 next choices determines the real payment they will get. They are to make a choice for the 18 next situations, and two of these choices will be randomly selected and they will be given the money fixed by the contract they get or not, depending on the climate lottery and the indemnification lottery. A first payment is validated at the end of the first nine choices on the actuary fair rate experiment, the drought lottery and if necessary the indemnification lottery are then played and the farmers know their mid-term payment. A second payment is selected at the end of the other nine choices, the experiment with loading factor, then the drought lottery and if necessary the indemnification lottery are played and the farmers know their full payment. A fixed amount of 650Fcfa is attributed to each participant before beginning, so that liquidity is not a constraint to participation and no farmer can lose money during the experiment. Farmers are explained that they can use this 650 F to pay the premium. For practical reasons, no cash is manipulated during the experiment. Distributing money before the beginning of incentivized choices could increase subscription to insurance contracts but is could also induce a feeling of indebtedness, which would make high take-up more doubtful. Since but find high take-up in average, the decision not to manipulate money during the experiment did not discourage take-up. Table 2 details premiums and indemnifications.

The average gains were around 700 Fcfa for the first set of nine questions and around 600 Fcfa for the second set of nine questions.

3.2 Sample description

The 9 villages are made of rather homogeneous small scale farmers. Table 3 shows the summary statistics for the main characteristics of the sample of farmers. Table 4 describe the samples of both insurance games. In addition, Tanaka, Camerer, and Nguyen (2010) lotteries where played at the beginning of the cessions to elicit farmers risk aversion and actuarially fair insurance games where played with uncompound risk but are not used in this paper.

3.3 Estimation strategy

The general specification of our empirical model is as follows:

$$Adoption_{it} = a_0 p + a_1 m + a_2 r + \beta X_{it} + b_0 + b_1 \eta_t + \epsilon_i t \qquad (7)$$

where $Adoption_{it}$ is a dummy variable taking 1 if the choice it is to get insurance, i is an individual index and t is an index for the choice identification. Vector X_{it} is a vector of control variables used in the random effects estimations only (table 6) and η_t are individual effects (random or fixed).

Table 2: Insurance contracts characteristics and expected gains

choice	load.	basis	drought	premium	outcome (Fcfa)					expec. gains (Fcfa)	
(#)	fact.	risk	freq.	(Fcfa)	not insured		insured			not	insured
	m	r	p	P	rain	drought	rain	drought		insured	
								indemn.	No indemn.		
1	1	0	1/20	40	800	0	760	760	-40	760	760
2	1	0	2/20	80	800	0	720	720	-80	720	720
3	1	0	7/20	280	800	0	560	560	-280	520	520
4	1	1/5	1/20	30	800	0	770	770	-30	760	760
5	1	1/5	2/20	60	800	0	740	740	-60	720	720
6	1	1/5	7/20	220	800	0	580	580	-220	520	520
7	1	2/5	1/20	20	800	0	780	780	-20	760	760
8	1	2/5	2/20	50	800	0	750	750	-50	720	720
9	1	2/5	7/20	170	800	0	630	630	-170	520	520
10	2	0	1/20	80	800	0	720	720	-80	760	720
11	2	0	2/20	160	800	0	640	640	-160	720	640
12	2	0	7/20	560	800	0	240	240	-560	520	240
13	2	1/5	1/20	60	800	0	740	740	-60	760	730
14	2	1/5	2/20	130	800	0	670	670	-130	720	660
15	2	1/5	7/20	450	800	0	350	350	-450	520	240
16	2	2/5	1/20	50	800	0	750	750	-50	760	740
17	2	2/5	2/20	100	800	0	700	700	-100	720	670
18	2	2/5	7/20	340	800	0	460	460	-340	520	350

Table 3: Households characteristics

Variable	Obs.	Mean	Std. Dev.	Min	Max
sex	205	1.3	0.5	1	2
age	204	40	12	17	72
education	204	0.5	0.5	0	1
family	204	9	5	1	30
total acreage (ha)	198	3.3	2.4	0.25	15
maize acreage (ha)	205	0.5	0.8	0	5
millet acreage (ha)	205	0.7	0.8	0	4
sorghum acreage (ha)	205	1.1	1.3	0	10
cattle	202	1.0	3.3	0	40

Table 4: Contract choices offered by villages

Lotteries	choices	Nb villages	Nb prod	Nb obs.
Actuarially fair	1 to 9	10	205	1,841
Loading factor	10 to 18	6	130	1,168

Note: actuarially fair rate lotteries could not be played in 4 out of 10 villages

Our data set has a panel structure with 205 cross sections and 18 times series. This is helpful to handle unobserved heterogeneity between observations, but the use of fixed effects is potentially biased when the decision variable is a dummy variable.

Building upon Green's suggestion, we start with estimating a probit random effects panel regression, with bootstrapped standard errors. The MLE of this model is the efficient-unbiased estimation method in case of no correlation between error terms and random effects. However, Hausman's test (Ho rejected significantly with Prob chi2 = 0.0000 and robust to specification changes) indicates that the difference between regression in random and fixed effects are significantly different, meaning that there exists unobserved fixed individual effects, thus arguing in favor of the use of a fixed effect model. A probit panel estimation with fixed effects is potentially biased. The bias would probably be not to big in our case since **?** find a 10 % bias in a panel with 100 cross sections and 8 time series, versus 205 CS and 18 TS in our sample. Greene recommends to use the Chamberlain's conditional maximum likelihood estimator (CMLE) to estimate a fixed effects logit panel (alternatively called conditional logit) which is unbiased if the individual effects are constant indeed (Hausman homogeneity test).

4 Empirical results

Table 5 shows the summary statistics of the insurance games. We computed the average of the two Tanaka, Camerer, and Nguyen (2010) first lottery games, using the hypothesis of a CRRA utility function, following Petraud, Boucher, Carter, et al. (2014) and when only considering people swithing once and only once from the safe to the riskier option. About 10% of the farmers are found to be risk seeking, the median of the CRRA parameter is 0.61 and 27% of the sample has the highest value (0.8).

Table 5: Summary statistics of the panel data

Variable	**Mean**	**Std. Dev.**	**Min.**	**Max.**	**N**
p	0.167	0.131	0.05	0.35	4089
r	0.2	0.163	0	0.4	4089
m	1.286	0.452	1	2	4089
adoption (1-9)	0.808	0.394	0	1	1841
adoption (10-18)	0.668	0.471	0	1	1168
$risk\quad aversion$ (CRRA)	0.471	0.448	-0.59	0.884	3622

Overall, we obtain high insurance take up rates, on average 80% for actuary fair rate and 67% with a loading factor $m = 2$ (table 5), comparable to other similar real earning games of contextualized agricultural insurance among farmers (Petraud, Boucher, Carter, et al., 2014).

Preliminary analysis with clustered probit show no significant impact of household characteristics on adoption rates (Table 6).

Fixed and random effects regressions validate that increasing the loading factor, the basis risk and, less intuitively, the probability of shock insured, significantly reduces

Table 6: Drivers of insurance hypothetical adoption, clustered probit, choices #1 to #9 (fair rate) & #10 to #18 (heavy loading)

	(1) adoption	(2) adoption	(3) adoption	(4) adoption
m	-0.752^{***}	-0.771^{***}	-0.662^{***}	-0.685^{***}
	(0.158)	(0.161)	(0.165)	(0.167)
p	-0.850^{***}	-0.855^{***}	-0.911^{***}	-0.923^{***}
	(0.195)	(0.196)	(0.205)	(0.208)
r	-0.364^{**}	-0.383^{**}	-0.386^{**}	-0.417^{***}
	(0.152)	(0.155)	(0.158)	(0.161)
CRRA_coef	0.260	0.179	0.288	0.199
	(0.181)	(0.187)	(0.198)	(0.205)
sex		0.234		0.171
		(0.187)		(0.190)
age		0.00326		0.000429
		(0.00717)		(0.00749)
chef exploit.		0.283		0.258
		(0.192)		(0.211)
alphabetization		0.0324		0.0784
		(0.350)		(0.361)
primary school		−0.0577		−0.159
		(0.343)		(0.349)
secondary school		−0.368		−0.502
		(0.412)		(0.411)
household size		−0.00296		0.00532
		(0.0150)		(0.0173)
cultivated area		0.00217		−0.0280
		(0.0196)		(0.0234)
Constant	1.738^{***}	1.221^{**}	1.281^{***}	1.012^{*}
	(0.250)	(0.501)	(0.340)	(0.569)
Observations	2722	2704	2722	2704
Village fixed effects	*No*	*No*	*Yes*	*Yes*

Standard errors in parentheses

* $p < .1$, ** $p < .05$, *** $p < .01$

insurance adoption (table 7, columns 1 to 3).

Moreover, the higher the loading factor, the higher is the negative effect of the probability of insured shock (table 7, columns 4 to 6). This implies that, as showed in the theoretical model, the optimal level of shock insured depends on the insurer loading.

The north/south gradient being the major feature of soudano-sahelian rainfall regimes, we constructed a dummy variable for the higher (drier) latitudes to look at discrepancies between villages of the north of the capital city (with an average of 700mm of annual cumulated rainfall) and those of the south (about 800mm of annual cumulated rainfall). We show that villages of the north finally proved to have a much stronger aversion for insurance against frequent events (with more probable payouts).

The northern and drier villages indeed drive the negative effect of p on adoption (cf. table 8, columns 1, 2 and 3). This result emphasize the role of the climate endured on insurance preferences. Moreover it does not drop the effect of the impact of the loading or the basis risk (table 8, columns 4, 5, and 6), showing that optimal insurance rate to be offered should also be fixed considering rainfall distribution (latitude in the case of the Sahel) but also basis risk and loading of the product.

Those results thus argues in favour of considering optimal event probability when designing index insurance as shown in the previous theoretical model.

Table 7: Drivers of insurance hypothetical adoption, xtprobit (RE: columns 1, 2, 4 & 5) and **xtlogit** (**FE**: columns 3 & 6) nolog, choices #1 to #9 (fair rate) & #10 to #18 (heavy loading)

	(1)	(2)	**(3)**	(4)	(5)	**(6)**
	adoption	adoption	adoption	adoption	adoption	adoption
m	-1.152^{***}	-1.130^{***}	-1.919^{***}	-0.336	-0.318	-0.498
	(0.279)	(0.255)	(0.225)	(0.243)	(0.281)	(0.312)
p	-1.417^{***}	-1.417^{***}	-2.402^{***}	2.936^{***}	2.938^{***}	5.320^{***}
	(0.318)	(0.363)	(0.445)	(0.818)	(0.905)	(1.283)
r	-0.506^{**}	-0.505	-0.886^{**}	-0.505^{**}	-0.504^{*}	-0.883^{**}
	(0.244)	(0.307)	(0.357)	(0.234)	(0.289)	(0.363)
p_m				-3.040^{***}	-3.046^{***}	-5.480^{***}
				(0.572)	(0.616)	(0.864)
Constant	3.237^{***}	2.751^{***}		2.273^{***}	1.801^{***}	
	(0.394)	(0.575)		(0.382)	(0.601)	
lnsig2u	1.088^{***}	0.942^{***}		1.147^{***}	0.997^{***}	
	(0.177)	(0.209)		(0.173)	(0.223)	
Observations	3009	3009	1596	3009	3009	1596
Village fixed effects	*No*	*Yes*	*No*	*No*	*Yes*	*No*

Standard errors in parentheses

* $p < .1$, ** $p < .05$, *** $p < .01$

Table 8: Drivers of insurance hypothetical adoption, xtprobit (RE: columns 1, 2, 4 & 5) and **xtlogit** (**FE**: columns 3 & 6) nolog, games 3 (fair rate) & 4 (heavy loading)

	(1) adoption	(2) adoption	**(3)** adoption	(4) adoption	(5) adoption	**(6)** adoption
m	-1.159^{***}	-1.161^{***}	-1.980^{***}	-0.437^{*}	-0.440^{*}	-0.670^{**}
	(0.250)	(0.217)	(0.229)	(0.226)	(0.245)	(0.318)
p	0.112	0.229	0.489	3.554^{***}	3.629^{***}	6.887^{***}
	(0.510)	(0.537)	(0.740)	(0.945)	(0.914)	(1.367)
r	-0.516^{*}	-0.515^{**}	-0.906^{**}	-0.513^{**}	-0.512^{*}	
	(0.286)	(0.208)	(0.360)	(0.246)	(0.289)	
p_dryClimate	-2.432^{***}	-2.638^{***}	-4.577^{***}	-1.825^{***}	-1.993^{***}	-3.684^{***}
	(0.609)	(0.640)	(0.939)	(0.599)	(0.643)	(0.974)
p_m				-2.675^{***}	-2.665^{***}	-4.939^{***}
				(0.620)	(0.570)	(0.876)
Constant	3.246^{***}	2.980^{***}		2.403^{***}	2.097^{***}	
	(0.406)	(0.479)		(0.373)	(0.588)	
lnsig2u	1.152^{***}	0.970^{***}		1.197^{***}	1.025^{***}	
	(0.181)	(0.202)		(0.236)	(0.178)	
Observations	3009	3009	1596	3009	3009	1596
Village fixed effects	*No*	*Yes*	*No*	*No*	*Yes*	*No*

Standard errors in parentheses
* $p < .1$, ** $p < .05$, *** $p < .01$

5 Discussion

We find that the demand for insurance decreases with the loading factor in accordance with previous results in the literature (Mobarak and Rosenzweig, 2012; Karlan, Osei, Osei-Akoto, and Udry, 2014). It decreases with basis risk, which is also consistent with previous empirical results (Giné, Townsend, and Vickery, 2008; Giné and Yang, 2009; Cole, Giné, Tobacman, Topalova, Townsend, and Vickery, 2013) and theoretical predictions (Clarke, 2016).

More interestingly, we find that the demand for insurance decreases with drought probability. This tends to indicate that in the trade-off between smoothing income and maintaining a higher income average, the second effects tend to dominate the first effect as the drought frequency increases.

In the theoretical model, an increase of the probability of shock p may also be interpreted as a change of climate regarding the specific index the insurance contract is based on, say the rainfall distribution. The size of the loss (L) being fixed for simplicity reasons: a situation with a larger probability of a shock of a given amplitude thus correspond to a drier climate. The negative effect of the cross variable p_{DRY} on adoption confirms that in the dryer villages, where the drought probability is greater, an increase in p produces a greater decrease in adoption, probably because it does not fit the rainfall distribution. However it may also be driven by the lower income average of these villages (3.5 ha in average vs. 4.15 in the southern villages), with a greater valuation of the average-income or other characteristics.

6 Conclusion

While insurers and reinsureres are reluctant to supply insurance products against frequent damages, it seems that, in the context of index-based insurances and developing countries, a trade-off between basis risk level and indemnification rate exists for a given level of losses.

We find that high frequency droughts get out of the range of insurable droughts when basis risk exists or when the loading factor is above 1. In order to increase uptake of such products, the pooling institution (either the state of a private agent depending on p) should take great care of the insurance strike (level of the index triggering payouts) setting, especially regarding long run historical series of yields and index allowing to estimate type II basis risk.

By offering a choice in the trigger (strike) setting, allows to consider optimal hedging level (or symetrically an optimal latitude in the Sahel).Our result suggest that index insurance may be unatractive to farmers under certain given climates.

We thus deepen Clarke (2016) reasoning and show the major role of the probability of the covered shock and show that index insurance adoption depends also on the probability of the event insured and that optimal probability of shock to be insured depends on the loading factor and the basis risk.

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7 Appendix

7.1 Experimental protocol

7.1.1 Introductory comments

You have the possibility to participate to a field experiment about drought insurance. Drought insurance is an agreement between a farmer and an insurer such that the farmer pays a premium in May and in case of drought, he receives an indemnity in November. We will describe 18 types of insurance, and for each one, you have to decide if you want to get the insurance and pay the premium. A the end of the experiment, you will get the amount of money that is defined in these contracts, depending on the choices you made in these games, and on the occurrence of drought or not. Out of the 18 choices, two will be randomly selected, and these two choices will determine how much money you will win. The amount you will win depends on your choices, but also on random since the occurrence of drought or rain is random. This money will be yours.

If you have questions during the games, raise your hand and we will answer to you. It is important that you do not talk with one another once the game has started. There is no false or true answer. It is important that you do not try to look at your neighbour's sheet.

This game will last 2 hours. If you think you cannot stay for 2 hours, please tell it now.

7.1.2 Instructions given to farmers. Training examples

Before starting with the experiment, we give two examples.
In this game, we consider that you produce maize and you have the choice to get an insurance against drought on your maize production.

In the example, you cultivate half an ha of maize and your yield is 8 bags of 100kg if the rain is good and 0 bag if there is a drought. Each bag you produce is sold 10 000Fcfa. If the rain is good, you earn 80 000Fcfa and if there is a drought you earn zero.

In the first example, drought is rare. There is a drought once every 20 years. In May, you decide to subscribe the insurance, then you pay a premium of 4 000Fcfa or not to subscribe to the insurance, and not to pay the premium. Then we must know if there is rain or drought. To do so, we put one orange ball in the bowl and 19 white balls in the bowl. A child with banded eyes picks one ball .
If he picks a white ball, the season is rainy and the harvest is good. If you have paid the insurance premium (4000F)the harvest value is 80000 Fcfa so that your income is 76000 Fcfa. If you did not pay the insurance, your income is 80000 Fcfa.
If the child picks the orange ball, the season is dry and the harvest is nil. If you had paid the premium (4000F) you get an indemnity to compensate for your loss (80 000Fcfa), so that your income is 76 000Fcfa. If you did not pay the premium, you get zero.
The choice you have to make is: "do you want to subscribe to this insurance ?"

In the second example, the drought is still rare, but there is a small risk that the insurer makes a mistake and does not pay the indemnity. There is one drought every 20 years and the insurer can make a mistake twice over ten times. This means that if there is a drought and if you have paid the premium, there is 2 chances over 10 that the insurer does not pay the premium. This is because, for example, the insurer thinks that

there has been rain but in reality, the rain has not fallen on your field or not during the useful period. The insurance premium is then cheaper (3 200Fcfa) because the insurer knows that he can make mistake. First you decide to pay the insurance premium or not, and then the child picks a ball in the bowl to check if the weather is rainy or dry.
If he picks a white ball, there is rain. Every body harvest 80 000Fcfa. the income of those who have paid the premium is 76 800 Fcfa, and those who have not paid the premium get 80 000Fcfa.
If the child picks an orange ball, there is a drought. The harvest is zero. Those who did not take the insurance get zero. The income of those who took the insurance depends on the issue in the bucket. In the bucket, there is two red balls and 8 orange balls. If the child picks a red ball, those who have paid the insurance get zero from the insurer, so that they have lost 3 200 Fcfa. If the child picks an orange ball, the income of those who have paid the insurance is 76 800 Fcfa.
The choice you have to make is: "do you want to subscribe to this insurance ?" Do you have questions ? has every one understood everything ?

7.1.3 Instructions given to farmers. Incentivised experiment

Now, the game is for real money. For each type of insurance, we will tell you the amount of the premium, the frequency of drought, and the risk that the insurer makes a mistake. For each type of insurance, you decide if you want to pay the premium or not. If you want to pay the premium, you make a cross in the blue column. If you do not want to pay the insurance, you make a cross in the yellow column. There are 18 choices in this game, for 18 types of insurance. At the end of the game, a child will pick two of the 18 balls with a number in this cage. The number on these two balls indicate the number of the choice for which you will receive money. Then , the child will pick one ball in the bowl to know if the rain was good, and one ball in bucket to know if you get the indemnity from the insurer. You will then receive the amount of money corresponding to your decision to get insurance or not. In the previous examples, the price of a bag is 10 000Fcfa. In the experiment, it is 100Fcfa. In the first example above, this means that the harvest is 800Fcfa instead of 80 000Fcfa if there is rain, and the premium is 40Fcfa instead of 4000Fcfa.

Do you have questions ? has every one understood everything ?

- Insurance 1. Drought occurs once every twenty years, and the insurer makes no mistake. The premium is 40Fcfa. There are 19 white balls and 1 orange ball in the bowl. If the child picks a white ball, there is rain, and those who take insurance win 760, and those who do not take insurance win 800Fcfa. If the child picks an orange ball, harvest is nil, those who take the insurance get 760, those who do not take the insurance get zero. Do you want to pay the premium and subscribe to the insurance ?

- Insurance 2. Drought occurs twice every twenty years, and the insurer makes no mistake. The premium is 80Fcfa. There are 18 white balls and 2 orange balls in the bowl. If the child picks a white ball, there is rain, and those who take insurance win 720, and those who do not take insurance win 800Fcfa. If the child picks an orange ball, harvest is nil, those who take the insurance get 720, those who do not take the insurance get zero. Do you want to pay the premium and subscribe to the insurance ?

- Insurance 3. Drought occurs seven times every twenty years, and the insurer makes no mistake. The premium is 280Fcfa. There are 13 white balls and 7 orange balls in the bowl. If the child picks a white ball, there is rain, and those who take insurance win 520, and those who do not take insurance win 800Fcfa. If the child picks an orange ball, harvest is nil, those who take the insurance get 520, those who do not take the insurance get zero. Do you want to pay the premium and subscribe to the insurance ?

- Insurance 4. Drought occurs once every twenty years, and the insurer makes 2 mistakes over 10 cases. The premium is 30Fcfa. There are 19 white balls and 1 orange ball in the bowl. If the child picks a white ball, there is rain, and those who take insurance win 770, and those who do not take insurance win 800Fcfa. If the child picks an orange ball, harvest is nil, those who do not take the insurance get zero and the income of those who take the insurance depends on the bucket issue. If the child picks a red ball in the bucket, they lose their 30 F and if the child picks an orange ball, they get 770Fcfa. Do you want to pay the premium and subscribe to the insurance ?

- Insurance 5. Drought occurs twice every twenty years, and the insurer makes 2 mistakes over 10 cases. The premium is 60Fcfa. There are 18 white balls and 2 orange balls in the bowl. If the child picks a white ball, there is rain, and those who take insurance win 740, and those who do not take insurance win 800Fcfa. If the child picks an orange ball, harvest is nil, those who do not take the insurance get zero and the income of those who take the insurance depends on the bucket issue. If the child picks a red ball in the bucket, they lose their 60Fcfa and if the child picks an orange ball, they get 740Fcfa. Do you want to pay the premium and subscribe to the insurance ?

- Insurance 6. Drought occurs seven times over twenty years, and the insurer makes 2 mistakes over 10 cases. The premium is 220Fcfa. There are 13 white balls and 7 orange balls in the bowl. If the child picks a white ball, there is rain, and those who take insurance win 580, and those who do not take insurance win 800Fcfa. If the child picks an orange ball, harvest is nil, those who do not take the insurance get zero and the income of those who take the insurance depends on the bucket issue. If the child picks a red ball in the bucket, they lose their 220Fcfa and if the child picks an orange ball, they get 580Fcfa. Do you want to pay the premium and subscribe to the insurance ?

- Insurance 7. Drought occurs once every twenty years, and the insurer makes 4 mistakes over 10 cases. The premium is 20Fcfa. There are 19 white balls and 1 orange ball in the bowl. If the child picks a white ball, there is rain, and those who take insurance win 780, and those who do not take insurance win 800Fcfa. If the child picks an orange ball, harvest is nil, those who do not take the insurance get zero and the income of those who take the insurance depends on the bucket issue. If the child picks a red ball in the bucket, they lose their 20Fcfa and if the child picks an orange ball, they get 780Fcfa. Do you want to pay the premium and subscribe to the insurance ?

- Insurance 8. Drought occurs twice every twenty years, and the insurer makes 4 mistakes over 10 cases. The premium is 50Fcfa. There are 18 white balls and 2 orange balls in the bowl. If the child picks a white ball, there is rain, and those who take insurance win 750, and those who do not take insurance win 800Fcfa. If the child picks an orange ball, harvest is nil, those who do not take the insurance get zero and the income of those who take the insurance depends on the bucket issue. If the child picks a red ball in the bucket, they lose their 50Fcfa and if the child picks an orange ball, they get 750Fcfa. Do you want to pay the premium and subscribe to the insurance ?

- Insurance 9. Drought occurs seven times every twenty years, and the insurer makes 4 mistakes over 10 cases. The premium is 170Fcfa. There are 13 white balls and 7 orange balls in the bowl. If the child picks a white ball, there is rain, and those who take insurance win 630, and those who do not take insurance win 800Fcfa. If the child picks an orange ball, harvest is nil, those who do not take the insurance get zero and the income of those who take the insurance depends on the bucket issue. If the child picks a red ball in the bucket, they lose their 170Fcfa and if the child picks an orange ball, they get 630Fcfa. Do you want to pay the premium and subscribe to the insurance ?

Nine similar choices are made in the case where the insurer makes profit (loading factor $m = 2$). The 18 insurance products are summarized below.

Table 9: Hypothetical premiums and loading factors, basis risks and drought frequencies

choice number	Loading factor	Basis risk	Drought frequency	Premium (Fcfa)	outcome					ΔEU
					not insured		insured			
	m	r	p	P	Rain	drought	rain	Drought		
								indemnity	No indemnity	
1	1	0	1/20	4000	80000	0	76000	76000	-4000	0
2	1	0	2/20	8000	80000	0	72000	72000	-8000	0
3	1	0	7/20	28000	80000	0	56000	56000	-28000	0
4	1	1/5	1/20	3000	80000	0	77000	77000	-3000	0
5	1	1/5	2/20	6000	80000	0	74000	74000	-6000	0
6	1	1/5	7/20	22000	80000	0	58000	58000	-22000	0
7	1	2/5	1/20	2000	80000	0	78000	78000	-2000	0
8	1	2/5	2/20	5000	80000	0	75000	75000	-5000	0
9	1	2/5	7/20	17000	80000	0	63000	63000	-17000	0
10	2	0	1/20	8000	80000	0	72000	72000	-8000	-4000
11	2	0	2/20	16000	80000	0	64000	64000	-16000	-8000
12	2	0	7/20	56000	80000	0	24000	24000	-56000	-28000
13	2	1/5	1/20	6000	80000	0	74000	74000	-6000	-3000
14	2	1/5	2/20	13000	80000	0	67000	67000	-13000	-6000
15	2	1/5	7/20	45000	80000	0	35000	35000	-45000	-28000
16	2	2/5	1/20	5000	80000	0	75000	75000	-5000	-2000
17	2	2/5	2/20	10000	80000	0	70000	70000	-10000	-5000
18	2	2/5	7/20	34000	80000	0	46000	46000	-34000	-17000

Table 10: Hypothetical premiums and loading factors, basis risks and drought frequencies

choice number	Loading factor	Basis risk	Drought frequency	Premium (Fcfa)	outcome					ΔEU
					not insured		insured			
	m	r	p	P	Rain	drought	rain	Drought		
								indemnity	No indemnity	
1	1	0	1/20	4000	80000	0	76000	76000	-4000	0
2	1	0	2/20	8000	80000	0	72000	72000	-8000	0
3	1	0	7/20	28000	80000	0	56000	56000	-28000	0
4	1	1/5	1/20	3000	80000	0	77000	77000	-3000	0
5	1	1/5	2/20	6000	80000	0	74000	74000	-6000	0
6	1	1/5	7/20	22000	80000	0	58000	58000	-22000	0
7	1	2/5	1/20	2000	80000	0	78000	78000	-2000	0
8	1	2/5	2/20	5000	80000	0	75000	75000	-5000	0
9	1	2/5	7/20	17000	80000	0	63000	63000	-17000	0
10	2	0	1/20	8000	80000	0	72000	72000	-8000	-4000
11	2	0	2/20	16000	80000	0	64000	64000	-16000	-8000
12	2	0	7/20	56000	80000	0	24000	24000	-56000	-28000
13	2	1/5	1/20	6000	80000	0	74000	74000	-6000	-3000
14	2	1/5	2/20	13000	80000	0	67000	67000	-13000	-6000
15	2	1/5	7/20	45000	80000	0	35000	35000	-45000	-28000
16	2	2/5	1/20	5000	80000	0	75000	75000	-5000	-2000
17	2	2/5	2/20	10000	80000	0	70000	70000	-10000	-5000
18	2	2/5	7/20	34000	80000	0	46000	46000	-34000	-17000

Table 11: Matrice des paiements avec risque de base de type 2 en cas de scheresse ralise

		Producteur assure			Producteur non assure	
		Secheresse		Non secheresse	Secheresse	Non secheresse
P	Prime	Pas fiable	Fiable			
0,07	36	-36	464	464	0	500
0,08	42	-42	458	458	0	500
0,10	50	-50	450	450	0	500
0,13	63	-63	438	438	0	500
0,17	83	-83	417	417	0	500
0,25	125	-125	375	375	0	500
0,50	250	-250	250	250	0	500

7.2 Model proofs

7.2.1 proof ΔEU decreasing in p at $p = 1$

If $p = 1$,

$$\begin{aligned} &\tfrac{\partial \Delta EU}{\partial p} = -ru(y - m(1-r)L) - m(1-r)^2 LU'(y - m(1-r)L) \\ &+ru(y - m(1-r)l - l) - rm(1-r)LU'(y - m(1-r)l - l) \\ &+u(y) - u(y-l) \end{aligned} \tag{8}$$

Noting that

$$m(1-r)Lu'(y - m(1-r)L) \geq (1-r)[u(y) - u(y - m(1-r)L)] \tag{9}$$

and

$$mr(1-r)Lu'(y - m(1-r)L - l) \geq r[u(y - m(1-r)L - l) - u(y-l)] \tag{10}$$

we can write

$$\begin{aligned} &\tfrac{\partial \Delta EU}{\partial p} \leq -ru(y - m(1-r)L) - (1-r)[u(y) - u(y - m(1-r)L) \\ &+ru(y - m(1-r)l - l) - r[u(y-l) - u(y - m(1-r)L - l)] \\ &+u(y) - u(y-l) \end{aligned} \tag{11}$$

This expression can be reorganised in the following way

$$\begin{aligned} &\tfrac{\partial \Delta EU}{\partial p} \leq -[u(y-l) - u(y - m(1-r)L)] \\ &-r\left[2[u(y - m(1-r)L) - u(y - m(1-r)l - l)] - [u(y) - u(y-l)]\right] \end{aligned} \tag{12}$$

Two cases should be distinguished.

If $m \geq \frac{1}{1-r}$, $u(y - m(1-r)L) - u(y-l) \leq 0$. Furthermore, concavity of u implies that $u(y) - u(y-l) < u(y - m(1-r)L) - u(y - m(1-r)l - l)$, thus $u(y) - u(y-l) < 2[y(y - m(1-r)L) - u(y - m(1-r)l - l)]$. Theen, $\frac{\partial \Delta EU}{\partial p} \leq 0$.

If $m \leq \frac{1}{1-r}$ the same expression can be reorganised in

$$\begin{array}{l} \frac{\partial \Delta EU}{\partial p} \leq -r\left[u(y-l)-u(y-m(1-r)L-l)\right]] \\ -[[u(y-l)-u(y-m(1-r)L-l)]-r[u(y)-u(y-m(1-r)L)]] \end{array} \tag{13}$$

where both brackets are negative since u is concave.
$\forall p \in [0;1] \qquad \frac{\partial \Delta EU}{\partial p} \leq 0$

7.2.2 proof $\Delta EU(p=1) < 0$

$$\begin{array}{r} \Delta EU(p=1) = -[u(y-l)-u(y-m(1-r)L)] \\ -r[u(y-m(1-r)L)-u(y-m(1-r)L-l)] \end{array} \tag{14}$$

where both brackets are positive if $m \geq \frac{1}{1-r}$

If $m < 1/(1-r)$ and $r < \frac{u(y-l)-u(y-m(1-r)L}{u(y-m(1-r)L-u(y-m(1-r)L-l}$, $\Delta EU > 0$.