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Tristan Le Cotty
Elodie Maitre d'Hotel
Raphaël Soubeyran
& Julie Subervie

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Inventory Credit as a Commitment Device to Save Grain until the Hunger Season

T. Le Cotty[*] E. Maitre d'Hotel[†] R. Soubeyran[‡] J. Subervie[§]

Abstract

In January 2013, we collected data from 653 farmers in Burkina Faso, who were asked hypothetical questions about risk aversion and time discounting. Ten months later, these farmers were offered the opportunity to participate in an inventory credit system, also called warrantage, in which they receive a loan in exchange for storing a portion of their harvest as a physical guarantee in one of the newlybuilt warehouses of the program. We found that a significant number of farmers chose to store grain in the warehouse without taking the maximum amount allowed for a loan in return and that farmers who exhibit a stronger present bias were significantly more likely to participate in the warrantage system than other, otherwise similar, farmers. We interpret these results as evidence that farmers use warrantage as a means to commit to saving a portion of their crop until the lean season. These results are in line with the main predictions of our theoretical model that explicitly takes the hyperbolic nature of farmers' time preferences into account.

Key Words: Commitment Savings, Inventory Credit, Hyperbolic Discounting.
JEL: D14, O12.

[*]CIRAD, UMR CIRED.

[†]CIRAD, UMR MOISA.

[‡]CEE-M, INRA, CNRS, SupAgro Montpellier, Univ. Montpellier, Montpellier, France.

[§]CEE-M, INRA, CNRS, SupAgro Montpellier, Univ. Montpellier, Montpellier, France. Corresponding author. Email: julie.subervie@inra.fr; Campus INRA-SupAgro, 2 place Pierre Viala, batiment 26, 34060 Montpellier Cedex 1, France. Phone: + 33(0)499 613 131. Fax: + 33(0)467 545 805.

1 Introduction

In developing countries, banks and financial institutions generally shy away from lending to the agricultural sector because farmers are highly exposed to production risk and often lack collateral.[1] There is an abundant literature showing that credit constraints may exacerbate the negative effects of intra-annual grain price volatility, forcing farmers to sell their grain at a low price during the post-harvest season,[2] and it has often been argued that providing credit access to poor farmers may help them smooth consumption.[3] In this context, inventory credit, also called warrantage, has emerged as a potential solution to this problem.

With warrantage, banks typically offer farmers an advance amounting to 80 percent of the market value of the amount of grain that they elect to secure in a certified warehouse over a six-month period. This is likely to improve farmers' food security in many ways. First, farmers who have access to credit may be more likely to engage in other income-generating activities, aiming not only to repay the loan but also to better cope with the lean season. Second, farmers who are able to repay the loan and get their collateral back can benefit from a possible increase in grain price. Third, farmers who store their crops as collateral until the time of loan repayment escape the prevalent social pressure to share their harvest with kin and neighbours.[4]

Last but not least, these farmers circumvent the temptation to sell their grain in order to purchase goods of no long-term value, thereby enabling them to mitigate self-discipline problems that could otherwise limit their ability to save grain. Indeed, individuals who exhibit more impatience for near-term trade-offs than for future trade-offs usually think to be patient enough in the future to be able to save the harvest that they store on site; but when the time comes they may nonetheless fail to do so, tempted to use their crop for immediate consumption. For that reason, individuals who realize that they may revisit their choice in the future may seek for a way to "tie their hands" to prevent this from happening. For developing countries like Burkina Faso in which formal commitment savings mechanisms are lacking, warrantage is likely to provide an effective device in this regard. It can even be seen as a "hard commitment" device, according to the terminology proposed by Bryan, Karlan, and Nelson (2010), since it offers users the possibility of constraining their future self's consumption physically, by storing their grain in a certified warehouse that is locked for six months and cannot be opened by anyone before the scheduled date. In this article, we offer a new rationale for the success of warrantage schemes, based on the demand for commitment.

We implemented a warrantage system in Burkina Faso, as part of the Farm Risk Management for Africa (FARMAF) project. We partnered with the Reseau des Caisses Populaires du Burkina Faso, a rural bank operating in Burkina Faso, and the Confédération Paysanne du Faso (CPF), a nationwide organization of farmers, to implement a warrantage system in the western region of Burkina

[1] See among others Bester (1987) and Hoff and Stiglitz (1990).

[2] See Stephens and Barrett (2011); Kazianga and Udry (2006); Dillon (2016); Casaburi and Willis (2016); Gross, Guirkinger, and Platteau (2017).

[3] See Burke, Bergquist, and Miguel (2018); Basu and Wong (2015); Fink, Jack, and Masiye (2014).

[4] Several recent studies indeed suggest that individuals living in poor communities often feel obligated to support relatives and neighbours (Platteau, 2000; Barr and Genicot, 2008; di Falco and Bulte, 2011) and that those who anticipate that their income will be "taxed" by neighbours may choose to spend their wealth quickly (Goldberg, 2017) or to hide part of it (Jakiela and Ozier, 2016) in order to escape solicitations. Baland, Guirkinger, and Mali (2011) also suggest that excess borrowing is a strategy used by some individuals in order to signal to their peers that they are cash constrained and cannot respond to their demands.

Faso. In January 2013, a series of hypothetical choice experiments were implemented in the field to elicit measures of discounting and risk aversion for a random sample of 653 farmers spread across seven villages. In 2013, each of the villages was provided a warehouse. In November 2013, each farmer living in these villages was offered credit in exchange for storing a portion of their harvest as collateral in one of these warehouses, with no opportunity to access the stored grain for a period of six months. We collected data on farmers' participation in the system in 2013 and again in 2015. We found that farmers electing to engage in warrantage stored a quite large portion of harvested crops – around 30 percent. We moreover found that a significant proportion of participants chose to store without taking out a loan, a behavior that cannot be explained by the liquidity constraint. One of the main contributions of this article is thus to provide evidence of a link between farmers' risk and time preferences and participation in the system.

We develop a theoretical model in which the farmer is sophisticated with respect to present bias and makes decisions about how to allocate his harvest for various uses. We consider a three period multi-self game in which participation in warrantage provides the farmer with a means to constrain his futures selves. The first self chooses to participate or not in the system as well as the quantity of grain to be stored in the warehouse and the amount of the loan (no more than 80 percent of the value of the collateral); the second self can consume the grain stored at home but has no access to the grain stored in the warehouse; finally the third self repays the loan and the interests and get the collateral back. The model provides four main results. First, there is a positive relationship between present-bias and participation into the warrantage scheme. Second, participants in warrantage are likely to fall into three categories: those who stored grain and borrowed the maximum amount allowed for a loan, those who stored grain and borrowed less than the maximum amount allowed for a loan, and those who stored grain without taking a loan. Third, farmers who store without taking the maximum loan cannot be time-consistent. Fourth, farmers who exhibit a strong present bias (whose hyperbolicity exceeds a certain threshold) may find it optimal to use warrantage even when it is more profitable to store grain at home.

We then match measures of farmers' risk aversion and time preferences with observed adoption of warrantage. We capture this relationship in a regression which includes a range of observable individual characteristics and village-year dummies. In line with the main prediction of the theoretical model, we find that farmers who exhibited hyperbolic preferences were significantly more likely to engage in the system. We interpret this result as evidence that time-inconsistent farmers use inventory credit as a means to commit to saving a portion of their crop until the hunger season. This result suggests that inventory credit is likely to provide support for people who wish to protect their harvest from their own, possibly short-sighted, impulses. While we cannot entirely rule out the possibility that this result arises due to an unobserved factor affecting both experimental measures of time and risk preferences as well as warrantage adoption (see Section 7 for a discussion of alternative explanations), it is worth noting that our findings are consistent with recent studies, suggesting that present-biased people may be particularly willing to engage in commitment devices in order to mitigate the anticipated impatience of their future selves.

Many theoretical models, such as the quasi-hyperbolic discounting model of Laibson (1997) or the temptation and self-control theory proposed by Gul and Pesendorfer (2001), imply a demand for commitment (see Bryan, Karlan and Nelson 2010 for a review of the literature).[5] These models predict that individuals who exhibit more impatience for near-term trade-offs than for future trade-offs, and are sophisticated enough to realize this, will engage in commitment devices in order to increase their welfare (O'Donoghue and Rabin, 1999).[6] Moreover, in the empirical literature, some recent studies have already established a link between hyperbolic preferences and decisions to engage in a commitment device (see Frederick, Loewenstein, and O'Donoghue (2002) for a review to the early 2000s and Sprenger (2015) for more recent papers). It is however difficult to find examples of pure commitment devices provided by the market in developing countries. Participation in a rotating savings and credit association (ROSCA) can be explained by a preference for commitment, since joining a ROSCA makes defaulting very difficult unless one is prepared to bear the associated costs, which can be significant (Aliber, 2001; Anderson and Baland, 2002; Gugerty, 2007; Ambec and Treich, 2007; Basu, 2011). In practice, however, it remains difficult to determine whether people use the ROSCA because they perceive it as a commitment savings device or for other reasons. Evidence supportive of the idea that some people use savings devices for their commitment value would establish an empirical link between the use of a commitment device and the hyperbolic nature of the preferences of its users. Two seminal empirical studies do provide this type of evidence. In a study run in the Philippines, Ashraf, Karlan, and Yin (2006) showed that women who exhibited hyperbolic preferences were significantly more likely to open a commitment savings product. In South India, Bauer, Chytilova, and Morduch (2012) found that women who exhibited present-biased preferences were more likely to borrow from a self-help group than from a bank or a moneylender, interpreting this result as evidence that these women use self-help groups as a means to commit themselves to save money each week.[7]

Our study builds on and extends this literature by providing the first field evidence that links time inconsistency to the decision to engage in a warrantage system, a promising development tool that is emerging in African countries. We show that there is heterogeneity in demand for a storage commitment device and that time-inconsistency can explain some of this heterogeneity. Our study thus provides new evidence regarding the relationship between time preferences, credit access, and storage choices among Burkinabe farmers, and presumably among farmers in sub-Saharan Africa more generally.

The article proceeds as follows. Section 2 describes the main features of the warrantage system that we implemented in Burkina Faso. Section 3 describes a theoretical model of a sophisticated hyperbolic farmer's decision to allocate the harvest between warrantage and alternative uses. Section 4 describes the surveys and Section 5 focuses on hypothetical risk and time preference data. Section 6 discusses how experimental choices correlate with observed adoption of warrantage. Section 7 provides alternative explanations for the apparent link between time-inconsistency and participation in warrantage. In particular, we discuss to what extent our findings may arise due to an unobserved

[5] Several papers have studied the theoretical properties of hyperbolic discounting (Phelps and Pollak, 1968; Laibson, 1997). Other approaches to model problems of temptation and self-control include Gul and Pesendorfer (2001), Fudenberg and Levine (2006) and Banerjee and Mullainathan (2010).

[6] Bernheim, Ray, and Yeltekin (2015) theoretically show that some external commitment devices can undermine the effectiveness of internal self-control mechanisms.

[7] More recently, Giné et al. (2018) implemented artefactual field experiments in Malawi and showed that the revisions of money allocations toward the present are positively associated with measures of present-bias. In a developed-country context, Meier and Sprenger (2010) elicited individual time preferences using incentivized choice experiments in laboratory and showed that present-biased individuals are more likely to have credit card debt.

credit constraint or social taxes. Section 8 concludes.

2 Context and FARMAF project

Warrantage is not yet widespread in Africa. It emerged in Niger in the 2000's (Coulter and Onumah, 2002) and has been developing in Burkina Faso since 2005.[8] A precondition for a warrantage system to emerge is that banks must be confident that the stored product will be available should they need to withdraw it. From a market demand perspective, farmers who are willing to store a portion of their harvest for a period of six months must also be confident that their collateral will be returned once they repay the loan. Thus, each stakeholder in the system relies on the existence of a reliable network of certified warehouses.

As part of the FARMAF project, we implemented a warrantage system in seven villages located in the Tuy and Mouhoun provinces, in the western region of the country (Figure 1). The FARMAF project is one of the first programs aiming to develop warrantage in the country.[9] Except for the initial cost of building the warehouse and the initial organizational costs, 95 percent of which were covered by the FARMAF project and 5 percent by farmers, the system runs without material or financial assistance and has continued to function since 2013.

The warehouses were built in the villages so that farmers can bring their bags themselves with bicycles, motorcycles or donkey pulled carts. The warehouses have a storage capacity of up to 80 tons, which means that 50 households can each deposit 16 bags of 100 kg. In November 2015, i.e. after three seasons of warrantage, 85 percent of the storage capacity was reached. The warehouses are secured with two locks. The key to one of these locks belongs to the rural bank, and the other key belongs to the local farmers' organization. As a result of this dual-lock system, neither party can open the warehouse in the absence of the other.

The warrantage system was designed to correspond to the agricultural calendar (Figure 2). In the warrantage system as we implemented it, farmers are allowed to store cereals, sesame, and peanuts. Farmers store mainly maize, followed by sorghum and millet, which are characterized by very similar price patterns.[10] In Burkina Faso, land preparation and sowing for maize, sorghum and millet typically begin in June, and the crops grow during July and August, maturing between September and October.[11] Farmers who participate in the warrantage system receive a loan in November, which is often used to pay seasonal employees for cotton harvesting.[12] Farmers who are able to repay the

[8] Warrantage shares some features with the warehouse receipt systems (WRS) that exist in Ghana, Tanzania, and Zambia, but WRS cannot be considered commitment devices because farmers who own a receipt are able to sell their grains whenever they wish (Coulter, 2009).

[9] Previous programs include the warrantage program of the NGO SOS Sahel, which was carried out in eight provinces of Burkina Faso (Bam, Gnagna, Ioba, Loroum, Mouhoun, Namentenga, Nayala, and Sanmatenga) and the warrantage program of the NGO Comunità Impegno Servizio Volontariato (CISV), which was carried out in the provinces of Tuy and Ioba.

[10] Farmers may also store beans (niébé), but since the pre-storage drying process is much easier for grains than for beans, farmers tend not to store beans. Another reason why farmers store mainly maize is that maize yields are higher (maize responds better to fertilizer). Sorghum and millet are very much appreciated for self-consumption and traditional usages including making dolo (a kind of traditional beer), whereas maize is not only consumed but is also a cash crop. Cotton, the main cash crop, is not a possible candidate for warrantage, notably because a parastatal board controls the entire cotton sector.

[11] The length of the cropping cycle is around 100 days for maize and 120 days for millet and sorghum.

[12] We collected information on the use of the credit during a survey carried out in August 2016, i.e. at the end of the third warrantage season.

loan get their collateral back in May, at the lean season, when the price of grain is usually high.

Every year since 2013, farmers were solicited to deposit a portion of their harvest in one of these warehouses in exchange for a 6-month loan. The rural bank does not lend more than 80 percent of the value of the inventory at the time of the loan. Should borrowers default, this protects the rural bank even if the price of grain decreases by 20 percent, which is very unlikely to occur. The monthly interest rate charged by the bank is around 1 percent. The interest rate, as well as the value of the collateral, are determined by the rural bank.[13] Farmers were also charged the cost of storage, which amounted to 100 CFA francs (F thereafter) for each 100 kg bag of grain per month. This storage fee is based on information regarding previous warrantage programs that have been implemented in Burkina Faso and Niger. It includes the warehouse maintenance and the transaction costs incurred to deal with credit institutions (phone calls and travel from village to bank agencies). The borrower's name is written on each bag of grain that is deposited so that each farmer will be able to identify his deposit later. Farmers also have the opportunity to store grain without taking out a loan. When the loan matures, i.e. in May, the bank demands repayment of the amount borrowed plus interest before authorizing the restitution of a farmer's collateral. If the farmer is not able to reimburse the loan and interests, the collateral is sold. In practice, the farmer must find a buyer and meet him at the warehouse on the repayment date. In this case, the farmer reimburses the bank and keeps what remains. If the farmer is unable to find a buyer on the repayment date, he is subject to a penalty: 10 percent of the total debt per day late. If the farmer defaults, the bank keeps the collateral. We do not have data on the proportion of farmers who had to sell their collateral in order to repay their loan. However, we do know that no farmer received penalties between 2013 and 2015.

Farmers must make a tradeoff between the benefits of participating in the warrantage system (such as access to credit and to a commitment device) and its direct and indirect costs (the opportunity cost of the collateral deposit, the obligation to pay storage costs at the time of deposit, the risk of not being able to reimburse the loan, the possible lack of understanding of how the system functions, the possible lack of trust, etc.). In this system, the total cost of credit can easily be offset by the rising value of the collateral, which was around 40 percent on average over the last decade according to price surveys made by the Afrique Verte association on local markets.[14] However, the warrantage system may not be the cheapest alternative for immediate liquidity when the increase in grain prices is small. Indeed, warrantage is profitable only when the increase in the price of grain is sufficiently large compared to the interest rate. For instance, consider a household that owns some grain with a value of 10,000F (post-harvest) and requires 8,000F for immediate consumption. With warrantage, it must store 10,000F as collateral in order to obtain a loan of 8,000F and will be required to reimburse about 8,500F after six months. If the price of grain does not increase over this time period, it will end up with 1,500F ($10,000-8,500$). Without warrantage, it can sell grain to obtain 8,000F immediately and store 2,000F at home, ending up with 2,000F six months later (continuing to consider the case in which the price of grain does not increase). In this case, selling on the market to get cash immediately is obviously more profitable than participating in an inventory credit system. We examine in more details the theoretical mechanisms underlying the decision to participate in the

[13] In 2013, the interest rate was 0.7 percent in Magnimasso, 0.8 percent in Lopohin, 1 percent in Tankuy, 1.5 percent in Bouéré, and 1.2 percent in Bladi, Biforo, and Gombélédougou. The mean value of a 100 kg bag of maize or sorghum as collateral was 10,000 CFA francs.

[14] Monthly local prices can be found at http://www.afriqueverte.org/

warrantage system in the next section.

3 Theoretical framework

In this section, we develop a theoretical model in which the farmer is sophisticated with respect to present bias and makes decisions about how to allocate his harvest for various uses. As we shall see, in this model, participation in warrantage provides the farmer with a means to constrain his future self.

3.1 A multi-self game

We consider three periods in this model for two reasons. First, hyperbolic discounting comes into play when there are more than two periods. Second, in the context of our study, farmers rarely end up with a surplus of grain at the end of the year.[15] As a result, it is reasonable to model decisions regarding post-harvest investments over a crop year. The first period is the post-harvest season (November), when the farmer must decide whether or not to participate in the warrantage system. The intermediate period extends from December to April, when the farmer is not able to access any stored grain as collateral. The final period is the lean season (starting in May), when the farmer is required to reimburse the amount borrowed as well as interest before getting his collateral back.

The available harvest is a quantity of grain, denoted H and expressed in kilograms, which can be consumed by the family, stored on the farm in a traditional granary, sold at the market to purchase other goods, or stored in a warehouse as collateral. Let p_t be the price of grain at time t and q_t the quantity of grain consumed at time t. In periods 2 and 3, the (indirect) utility of the household is a constant relative risk aversion (CRRA) utility function $U(c_t) = \frac{(c_t)^{1-r}}{1-r}$ where $r > 0$ (and $r \neq 1$) is the risk aversion parameter and c_t is the value of the grain (expressed in CFA francs) that is consumed at time t. We assume, for the sake of simplicity, that there is no utility stream in period 1. The farmer's expected utility at time $t = 3$ is denoted $EU(c_3)$. The farmer's discounted expected utility at time $t = 2$ is:

$$EU_2 = EU(c_2) + \frac{1}{1+\delta_1} EU(c_3), \tag{1}$$

where δ_1 is the discount rate of the second-period self (or Self 2), applied to the utility stream that he receives in period 3. The farmer's expected utility at time $t = 1$ is:

$$EU_1 = \frac{1}{1+\delta_1} EU(c_2) + \frac{1}{1+\delta_2} EU(c_3), \tag{2}$$

where δ_1 (resp. δ_2) is the discount rate of the first-period self (Self 1), applied to the utility stream that he receives over period 2 (resp. period 3).

In this model, hyperbolic discounting arises from the fact that $\frac{1}{1+\delta_2}$ does not necessarily equal $\left(\frac{1}{1+\delta_1}\right)^2$. Let us write the hyperbolic discounting parameter, denoted h, as a ratio of the discount

[15] See Bernheim, Ray, and Yeltekin (2015) or Harris and Laibson (2001) for infinite horizon models that focus on the consumption decision problem of a budget constrained individual with (quasi-) hyperbolic time preferences. Although we could have extended one of these models to include the specific features of warrantage, it would have led to a rather untractable model.

factors: $h = -\frac{\left(\frac{1}{1+\delta_1}\right)^2}{\frac{1}{1+\delta_2}}$ with $h \geq -1$. If $h = -1$, the farmer has standard exponential time preferences, and $\frac{1}{1+\delta_2} = \left(\frac{1}{1+\delta_1}\right)^2$. If $h > -1$, the farmer has (present-biased) hyperbolic preferences, and $\frac{1}{1+\delta_2} < \left(\frac{1}{1+\delta_1}\right)^2$. In the specific case of quasi-hyperbolic preferences (also called the $\beta\delta$ model), we have $\frac{1}{1+\delta_1} = \frac{\beta}{1+\delta}$, $\frac{1}{1+\delta_2} = \frac{\beta}{(1+\delta)^2}$ and then $h = -\beta$.

At time $t = 1$, the farmer decides whether or not to participate in the warrantage system. If he opts to participate, he chooses the quantity of grain, denoted w, that is stored in the warehouse as collateral, and the loan rate, denoted θ, with $0 \leq \theta \leq 0.8$. Notice that the value of the loan is then $p_1\theta w$. In order to be able to get his grain back at time $t = 3$, the farmer must reimburse the principal amount of the loan as well as the interest $(1+i)p_1\theta w$, where i is the interest rate.

In order to take into account the difference between returns to warrantage and returns to alternative investments (whether on-farm storage or investment in a small business), we assume that the return to the grain stored in the warehouse as collateral equals $1-\sigma$ times the return to the grain that is neither stored in the warehouse nor consumed, where σ refers to the costs of warrantage and $0 < \sigma < 1$.

In order to keep the model as simple as possible, we assume that the price of grain is low in the first two periods, i.e. $p_1 = p_2 = \underline{p}$. On the contrary, we assume that the farmer is uncertain about the price of grain in the last period. The price of grain thus increases in period 3 up to $\overline{p}$ with probability $\pi > 0$ and remains low with probability $1-\pi > 0$. Let us denote Δ as the maximum percent increase in the price of grain, i.e. $\Delta = \frac{\overline{p}-\underline{p}}{\underline{p}}$.

At time $t = 1$, the farmer chooses w and θ such that his current period discounted utility (EU_1) is maximised and such that the first-period budget constraint $H-(1-\theta)w \geq 0$ holds and $0 \leq \theta \leq 0.8$. At time $t = 2$, the farmer chooses the consumption level c_2 that maximizes his period 2 discounted utility, with:

$$c_2 = \underline{p}q_2 \tag{3}$$

and he faces a budget constraint that is affected by the quantity of grain stored in the warehouse at time $t = 1$:

$$H-(1-\theta)w - q_2 \geq 0, \tag{4}$$

where the impact of committing to warrantage is clear, as w reduces the amount of grain available for second-period consumption.

At time $t = 3$, the household consumes all that remains of its grain:

$$c_3 = p_3\left(H-(1-\theta)w - q_2\right) + p_3(1-\sigma)w - (1+i)\underline{p}\theta w, \tag{5}$$

where $p_3\left(H-(1-\theta)w - q_2\right)$ is the value of savings at home, $p_3(1-\sigma)w$ is the value of the grain stored in the warehouse, and $-(1+i)\underline{p}\theta w$ is the reimbursement of the loan and the interest. The price of grain p_3 equals $\overline{p}$ with probability π and $\underline{p}$ with probability $1-\pi$.

3.2 Case with hyperbolic time preferences

We solve the game played by the farmer and his future selves (and characterize the sub-game perfect Nash equilibrium) through backward induction. We focus on the case where the maximum return to grain stored in the warehouse is larger than the reimbursement of the loan, i.e. $(1-\sigma)(1+\Delta) > 1+i$.[16]

Optimal warehouse storage

In the case where the budget constraint of Self 2 is binding in equilibrium, we obtain clear-cut predictions regarding the effects of present bias on the optimal quantity of grain w^* that is stored as collateral. In particular we find the following result:

Proposition 1 [present bias & optimal warehouse storage]: *There exists a threshold $\underline{h} < 0$ above which the budget constraint of Self 2 is binding ($q_2^* = H-(1-\theta^*)w^*$). In this case, the optimal quantity of grain w^* increases with the hyperbolic preference parameter h:*

$$\frac{\partial w^*}{\partial h} > 0.$$

The proof is provided in the online supplementary appendix material (Proof A). The result given in the first part of Proposition 1 arises because, if the farmer is highly present-biased, and thus very impatient in the near future, his second-period self will consume a lot of grain. As a result, his budget constraint will be binding.

The result given in the second part of Proposition 1 arises because a farmer with sophisticated hyperbolic time preferences has the means to constrain his second-period self through warrantage. Formally, the optimal share of grain that the farmer decides to store in the warehouse is given by:

$$\frac{w^*}{H} = \left[1-\theta^* + \left[\frac{-h(1+\delta_1)(1-\theta^*)}{\pi\left[(1+\Delta)(1-\sigma)-(1+i)\theta^*\right]^{1-r} + (1-\pi)\left[1-\sigma-(1+i)\theta^*\right]^{1-r}}\right]^{\frac{1}{r}}\right]^{-1}, \qquad (6)$$

where θ^* is the optimal loan rate. In the appendix, we show that this rate does not depend on time preferences (δ_1 and h). This characterization also leads to the prediction that the optimal quantity of grain w^* decreases with the impatience parameter δ_1. In contrast, the effect of the risk aversion parameter on the optimal quantity of grain w^* remains ambiguous, since it appears to affect optimal storage in various ways.[17]

Optimal loan rate

In the case where the budget constraint of Self 2 is binding in equilibrium, we find the following result:

Proposition 2 [optimal loan rate]: *If $h \geq \underline{h}$, then the optimal loan rate is such that:*
Case 1: The farmer borrows the maximum amount allowed for a loan if her level of risk aversion is sufficiently low, i.e. $\theta^* = 0.8$ if $r < \underline{r}$,
Case 2: The farmer borrows less than the maximum amount allowed for a loan if her level of risk aversion is intermediate, i.e. $0 < \theta^* < 0.8$ if $\underline{r} \leq r \leq \overline{r}$.

[16] Even in the event of a small increase in grain prices, the condition still holds for very high (and thus unlikely) values of σ. If this inequality does not hold, then the farmer would never be able to reimburse his loan. In such a case, the bank would never lend money.

[17] This is due to the fact that the risk aversion parameter in CRRA utility functions captures both risk aversion and intertemporal elasticity of substitution. It thus also plays a role in smoothing consumption over time.

Case 3: The farmer does not take out a loan if she is sufficiently risk averse, i.e. $\theta^* = 0$ *if* $r > \overline{r}$,

where $\overline{r} = \frac{Ln\left[\frac{\pi}{1-\pi}\frac{(1+\Delta)(1-\sigma)-(1+i)}{\sigma+i}\right]}{Ln[1+\Delta]}$ and $\underline{r} = \frac{Ln\left[\frac{\pi}{1-\pi}\frac{[(1+\Delta)(1-\sigma)-(1+i)]}{(\sigma+i)}\right]}{Ln\left[\frac{(1+\Delta)(1-\sigma)-0.8(1+i)}{1-\sigma-0.8(1+i)}\right]}$.

The proof of this result is provided in the online supplementary appendix material (Proof A). Proposition 2 reveals a typology of participants in the warrantage scheme. Participants can be divided into three groups, namely, those who store grain and borrow the maximum loan amount allowed, those who store grain and borrow less than the maximum amount allowed, and those who store grain without taking out a loan. This last group is of special interest for our study, since it brings together participants who are explicitly seeking to use the commitment mechanism of the proposed scheme, i.e. those farmers who have sufficiently hyperbolic time preferences and are highly risk averse.

Proposition 2 moreover leads to the prediction that the optimal loan rate decreases with the risk aversion parameter in the case where level of risk aversion is intermediate, i.e. when $\underline{r} \le r \le \overline{r}$. The reason for this is that taking a credit for investing is a risky choice: if the rate of return on the investment is lower than the interest rate, the farmer loses money. For this reason, risk-averse farmers will borrow less than others, ceteris paribus. The optimal loan rate is given by the following expression:

$$\theta^* = \frac{1-\sigma}{1+i}\frac{\left[\frac{\pi[(1+\Delta)(1-\sigma)-(1+i)]}{(1-\pi)(\sigma+i)}\right]^{\frac{1}{r}} - (1+\Delta)}{\left[\frac{\pi[(1+\Delta)(1-\sigma)-(1+i)]}{(1-\pi)(\sigma+i)}\right]^{\frac{1}{r}} - 1}. \tag{7}$$

Finally, and perhaps more surprisingly, Proposition 2 predicts that the loan rate θ^* is independent of time preferences. The reason for this is that borrowing is not an intertemporal choice as such in our model. Although borrowing means having more cash in hand today and assuming the burden of loan repayment in the future, it does not create any imbalance in the consumption path. This is because the farmer has the means to smooth his consumption : he can store grain either at home (which will increase his wealth in the second period) or in the warehouse (which will increase his wealth in the third period).

3.3 Case with time-consistent preferences

To better understand the characteristics of farmers who store grain but do not take out the maximum loan amount, we examine the optimal loan rate θ^* in a model where the farmer has consistent time preferences, i.e. $h = -1$. An important result arises from the comparison of the two models:

Proposition 3: *In contrast to a present-biased farmer, a farmer having time-consistent preferences (i.e.* $h = -1$*) always chooses the maximum loan rate* $\theta^* = 0.8$*, whatever his level of risk aversion.*

The proof is provided in the online supplementary appendix material (Proof B). The intuition behind this result is as follows: a farmer who has time-consistent preferences does not benefit from warehouse storage per se because he does not value commitment devices, and he faces a cost $\sigma > 0$ per unit stored in the warehouse. Consequently, he will store the exact amount of grain necessary in order to obtain the loan amount he needs. In other words, he will choose the maximum loan rate.

Proposition 3 highlights the difference between the time-consistent model and the hyperbolic model. In the latter, a farmer can very well store without taking out the maximum amount of credit, provided he is sufficiently hyperbolic (i.e. $h \geq \underline{h}$) and sufficiently risk averse (i.e. $r > \overline{r}$), as stated in Proposition 2. Thus, the mere fact that there are farmers in our sample who store grain without taking the maximum credit (or even without taking any credit) suggests that the hyperbolic model outperforms the time-consistent one in describing farmer decisions to participate in warrantage.

3.4 Case with price certainty

Finally, to better understand some farmersâĂŹ decision to participate in warrantage when it is more profitable to store grain at home, we examine the particular case where the price increase is known with certainty (i.e. $\pi = 1$). Although Proposition 1 states that there exists a threshold in present bias beyond which the budget constraint of Self 2 is necessarily binding, we were not able to characterize this threshold in the general case. It is however possible to do so in the particular case where the price increase is known with certainty, i.e. $\pi = 1$. This model provides two results. First, risk aversion does not affect the optimal loan rate under price certainty and we thus always have $\theta^* = 0.8$. Second, there are two situations in which warrantage appears as an optimal solution for the farmer, as shown in Figure 3.

In case (i), we have $0.8(\Delta - i) - (1+\Delta)\sigma \geq 0$, which implies that the increase in the price of grain is sufficient to offset the costs of warrantage (given that the farmer chooses the maximum loan rate). In this case, it is more profitable to participate in the warrantage scheme, and all farmers will do so. The budget constraint of Self 2 is binding, meaning here that Self 2 has the exact amount of grain he will consume.

In case (ii), we have $0.8(\Delta - i) - (1+\Delta)\sigma < 0$, which implies that it is more profitable to store grain at home. Farmers whose hyperbolic preference parameter h is smaller than the threshold $\underline{h}$ do not use warrantage and the budget constraint of Self 2 is not binding. On the contrary, farmers whose hyperbolic preference parameter is above this threshold find it optimal to use warrantage in order to make the budget constraint of Self 2 binding because it is an efficient way to limit Self 2's consumption. We are able to (implicitly) characterize the threshold for any level of risk aversion and we are able to solve for an explicit formula in the case where the risk aversion parameter is $r = 0.5$ (which is the median value in our sample). In this case we show that $\underline{h} = -1 + \sqrt{\frac{(1+\Delta)\sigma - 0.8(\Delta - i)}{0.2(1+\Delta)}\left(1 + \frac{1+\Delta}{(1+\delta_1)^2}\right)}$. The proof is provided in the online supplementary appendix material (Proof C).

In sum, our theoretical model highlights four important qualitative results regarding our understanding of farmer decisions regarding whether or not to participate in a warrantage program. First, the quantity of grain that is stored in the warehouse increases when the hyperbolic parameter increases (Proposition 1). Second, participants are likely to fall into three categories, defined according to the model parameters, and the optimal loan rate decreases with risk aversion (Proposition 2). Third, farmers who store grain without taking out a loan are necessarily present-biased (Proposition 3). Fourth, farmers who exhibit a strong present bias (whose hyperbolicity exceeds a certain threshold) may find it optimal to use warrantage even when it is more profitable to store grain at home âĂŞ a result we highlighted in the particular case where the price of grain is known with certainty. In what follows, we show to what extent our data are in line with these predictions. We provide a descriptive statistical analysis of our data which shows that the typology presented in

Proposition 2 can be observed in the real world,[18] and that the hyperbolic model should be preferred to the time-consistent model in explaining farmer decisions to participate in the warrantage scheme. Our main empirical contribution is to provide a test for Proposition 1 using our data.

4 Survey Data

Our main analysis is based on three surveys: a baseline survey run in January 2013 on a sample of 653 households living in the villages where the warehouses were later built, and two follow-up surveys, which were carried out among the subgroup of farmers who participated in the warrantage system in 2013 (the first year of the project) and those who participated in 2015 (the third year of the project).

4.1 Survey Procedure

All data were collected in cooperation with the CPF in 7 villages where the number of CPF members is known to be large. In these villages, we interviewed all CPF members, as well as a number of non-CPF members. For the baseline survey, we stratified the sample such that CPF members represented two-thirds of the total number of surveyed farmers. An average of 90 households were interviewed in each village. Twenty investigators and two supervisors were recruited for the data collection. Surveys and experiments were conducted in the Dioula language. The enumerators interviewed the heads of households, who were defined as the person responsible for making the farming decisions of the household.

Of the 653 farmers surveyed in January 2013, 103 (16 percent) accepted the offer to participate in the warrantage system in November 2013. Data on individual loan amounts and quantities stored were collected at the time of their deposits. These 103 farmers were also asked about the total quantity of crops harvested before warrantage.

We returned to the field at the end of 2015, at the end of the third round of the project. Of the seven villages enrolled in the program in 2013, one village had decided to leave the program and not to participate in the 2015 follow-up survey. As a result, we were unable to determine the total number of participants in this village in 2015. Of the farmers surveyed in January 2013 in the 6 other villages, 167 (33 percent) had chosen to participate in the warrantage system in 2015. From these participants we collected another round of data on crop harvest, quantities stored, and loan amounts.

4.2 Sample Characteristics

Table 1 reports mean values for various farmer characteristics collected during the baseline survey. On average, the surveyed households are comprised of 11 members, 6 of whom are employed in farming activities. In almost all cases (98 percent), the household is headed by a man of an average age of 42 years, who reports having received a formal education in 31 percent of cases. In the Tuy and

[18] However, we do not empirically test the existence of a relationship between the loan rate and the degree of risk aversion because this would require the use of a valid instrument, which we lack. Indeed, such a relationship cannot be estimated using a simple reduced form model because in regressing loan rates on risk aversion for farmers who chose to store grain in the warehouse, we are unable to observe the relationship for the sample as a whole. This is the standard problem of sample selection (Heckman, 1979).

Mouhoun provinces, the main crops are cotton, maize, sorghum, millet, and sesame. On average, the surveyed households own 8 hectares of land. They devote about 17 percent of their land to maize and about 32 percent to cotton.

We compare our data with the nationally-representative agricultural survey carried out by the Ministry of Agriculture of Burkina Faso in 2013 (see Table 2). This survey includes 5,197 rural households that were randomly selected in each of the 45 provinces of Burkina Faso, among which 265 households were located in the Tuy and Mouhoun provinces, where our project was implemented. Table 2 shows that average household characteristics are very similar between our sample and the households from the same geographic area that were included in the national survey. This suggests that, although we focused on CPF members for the study, our sample appears to be quite representative of households located in western Burkina Faso.

4.3 Participation in Warrantage

Table 3 provides detailed information for the subset of surveyed farmers who decided to participate in warrantage in 2013 and/or in 2015. Overall, farmers electing to engage in warrantage stored a large portion of harvested crops : about 28 percent on average in 2013 and 34 percent in 2015. Storage was comprised mainly of maize versus other staple food crops such as sorghum and millet. It is worth mentioning that the composition of the sample of participants corresponds with Proposition 2 of the theoretical model presented in Section 3. We indeed find that the participants in the scheme are divided into three groups. In 2013, 67 participants (65 percent) borrowed 80 percent of the value of their stored harvest (the maximum amount allowed for a loan), 26 participants (25 percent) borrowed less, and the remaining 10 percent chose to store without taking out a loan. The situation was slightly different in 2015, as 77 participants (50 percent) borrowed less than the maximum amount allowed for a loan, and the proportion of those who chose to store without taking out a loan was also much higher (25 percent).

Tables 4 and 5 provide a simple calculation of the total cost and returns of warrantage in 2013 and 2015 for the average farmer of the sample and in each category of borrowing. In 2015, the total cost of credit was easily offset by the rising value of the collateral, as shown in Table 4: the net gain of warrantage for the average farmer who stored 10 bags of maize in the warehouse and borrowed 42 percent of the value of the quantity stored, was about 29,700 F. We calculate the net gain of warrantage by taking the added-value of grain stored in the warehouse after six months (about 27,100 F), minus the storage costs (100 F per bag and per month, i.e. 6,000 F here), plus the gain of the invested loan (11,400 F) supposing that the return on this investment is equal to that of grain storage (i.e. 25 percent here), minus the reimbursement of the loan (about 2,800 F) that include the capital and the interests (about 1 percent per month).[19] In order to get an idea of how much the average farmer is willing to pay to store his grain in the warehouse rather than at home, we moreover calculate the net gain of storing the same quantity on farm, in the case where the farmer would invest a share θ (i.e his loan rate) of the value of the bags available, while the remaining share $(1-\theta)$ would be stored at home at no cost. We obtain a net gain of storing at home at no cost of about 27,100 F, which means that on average that year, warrantage was a more profitable option. However,

[19] Inflation was very low over this period: 0.53 percent in 2013, -0.26 percent in 2014, and 0.95 percent in 2015 according to the World Bank. We thus ignored it in the calculation.

the same calculation by category of borrowing highlights that storing at home was more profitable than warrantage for those who did not take any credit, since they recorded a loss of 2,160 F (or 600 F per bag).

In 2013, the story was different, because the rise in grain prices was exceptionally low (only three per cent on average). As a result, the capital gain was not enough to offset the cost of warrantage, as shown in Table 5. Thus, it would have been more profitable not to use the warehouse and to sell grain to invest instead of using a loan. The average farmer who stored 14 bags of maize in the warehouse indeed recorded a loss of 11,000 F (or 800 F per bag). Figure 4 plots the cost of warrantage relative to storing at home at no cost for each participant, showing that a number of farmers are willing to participate into the scheme even if it may be quite costly.

5 Hypothetical Risk and Time Preference Data

In this section, we describe the risk and time preference data that were collected during the baseline survey. We describe the design and procedure of the experiments and we explain how we estimated the individual risk and time preferences from the experimental results. It is important to mention that we make use of hypothetical surveys instead of incentivized scoring rules, not only because it is cheaper and easier to administer to large samples, but also because we wished to avoid disturbing the operations of other activities run by the same project. In particular, running incentivized games in seven CPF villages could have caused frustration in other CPF villages that were not included in the sample used for the inventory credit study.

5.1 Risk Preferences

This section presents the estimation of the risk aversion parameter.

5.1.1 Design and Procedure of Experiments

Our experiments were built on the risk aversion experiments developed by Holt and Laury (2002). We used a multiple price list design to measure individual risk preferences. We ran two experiments offering progressively lower and higher payoffs. In each experiment, participants were presented with a choice between two lotteries of risky and safe options, and this choice was repeated nine times with different pairs of lotteries, as illustrated in Table S1. Farmers were asked to choose either lottery A or lottery B. For example, the first row of Table S1 indicates that lottery A offers a 10% probability of receiving 1,000 CFA and a 90% probability of receiving 800 CFA, while lottery B offers a 10% probability of a 1,925 CFA payoff and a 90% probability of 50 CFA payoff.

The low payoff amounts were chosen because they were in line with the ranges of relative risk aversion parameters in previous experiments by Holt and Laury (2002) and Andersen et al. (2008), and because they amount to approximately one day's worth of income for a non-skilled worker in Burkina Faso (around 1,000 CFA a day, i.e. about 2 USD a day in 2012), which seemed credible to respondents. In the second experiment, farmers were asked to choose between lotteries with payoffs that were ten times higher (10,000 CFA, or around 20 USD, which corresponds to the average price of a 100 kg bag of maize during the harvest season).

In practice, lotteries A and B were represented by two bags of 10 marbles of different colours: green for 1000 CFA, blue for 800 CFA, black for 1925 CFA and transparent for 50 CFA.[20] The composition of the bags was made known to the farmers, but they could not see inside the bags. As indicated in the last column of Table S1, risk neutral individuals ($r = 0$) are expected to switch from lottery A to lottery B at row 5, risk loving individuals ($r < 0$) are expected to switch to lottery B before row 5, and risk averse individuals ($r > 0$) are expected to switch to lottery B after row 5.

5.1.2 Analysis of Game Results

In order to render our results comparable to previous studies, we assume a constant relative risk aversion (CRRA) utility function, which enables us to compute the intervals provided in the last column of Table S1. The CRRA utility function has the following form: $U(x) = x^{1-r_i}/(1-r_i)$, where x is the lottery prize and r_i, denoting the constant relative risk aversion of the individual, is the parameter to be estimated. Expected utility is the probability weighted utility of each outcome in each row. An individual is indifferent between lottery A, with associated probability p of winning a and probability $1-p$ of winning b, and lottery B, with probability p of winning c and probability $1-p$ of winning d, if and only if the two expected utility levels are equal:

$$p.U(a) + (1-p).U(b) = p.U(c) + (1-p).U(d),$$

or,

$$p.\frac{a^{1-r_i}}{1-r_i} + (1-p).\frac{b^{1-r_i}}{1-r} = p.\frac{c^{1-r_i}}{1-r_i} + (1-p).\frac{d^{1-r_i}}{1-r_i}$$

which can be solved numerically in terms of r_i.

We estimate risk aversion measures from these data in the following way. First, we compute the midpoint of the intervals for the low payoff and the high payoff experiments.[21] We then take the average of the two interval midpoints as a measure of risk aversion. This averaging has the advantage of reducing measurement error compared to approaches based on a single experimental measure (Falk et al., 2016). We find that most farmers are risk averse, with an average of $r = 0.29$ (see Table 6). This average value is lower than those obtained by Harrison, Humphrey, and Verschoor (2010), who conducted similar experiments in India, Ethiopia, and Uganda.

5.2 Time Preferences

This section presents the estimation of the time-discounting parameter.

5.2.1 Design and Procedure of Experiments

We elicit the individual time-discounting parameters following Andersen et al. (2008), who incorporate measures of risk aversion into the utility function curvature, which Andreoni, Kuhn, and Sprenger (2015) refer to as the double multiple price list (DMPL) method, since it relies on one mul-

[20] We conducted specific training sessions for the surveyors and equipped them with a material enabling them to explain the experimental games to farmers in a concrete way in order to facilitate their understanding of the game.

[21] We take the upper bound for the first interval and the lower bound for the last interval.

tiple price list for time and one for risk.[22] We built two time preference experiments in the spirit of Harrison, Lau, and Williams (2002) and Coller and Williams (1999). However, we had to adapt the content of the experiment in order to offer hypothetical pay-offs that were plausible to respondents. The two experiments differed in the time delays offered. Our design thus differs from previous studies, such as Bauer, Chytilova, and Morduch (2012) and Ashraf, Karlan, and Yin (2006), which include a binary variable indicating whether the time-discount rate elicited in the near future experiment is higher than in the distant future experiment.[23]

In the first experiment, farmers were invited to choose between receiving a given amount in one day's time (option A) or receiving a larger amount in five-days' time (option B), and this choice was repeated nine times, with increasing payoffs as option B. Table S2 displays the experiment aiming to elicit the four-day discount rate. Note that we introduced a short delay in the current income option in the earlier time frame (1 day, i.e. tomorrow rather than today). This method should control for potential confounds due to lower credibility and higher transaction costs that may be associated with future payments (Bauer, Chytilova, and Morduch, 2012; Harrison, Lau, and Williams, 2002).

In the second experiment, farmers were invited to choose between receiving a given amount in one month's time (option A) or receiving a larger amount in two-months' time (option B), and this choice was repeated eight times, with increasing payoffs as option B. Table S3 displays the experiment aiming to elicit the one-month discount rate.

5.2.2 Analysis of Game Results

In order to render our results comparable to other studies, we assume that farmers have additively time-separable preferences with a per-period CRRA utility function. The form of the utility function is still: $U(x) = x^{1-r_i}/(1-r_i)$, where x is the lottery prize and r_i denotes the constant relative risk aversion of the individual. An agent is indifferent between receiving payment M_t at time t or payment M_{t+1} at time $t+1$ if and only if:

$$U(w+M_t) + \frac{1}{1+\delta_i}U(w) = U(w) + \frac{1}{1+\delta_i}U(w+M_{t+1})$$

[22] Andreoni, Kuhn, and Sprenger (2015) moreover show that the convex time budgets (CTB) method, already used by Andreoni and Sprenger (2012), Augenblick, Niederle, and Sprenger (2015) and Giné et al. (2018), is a good alternative elicitation tool, as it is likely to increase predictive power relative to DMPL estimates at the individual level (while it make predictions close to DMPL ones at the distributional level).

[23] Our design does not allow us to construct such a binary variable, since the two experiments that we used differed in the time delays offered (subjects were given the opportunity to wait five days in the first experiment and one month in second experiment, and the rewards in the two experiments were not equivalent). We acknowledge that this prevents us from directly comparing our measurements to those of Bauer, Chytilova, and Morduch (2012) and Ashraf, Karlan, and Yin (2006), but it is a trade-off that we were obliged to make in order to construct a time experiment that made sense to participants. We ran a pilot study with several volunteer farmers, who were asked the same questions as in Andersen et al. (2008), where respondents are offered a choice between Option A in one month and Option B in seven months. All of the respondents in the pilot preferred to receive the small amount in one month, rather than the greater amount in seven months, no matter how big the greater amount was. We thus had to adapt the far-future experiment in order to offer farmers a more plausible tradeoff, which led us to build an experiment based on a delay of one month. We constructed the near-future experiment in an equally ad hoc manner. Trial and error led us to build the near-future experiment using a 4-day delay.

where w is his background consumption and δ_i accounts for the discount rate. Using the CRRA per-period utility function and assuming no background consumption ($w = 0$), we write:

$$\frac{M_t^{1-r_i}}{1-r_i} = \frac{1}{1+\delta_i}\frac{M_{t+1}^{1-r_i}}{1-r_i},$$

from which we can explicitly solve for δ_i as a function of risk aversion r_i:

$$\delta_i = \left[\frac{M_{t+1}}{M_t}\right]^{1-r_i} - 1$$

We use the previously estimated risk aversion parameters (r_i) to calculate the interval bounds. We then compute interval midpoints for the two time preference experiments, and take the average of these two midpoints as our estimate of an individual's discount rate.[24] We find that farmers are very impatient on average, with an average discount rate of 7 percent for a four day period, i.e. 66 percent per month (see Table 6).

Our estimates of the time preference parameter fall well above previous discount rate estimates among selected populations in developed countries, which range between one and three percent per month (Harrison, Lau, and Williams, 2002). Our estimates also suggest that the farmers in our sample have higher discount rates than the rural villagers who participated in the experiments conducted by Tanaka, Camerer, and Nguyen (2010) in Vietnam and Bauer, Chytilova, and Morduch (2012) in India. Our discount rate estimates also differ from those provided by Liebenehm and Waibel (2014), who conducted similar experiments with 211 households in Mali and Burkina Faso in 2007 and 2011. They report discount rates close to zero, meaning that surveyed households are extremely patient. However, they use a different experiment design (the respondents are offered a choice between immediate vs future rewards) and a different estimation procedure (including a noise parameter), which may have lead to lower discount rate estimates.

From the two elicited measures of impatience, we are then able to identify farmers who exhibit hyperbolic preferences. In order to construct a measure of hyperbolic discounting in accordance with the theory (see Section 3), we compute a measure of hyperbolic preferences which equals (minus) the ratio of the four-day delay discount factor and the one-month delay discount factor (converted to the equivalent discount factor for a four-day delay):

$$h_i = -\frac{1/(1+\delta_{\text{near}})}{1/(1+\delta_{\text{far}})}$$

where $1/(1+\delta_{\text{near}})$ (resp. $1/(1+\delta_{\text{far}})$) refers to the four-day delay discount factor (resp. one-month delay discount factor). A parameter h_i greater than -1 indicates that the farmer is more impatient in the near future compared to a more distant future. The higher this parameter is, the stronger the hyperbolicity is.

We find that a large number of participants exhibit hyperbolic time preferences, and we obtain an average hyperbolic parameter of -1.03 (see Table 6) and a median value of -1.005 which indicates that almost half of the sample exhibits hyperbolic preferences. This result is in line with recent literature that demonstrates the existence of hyperbolic discounting based on experimental data

[24] In order to render the two time-discounting measures comparable, we converted the one-month discount rate to the equivalent discount rate for a four-day delay.

(Ashraf, Karlan, and Yin, 2006; Giné et al., 2018).

6 Linking preferences to warehouse inventory credit adoption

In this section, we provide an empirical framework to test Main Prediction from Section 3, stating that the optimal quantity of grain w^* increases with the hyperbolic preference parameter h. We first present the empirical model that relates warrantage adoption to risk and time preferences. We then present the main results and the robustness checks.

6.1 Econometric Framework

We estimate an empirical model where farmer i's decision to engage in the system is a function of her discount rate δ_i, level of risk aversion r_i, level of hyperbolic discounting h_i, other observable individual characteristics X_i, and village-by-year fixed effects:

$$W_{it} = f(\delta_i, r_i, h_i, X_i, \eta_{tv}, \epsilon_{it}) \tag{8}$$

where η_{tv} is a vector of village-by-year dummies and ϵ_{it} is the individual error term.

Following de Janvry and Sadoulet (2006), we selected control variables X with the aim of controlling for household-specific features that affect production choices and hence the amount of harvest available to a farmer at the time when he makes his allocation decision (which we denote H in the theoretical model). Aside from risk and time preferences, both empirical models thus include a large set of farmer characteristics from the baseline survey, which include age and sex of the household's head, whether he received a formal education or not, the total land area (in hectares), the number of cattle, plows, and poultry, as well as the size of the labour force (measured as the number of family members who are employed in farming activities). The village-by-year dummies control for all other factors that appear in the theoretical model: the rate of return for doing something other than warrantage (which we denote $(1+\Delta)$ in the theoretical model), the rate of return provided by warrantage $((1-\sigma)(1+\Delta))$, and the interest rate of the loan (i).

We first estimate a probit regression, in which the dependent variable, W_{it}, takes on the value one if the farmer stored grain in the warehouse in year t (with or without a loan), and takes on the value zero otherwise:

$$\Pr(W_{it} = 1|\delta_i, r_i, h_i, X_i) = \Pr(\lambda_0 + \lambda_1\delta_i + \lambda_2 r_i + \lambda_3 h_i + X_i'\alpha_1 + \eta_{tv}'\alpha_2 + \epsilon_{it} > 0) \tag{9}$$

The degree of hyperbolic discounting, h_i, is the hyperbolic parameter as computed in Section 5.2.2. A positive coefficient λ_3 should then be interpreted as evidence that the more farmers exhibit hyperbolic time preferences, the more they use inventory credit.

We compute robust standard errors in a standard way. To test to what extent our results are robust to cluster-corrected standard errors, we moreover provide the p-values calculated by using the score bootstrap method after clustering standard errors at the village level (Kline and Santos, 2012).[25] We also fit a tobit model where the left-censored dependent variable W_i is the fraction

[25] The score bootstrap developed by Kline and Santos (2012) is an adaptation of the wild bootstrap of Wu (1986) and Liu (1988) for estimators such as probit.

of harvest stored in the warehouse (with or without a loan). Given that 2013 was the first year in which the warrantage system was implemented and 2015 was the third year, the results for the two years may differ. In what follows, we thus report estimates for 2013 and 2015 separately, as well as estimates based on both years together.

6.2 Results

Table 7 displays the results of a probit model that links individual preferences and participation in a warrantage program. Overall, the results appear very stable. We do not find evidence that risk aversion and time discounting affect the probability of engaging in the warrantage system at standard levels of significance (Column 1). We do, however, find a significant and positive correlation between hyperbolic preferences and participation (Column 2). In order to examine to what extent this correlation may differ across years, we include an interaction term (hyperbolic parameter times year 2015) in the main model. We do not find any evidence of a stronger correlation in 2015 (Column 3), and continue to find a positive correlation between hyperbolic preferences and participation when we estimate the model using 2013 data only (Column 4) and 2015 data only (Column 5). Taking our main result (as displayed in Column 2), we calculate that a one standard deviation increase in the hyperbolic parameter is associated with a 21 percent increase in the probability of participating in warrantage. These results suggest that hyperbolic preferences may be a driver of the adoption of the warrantage system and that this effect remains stable in subsequent years.

Next, we investigate whether risk and time preferences may be related to the quantity that the farmer chooses to store in the warehouse. Table 8 displays the results of a tobit model, in which the dependent variable is the fraction of the total harvest that is stored in the warehouse. We do not find any evidence of a link between risk aversion or time discounting and quantity stored (Column 1). In contrast, the correlation with the hyperbolic parameter is positive and significant (Column 2). Here again, the size of the coefficient seems stable across time (Column 3), and the correlation holds when considering 2013 alone (Column 4). The coefficient is of similar size but weakly significant (the p-value is 0.11) when considering 2015 alone (Column 5).

We check whether our findings are driven by the small number of farmers who store grain in a warehouse without taking up a loan. To do so, we re-estimate the same probit model excluding those farmers and find that previous results hold, which suggest that hyperbolic preferences may be a driver of warrantage adoption even among those who ask for a loan (see Table S4 in the online supplementary appendix material).

In our sample, a fraction of farmers chose only lottery B for the entire payoff series (about 15 percent of players in the low payoff series and up to 18 percent of players in the high payoff series chose this way), which would suggest that these farmers are extreme risk-lovers. One concern that arises with these results is that these farmers did not understand how the game worked and incidentally drive our main result. Therefore, as a robustness check, we explicitly consider these risk lovers as a specific subset of the population. We augment our basic specification (Table 7) with an interaction term between the hyperbolic preference parameter and a dummy which equals one if the farmer always chose the risky lottery (lottery B) in the two risk experiments (13 percent of the farmers behave this way). Our main results still hold (see Table S5 in the online supplementary appendix material).

Finally, we check the robustness of the main results by including binary variables for the quintiles of the variables of interest (r, δ, and h) instead of continuous variables. We provide the results in Tables S6 and S7 in the online supplementary appendix material. They reveal that the results are driven by the very high levels of time discounting.

7 Alternative explanations

In this section, we discuss alternative explanations for our results. In particular, we discuss whether individual income shocks or social pressure may explain our results. In each case, we provide arguments that make us confident that individual preferences are indeed linked to warrantage adoption.

7.1 Income Shocks

One could argue that our findings may arise due to an unobserved shock to income affecting both experimental measures of discounting and inventory credit adoption. Income shocks indeed have the potential to affect the way that farmers answer time-discounting questions, as well as their decisions to engage in inventory credit systems. If individuals are sufficiently liquidity-constrained, a negative shock such as a crop failure due to reduced rainfall, for example, could cause them to respond as if they were more impatient now than in the future and simultaneously affect their savings behaviour. If this were the case, it is plausible that the correlation that we observe could be caused by these shocks rather than by a direct link between hyperbolic preferences and inventory credit adoption.

However, we argue that such an assumption is very unlikely to hold in our study due to the fact that a negative shock to income is likely to *increase* measures of hyperbolic preferences (Dean and Sautmann, 2016) and *decrease* savings. On the contrary, our findings suggest the existence of a *positive* correlation between hyperbolic preferences and savings, which is in line with a demand for commitment.

One could also argue that most farmers who engaged in the inventory credit system chose to take a loan, which might indicate that they need cash, and this presumably due to a negative shock to income. We believe that this interpretation is unlikely to hold, as well. First, farmers who are liquidity constrained have the option to sell their crops on the market (instead of taking a loan, which amounts to 80 percent of the value of their crop only). Second, it is challenging to identify an unobserved factor that would be likely to affect both the experimental measures of a farmer surveyed in January and the need for cash during the harvest season in November.

However, despite their improbability, we cannot definitively rule out the possibility that unobserved shocks to income could affect experimental measures of time-discounting and inventory credit adoption in more complex ways. We therefore design a robustness check to address this concern. To do so, we exploit a new dataset that was collected in January 2016 from the sample of farmers who responded to the baseline survey. This follow-up survey provides the amount of maize, sorghum and millet harvested in October 2015 by participants and *non*-participants in warrantage in 2015. We include this variable as an additional control in the model of warrantage adoption. Because we do not have data on the 2013 harvest for farmers who did not participate in warrantage in 2013, we are able to perform this robustness test for the year 2015 only. We find that the link between time-inconsistency and warrantage adoption is robust to the inclusion of the harvest (see

Column 1 of Table S8 in Appendix). The correlation between time-inconsistency and quantity store remains of the same magnitude as before but lacks precision (see Column 2 of Table S8 in the online supplementary appendix material).

7.2 Social Pressure

A final concern is that we inappropriately interpret our results as evidence that those farmers who engage in the inventory credit system are seeking a commitment savings device for its inherent benefits. As we point out at the beginning of the paper, there are a variety of reasons why farmers may opt to participate in warrantage. One of these reasons is that farmers who store their crops in warehouses are able to escape social pressure to share their harvest with kin and neighbours. Engaging in an inventory credit system may thus be an option for individuals seeking to escape this type of social pressure.

One could argue that our findings may arise due to an unobserved shock affecting both the way a farmer responds to time discounting questions and the standard of living of his neighbours. However, we include village-by-year fixed-effects in our model, which means that such covariant shocks are controlled for in our study.

8 Conclusion

Self-discipline problems may limit farmers' ability to save grain until the lean season, which may in turn hinder their capacity to ensure the food security of their household. In developing countries such as Burkina Faso, formal commitment savings devices are lacking. We argue that warrantage systems are likely to be effective commitment savings devices in this regard.

We partnered with a rural bank and a farmers organization in order to implement a warrantage system in seven villages in Burkina Faso, and we analyse the link between farmers' risk and time preferences and their likelihood to engage in the warrantage system. Our analysis is based on a series of hypothetical choice experiments in the field designed to elicit risk and time preferences before the beginning of the program, a baseline household survey, and two follow-up surveys carried out among participants in warrantage in the first and the third year of implementation. We found that farmers who exhibit stronger hyperbolic preferences are more likely to participate in the warrantage system than other, otherwise similar, farmers.

Inventory credit systems have been celebrated for giving farmers access to credit and, in doing so, providing them with an opportunity to overcome the "sell low buy high" phenomenon, notably because providing access to credit enables farmers to adjust their selling activities throughout the year and take advantage of seasonal price fluctuations. It is important to note that our findings do not discount the importance of the central feature of inventory credit systems, i.e. the credit itself. Instead, we emphasize the features that are likely to motivate a farmer's decision to use such a system. Because the vast majority of farmers who entered the system chose to take out a loan, it appears that credit access serves as a strong motivation for engaging in the inventory credit system. The evidence we present here suggests that another explanation for the growing popularity of these systems may rest in their role in helping farmers to overcome their self-discipline problems.

The results of our theoretical model moreover suggest that there may be a variety of farmer responses to warrantage programs. Despite rising prices during the lean season, some farmers may not wish to store their grain in a certified warehouse over a six-month period. Specifically, these are farmers who are either not (or only slightly) inconsistent in their temporal preferences, or not sophisticated enough to realize that they are actually time-inconsistent and are too risk averse to take credit, as well as those who are too impatient to save their grain.

The warrantage system that was implemented in 2013 continues to function today. It should be noted, however, that the long term on-the-ground presence of the project proponent - the CPF - and the trust that characterized the relationship between farmers, the CPF and the rural bank in the study areas probably contributed to such encouraging results. In a less favorable context, many households may have been reluctant to entrust their grain to a farmer organization. It must also be recognized that the efficiency of the system can be significantly reduced when the state intervenes in the marketplace via price stabilization, as occurred in 2013. Finally, beyond the participation rate, the success of the systems should also be measured through its impact on households' standard of living and food security. More work needs to be done in order to quantify these effects.

Acknowledgements

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References

Ai, C., and E.C. Norton. 2003. "Interaction terms in logit and probit models." *Economics Letters* 80:123 – 129.

Aliber, M. 2001. "Rotating savings and credit associations and the pursuit of self-discipline: A case study in South Africa." *African Review of Money Finance and Banking*, pp. 51–73.

Ambec, S., and N. Treich. 2007. "Roscas as financial agreements to cope with self-control problems." *Journal of Development Economics* 82:120 – 137.

Andersen, S., G.W. Harrison, M.I. Lau, and E.E. Rutstrom. 2008. "Eliciting Risk and Time Preferences." *Econometrica* 76:583–618.

Anderson, S., and J.M. Baland. 2002. "The Economics of Roscas and Intrahousehold Resource Allocation." *Quarterly Journal of Economics* 117:963–995.

Andreoni, J., M.A. Kuhn, and C. Sprenger. 2015. "Measuring time preferences: A comparison of experimental methods." *Journal of Economic Behavior & Organization* 116:451 – 464.

Andreoni, J., and C. Sprenger. 2012. "Risk Preferences Are Not Time Preferences." *American Economic Review* 102:3357–76.

Ashraf, N., D. Karlan, and W. Yin. 2006. "Tying Odysseus to the Mast: Evidence from a Commitment Savings Product in the Philippines." *Quarterly Journal of Economics* 121:635–672.

Augenblick, N., M. Niederle, and C. Sprenger. 2015. "Working over Time: Dynamic Inconsistency in Real Effort Tasks." *Quarterly Journal of Economics* 130:1067–1115.

Baland, J.M., C. Guirkinger, and C. Mali. 2011. "Pretending to Be Poor: Borrowing to Escape Forced Solidarity in Cameroon." *Economic Development and Cultural Change* 60:1 – 16.

Banerjee, A., and S. Mullainathan. 2010. "The Shape of Temptation: Implications for the Economic Lives of the Poor." NBER Working Papers No. 15973, National Bureau of Economic Research.

Barr, A., and G. Genicot. 2008. "Risk Sharing, Commitment, and Information: An Experimental Analysis." *Journal of the European Economic Association* 6:1151–1185.

Basu, K. 2011. "Hyperbolic Discounting and the Sustainability of Rotational Savings Arrangements." *American Economic Journal: Microeconomics* 3:143–71.

Basu, K., and M. Wong. 2015. "Evaluating seasonal food storage and credit programs in east Indonesia." *Journal of Development Economics* 115:200 – 216.

Bauer, M., J. Chytilova, and J. Morduch. 2012. "Behavioral Foundations of Microcredit: Experimental and Survey Evidence from Rural India." *American Economic Review* 102:1118–39.

Bernheim, B.D., D. Ray, and S. Yeltekin. 2015. "Poverty and Self-Control." *Econometrica* 83:1877–1911.

Bester, H. 1987. "The role of collateral in credit markets with imperfect information." *European Economic Review* 31:887–899.

Bryan, G., D. Karlan, and S. Nelson. 2010. "Commitment Devices." *Annual Review of Economics* 2:671–698.

Burke, M., L.F. Bergquist, and E. Miguel. 2018. "Sell Low and Buy High: Arbitrage and Local Price Effects in Kenyan Markets." Working Paper No. 24476, National Bureau of Economic Research, April.

Casaburi, L., and J. Willis. 2016. "Time vs. State in Insurance: Experimental Evidence from Contract Farming in Kenya." Working paper.

Coller, M., and M. Williams. 1999. "Eliciting Individual Discount Rates." *Experimental Economics* 2:107–127.

Coulter, J. 2009. "Review of Warehouse Receipt System and Inventory Credit Initiatives in Eastern and Southern Africa." Report, UNCTAD under the All ACP Agricultural Commodities Programme (AAACP).

Coulter, J., and G. Onumah. 2002. "The role of warehouse receipt systems in enhanced commodity marketing and rural livelihoods in Africa." *Food Policy* 27:319 – 337.

de Janvry, A., and E. Sadoulet. 2006. *Progress in the Modeling of Rural Households' Behavior under Market Failures*, Boston, MA: Springer US. pp. 155–181.

Dean, M., and A. Sautmann. 2016. "Credit Constraints and the Measurement of Time Preferences." Working paper.

di Falco, S., and E. Bulte. 2011. "A Dark Side of Social Capital? Kinship, Consumption, and Savings." *Journal of Development Studies* 47:1128–1151.

Dillon, B. 2016. "Selling crops early to pay for school: A large-scale natural experiment in Malawi." Working paper.

Falk, A., A. Beckery, T. Dohmenz, D. Huffman, and U. Sunde. 2016. "The Preference Survey Module: A Validated Instrument for Measuring Risk, Time, and Social Preferences." Working paper.

Fink, G., B.K. Jack, and F. Masiye. 2014. "Seasonal credit constraints and agricultural labor supply: evidence from Zambia." Working paper, National Bureau of Economic Research.

Frederick, S., G. Loewenstein, and T. O'Donoghue. 2002. "Time Discounting and Time Preference: A Critical Review." *Journal of Economic Literature* 40:351–401.

Fudenberg, D., and D.K. Levine. 2006. "A Dual-Self Model of Impulse Control." *American Economic Review* 96:1449–1476.

Giné, X., J. Goldberg, D. Silverman, and D. Yang. 2018. "Revising Commitments: Field Evidence on the Adjustment of Prior Choices." *Economic Journal* 128:159–188.

Goldberg, J. 2017. "The Effect of Social Pressure on Expenditures in Malawi." Working paper.

Gross, J., C. Guirkinger, and J. Platteau. 2017. "Buy As You Need: Nutrition and Food Storage Imperfections." Working paper, London, Centre for Economic Policy Research.

Gugerty, M.K. 2007. "You Can't Save Alone: Commitment in Rotating Savings and Credit Associations in Kenya." *Economic Development and Cultural Change* 55:251–82.

Gul, F., and W. Pesendorfer. 2001. "Temptation and Self-Control." *Econometrica* 69:1403–1435.

Harris, C., and D. Laibson. 2001. "Dynamic Choices of Hyperbolic Consumers." *Econometrica* 69:935–957.

Harrison, G.W., S. Humphrey, and A. Verschoor. 2010. "Choice under Uncertainty: Evidence from Ethiopia, India and Uganda." *Economic Journal* 120:80–104.

Harrison, G.W., M.I. Lau, and M.B. Williams. 2002. "Estimating Individual Discount Rates in Denmark: A Field Experiment." *American Economic Review* 92:1606–1617.

Heckman, J.J. 1979. "Sample Selection Bias as a Specification Error." *Econometrica* 47:153–61.

Hoff, K., and J.E. Stiglitz. 1990. "Introduction: Imperfect Information and Rural Credit Markets - Puzzles and Policy Perspectives." *World Bank Economic Review* 4:235–250.

Holt, C.A., and S.K. Laury. 2002. "Risk Aversion and Incentive Effects." *American Economic Review* 92:1644–1655.

Jakiela, P., and O. Ozier. 2016. "Does Africa Need a Rotten Kin Theorem? Experimental Evidence from Village Economies." *Review of Economic Studies* 83:231.

Kazianga, H., and C. Udry. 2006. "Consumption smoothing? Livestock, insurance and drought in rural Burkina Faso." *Journal of Development Economics* 79:413–446.

Kline, P., and A. Santos. 2012. "A Score Based Approach to Wild Bootstrap Inference." *Journal of Econometric Methods* 1:23–41.

Laibson, D. 1997. "Golden Eggs and Hyperbolic Discounting." *Quarterly Journal of Economics* 112:443–478.

Liebenehm, S., and H. Waibel. 2014. "Simultaneous Estimation of Risk and Time Preferences among Small-scale Cattle Farmers in West Africa." *American Journal of Agricultural Economics* 96:1420–1438.

Liu, R.Y. 1988. "Bootstrap Procedures under some Non-I.I.D. Models." *Annals of Statistics* 16:1696–1708.

Meier, S., and C. Sprenger. 2010. "Present-Biased Preferences and Credit Card Borrowing." *American Economic Journal: Applied Economics* 2:193–210.

O'Donoghue, T., and M. Rabin. 1999. "Doing It Now or Later." *American Economic Review* 89:103–124.

Phelps, E.S., and R.A. Pollak. 1968. "On Second-Best National Saving and Game-Equilibrium Growth." *Review of Economic Studies* 35:185–199.

Platteau, J.P. 2000. *Institutions, Social Norms and Economic Development*. Harwood Academic Publishers, Amsterdam.

Sprenger, C. 2015. "Judging Experimental Evidence on Dynamic Inconsistency." *The American Economic Review* 105:280–285.

Stephens, E.C., and C.B. Barrett. 2011. "Incomplete Credit Markets and Commodity Marketing Behaviour." *Journal of Agricultural Economics* 62:1–24.

Tanaka, T., C.F. Camerer, and Q. Nguyen. 2010. "Risk and Time Preferences: Linking Experimental and Household Survey Data from Vietnam." *American Economic Review* 100:557–71.

Wu, C.F.J. 1986. "Jackknife, Bootstrap and Other Resampling Methods in Regression Analysis." *Annals of Statistics* 14:1261–1295.

Figures and Tables

Figure 1: Location of participant villages

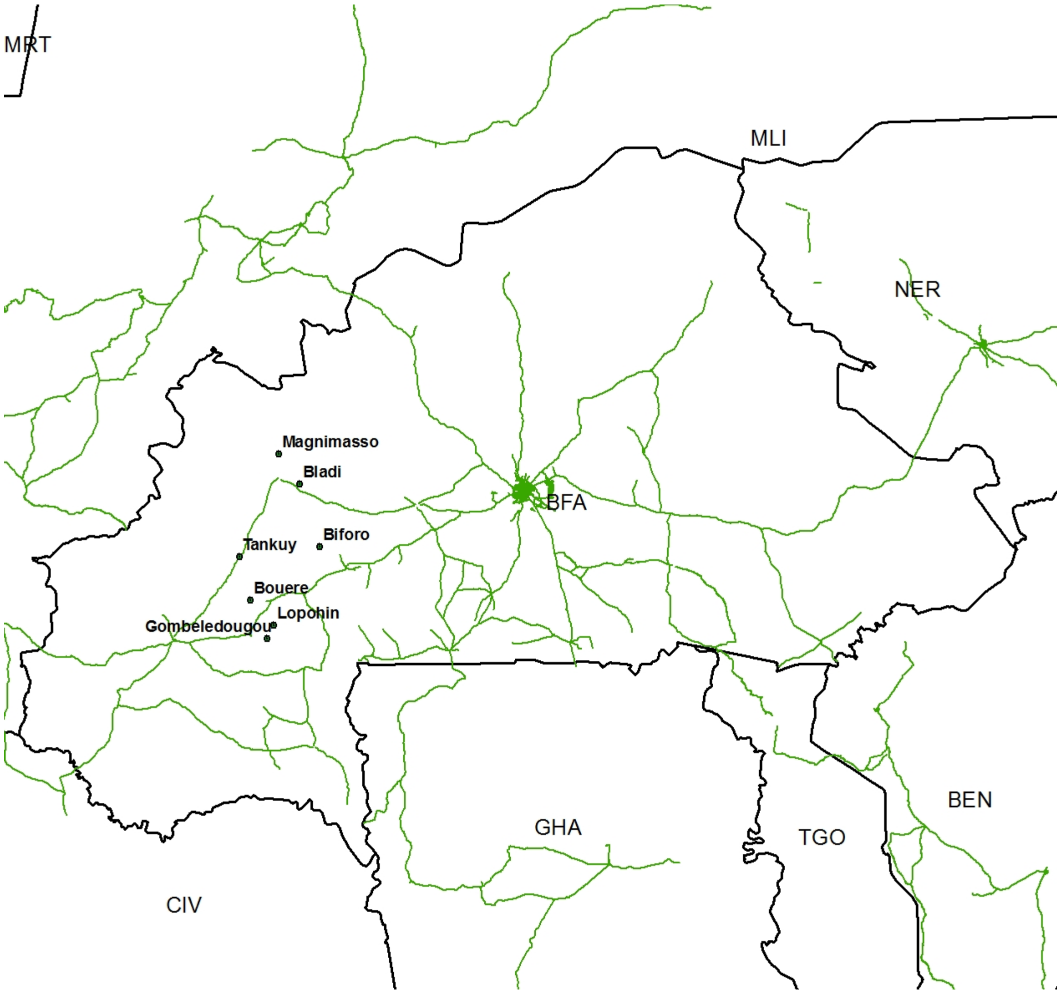
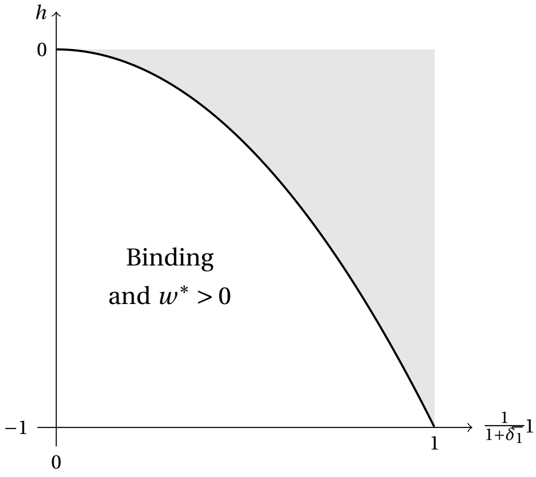


Figure 2: Agricultural Production and Warrantage Calendar in the Tuy and Mouhoun Provinces

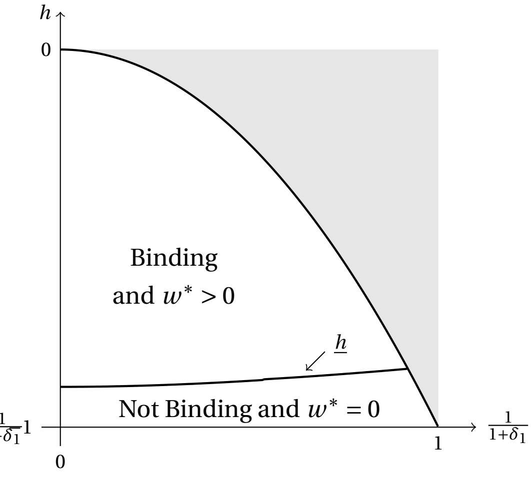
<table>
<tr><th></th><th>June</th><th>July</th><th>August</th><th>Sept</th><th>Oct</th><th>Nov</th><th>Dec</th><th>January to April</th><th>May</th></tr>
<tr><td>Grain production</td><td>Tilling</td><td>Sowing
Fertilizing</td><td colspan="2">Plant growing
Weeding
Fertilizing</td><td colspan="2">Harvesting</td><td colspan="3"></td></tr>
<tr><td>Cotton production</td><td>Tilling</td><td>Sowing
Fertilizing</td><td colspan="3">Plant growing
Weeding
Fertilizing</td><td colspan="2">Harvesting</td><td colspan="2"></td></tr>
<tr><td>Inventory Credit (or warrantage)</td><td colspan="5"></td><td colspan="2">Storage
Credit delivery</td><td></td><td>Credit repayment
Collateral restitution</td></tr>
</table>

Note: Grain production refers to production of maize, millet and sorghum.

Figure 3: Decision to participate in warrantage under price certainty



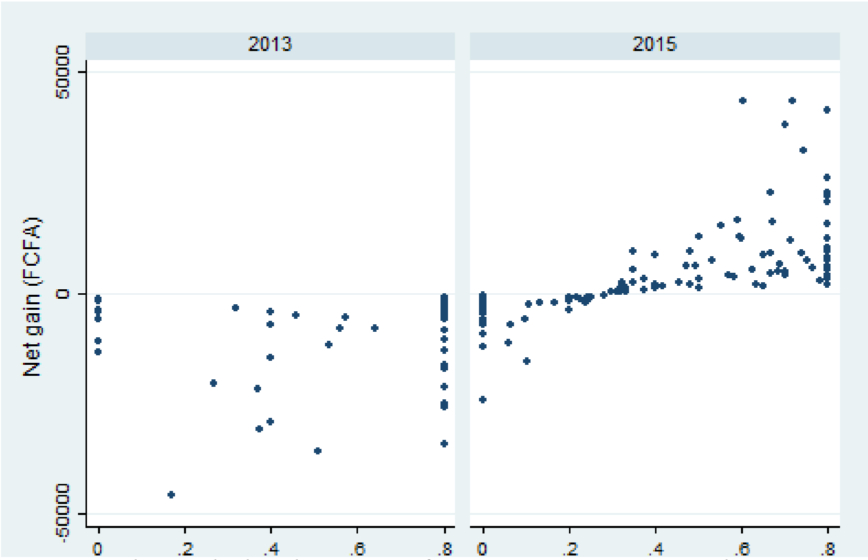
(a) Case (i): $0.8(\Delta - i) - (1+\Delta)\sigma \geq 0$



(b) Case (ii): $0.8(\Delta - i) - (1+\Delta)\sigma < 0$

Note: This Figure displays the areas for which the budget constraint of Self 2 is binding or not in equilibrium, for $\pi = 1$ and $r = 0.5$. The parameter values used to plot panel (b) are $\sigma = 0.15$, $\Delta = 30\%$ and $i = 0.06$.

Figure 4: Net gain of warrantage versus storing at home in the sample



Note: This graph plots the net gain of warrantage versus storing at home, as calculated in Tables 4 and 5. The price increase was 3% in 2013 and 25% in 2015.

Table 1: Household characteristics: summary statistics

Characteristics	Unit	Obs	Mean	Std. Dev.
Family size	number	653	11.19	7.61
Labor force	number	653	5.89	4.44
Sex	yes=man	653	0.98	0.13
Age	years	653	41.85	13.43
Education (literate)	yes=1	653	0.31	0.46
Cattle (none)	yes=1	653	0.30	0.46
Cattle (less than 10)	yes=1	653	0.58	0.49
Cattle (more than 10)	yes=1	653	0.11	0.32
Plow	number	653	1.63	1.42
Poultry	number	653	15.88	20.12
Total land area	ha	653	8.10	6.24
Maize area	%land area	653	0.17	0.18
Cotton area	%land area	653	0.32	0.21

Notes: This table shows summary statistics for a set of characteristics measured in January 2013 during the baseline survey.

Table 2: Representativeness of the sample

	Sample used	National Survey
Family size number (number)	11.2	11
Age (years)	41.9	44.4
Education (=1 if literate)	0.31	0.32
Cattle (=1 if none)	0.3	0.22
Cattle (=1 if less than 10)	0.58	0.6
Cattle (=1 if more than 10)	0.11	0.18
Total land area (ha)	8.1	7.4
Maize area (ha)	1.4	1.5
Cotton area (ha)	2.6	2.6
Obs.	653	265

Note: This table displays summary statistics for main characteristics of farmers. Sample A refers to the sample used in the present study. Sample B refers an extraction from a national agricultural survey led in 2013 by the Ministry of Agriculture of Burkina Faso. Sample B is representative of the Tuy and Mouhoun regions.

Table 3: Participation in warrantage: summary statistics

	no loan	< max.	=max.	
Participation in 2013	0%	]0%, 80%[	80%	All
Number of farmers	10	26	67	103
Average nb of maize bags stored	6	18.7	13.5	14.1
Average nb of sorghum bags stored	1.2	1.7	1.7	1.7
Average nb of millet bags stored	1	0.9	0.3	0.5
Average share of harvest stored (%)	32	42	22	28
Average amount of credit (kCFA)	0	89.2	124.7	103.6
Participation in 2015				
Number of farmers	38	77	38	167[(a)]
Average nb of maize bags stored	3.6	13.0	12.3	10.4
Average nb of sorghum bags stored	0.6	1.4	0.6	1.0
Average nb of millet bags stored	0.2	0.4	0.0	0.2
Average share of harvest stored (%)	29	39	35	34
Average amount of credit (kCFA)	0	80.9	136.1	84.3

Note: This table shows summary statistics for the three groups of participants: Column "no loan" refers to those who stored some grain without taking up a loan; Column "< max." refers to those who borrowed less than the maximum amount allowed for a loan and Column "= max." refers to those who borrowed the maximum amount allowed (80% of the value of stored bags). (a) For 14 participants in 2015, data on the credit was not available and/or inconsistent, which results in missing data. Consequently, the number of participants by type of credit does not sum to 167.

Table 4: Costs and Returns of Warrantage in 2015

Parameters	no loan 0%	< max.]0%, 80%[	=max. 80%	All
Interest rate (over 6 months)	0.06	0.06	0.06	0.06
Price increase (rate)	0.25	0.25	0.25	0.25
Unit value of bags (FCFA francs)	10,857	10,857	10,857	10,857
Storage costs (unit cost over 6 months)	600	600	600	600
Number of bags stored	3.6	13	12	10
Loan rate	0.00	0.44	0.80	0.42
Net gain from warrantage				
Gain from storage	9,771	35,285	32,571	27,143
Storage cost	2,160	7,800	7,200	6,000
Gain from invested loan	0	15,526	26,057	11,400
Reimbursement of loan	0	3,821	6,412	2,805
Net gain	7,611	39,190	45,016	29,737
Net gain from storage at home at no cost				
Gain from storage	9,771	19,760	6,514	15,743
Storage cost	0	0	0	0
Gain from investment	0	15,526	26,057	11,400
Net gain	9,771	35,285	32,571	27,143
Relative gain of warrantage (vs home)				
Total relative gain	-2,160	3,905	12,445	2,595
Relative gain by bag	-600	300	1,037	259

Note: This table compares the costs and returns of warrantage for maize in 2015. The loan rate and the number of bags stored are mean values computed in each subgroup of participants, namely those who stored grain without taking a loan, those who stored grain and borrowed less than the maximum amount allowed for a loan, and those who stored grain and borrowed the maximum amount allowed for a loan. The value of a maize bag is the average price that was used in the seven warehouses to value the collateral at the time of the deposit. We calculate the net gain of storing at home supposing that the farmer invests a share θ of the value of the bags available, while the remaining share $(1-\theta)$ is stored at home at no cost.

Table 5: Costs and Returns of Warrantage in 2013

Parameters	no loan 0%	< max.]0%, 80%[	=max. 80%	All
Interest rate (over 6 months)	0.06	0.06	0.06	0.06
Price increase (rate)	0.03	0.03	0.03	0.03
Unit value of bags (FCFA francs)	10,143	10,143	10,143	10,143
Storage costs (unit cost over 6 months)	600	600	600	600
Number of bags stored	6	19	14	14
Loan rate	0.00	0.43	0.80	0.60
Net gain from warrantage				
Gain from storage	1,826	5,782	4,260	4,260
Storage cost	3,600	11,400	8,400	8,400
Gain from invested loan	0	2,486	3,408	2,556
Reimbursement of loan	0	5,098	6,989	5,242
Net gain	-1,774	-8,231	-7,721	-6,825
Net gain from storage at home at no cost				
Gain from storage	1,826	3,295	852	1,704
Storage cost	0	0	0	0
Gain from investment	0	2,486	3,408	2,556
Net gain	1,826	5,782	4,260	4,260
Relative gain of warrantage (vs home)				
Total relative gain	-3,600	-14,012	-11,981	-11,086
Relative gain by bag	-600	-737	-856	-792

Note: This table compares the costs and returns of warrantage for maize in 2013. The loan rate and the number of bags stored are mean values computed in each subgroup of participants, namely those who stored grain without taking a loan, those who stored grain and borrowed less than the maximum amount allowed for a loan, and those who stored grain and borrowed the maximum amount allowed for a loan. The value of a maize bag is the average price that was used in the seven warehouses to value the collateral at the time of the deposit. We calculate the net gain of storing at home supposing that the farmer invests a share θ of the value of the bags available, while the remaining share $(1-\theta)$ is stored at home at no cost.

Table 6: Risk and time preferences: summary statistics

				Quantiles		
	Obs.	Mean	Std. Dev.	0.25	0.5	0.75
Risk aversion (r)	653	0.292	1.095	-0.358	0.545	1.370
Time discount rate (δ)	653	0.068	0.187	-0.010	0.022	0.060
hyperbolic parameter (h)	653	-1.029	0.108	-1.040	-1.005	-0.984

Note: This table displays detailed statistics for elicited measures of risk aversion and time discounting. Time discount rate is expressed in percentage per each four day. The hyperbolic parameter equals (minus) the ratio of the four-day delay discount factor and the one-month delay discount factor (converted to the equivalent discount factor for a four-day delay).

Table 7: Participation in warrantage: probit regression

	(1)	(2)	(3)	(4)	(5)
Risk aversion (r)	0.000	-0.013	-0.013	0.015	-0.035
	(0.053)	(0.053)	(0.053)	(0.077)	(0.075)
	[0.997]	[0.685]	[0.685]	[0.790]	[0.472]
Time discounting (δ)	-0.350	0.205	0.195	0.319	0.138
	(0.321)	(0.384)	(0.386)	(0.588)	(0.509)
	[0.328]	[0.801]	[0.808]	[0.599]	[0.873]
Hyperbolic pref. (h)		1.769***	1.984**	1.971**	1.655**
		(0.633)	(0.907)	(1.016)	(0.802)
		[0.092]	[0.082]	[0.224]	[0.047]
Hyperbolic pref. x 2015			-0.013		
			(0.263)		
			[0.280]		
Village-by-Year FE	yes	yes	yes	yes	yes
Nb. obs.	1,149	1,149	1,149	653	496
Survey	2013 & 2015	2013 & 2015	2013 & 2015	2013	2015
Controls					
Plow	-0.020	-0.024	-0.024	-0.010	-0.039
	(0.045)	(0.046)	(0.046)	(0.066)	(0.063)
	[0.732]	[0.677]	[0.673]	[0.915]	[0.434]
Labor force	-0.022$^\diamond$	-0.022$^\diamond$	-0.022$^\diamond$	-0.032$^\diamond$	-0.012
	(0.014)	(0.014)	(0.014)	(0.021)	(0.019)
	[0.080]	[0.070]	[0.070]	[0.059]	[0.351]
Education	0.395***	0.408***	0.408***	0.432***	0.390***
	(0.099)	(0.100)	(0.100)	(0.145)	(0.139)
	[0.002]	[0.002]	[0.002]	[0.024]	[0.009]
Age	-0.006*	-0.006*	-0.006*	-0.006	-0.006
	(0.004)	(0.004)	(0.004)	(0.005)	(0.005)
	[0.189]	[0.187]	[0.187]	[0.353]	[0.141]
Sex	-0.034	-0.160	-0.160	0.142	-0.385
	(0.324)	(0.325)	(0.324)	(0.542)	(0.448)
	[0.955]	[0.845]	[0.851]	[0.787]	[0.673]
Total land area	0.071***	0.071***	0.072***	0.072***	0.072***
	(0.012)	(0.012)	(0.012)	(0.016)	(0.017)
	[0.001]	[0.001]	[0.001]	[0.007]	[0.009]
Cattle (less than 10)	0.422***	0.439***	0.440***	0.510***	0.398***
	(0.141)	(0.142)	(0.142)	(0.209)	(0.195)
	[0.066]	[0.059]	[0.059]	[0.046]	[0.065]
Cattle (more than 10)	0.252	0.279	0.279	0.484$^\diamond$	0.099
	(0.223)	(0.224)	(0.224)	(0.316)	(0.314)
	[0.557]	[0.505]	[0.499]	[0.367]	[0.775]
Poultry	0.001	0.001	0.001	0.001	0.000
	(0.002)	(0.002)	(0.002)	(0.004)	(0.003)
	[0.876]	[0.862]	[0.863]	[0.793]	[0.988]

Note: This table displays probit regressions where the dependent variable is a dummy variable that equals one if the farmers participated in the warrantage system and zero elsewhere. Three asterisks *** (resp. **, *, $^\diamond$) denote rejection of the null hypothesis of no impact at the 1% (resp. 5%, 10%, 15%) significance level. Robust standard errors are in parentheses. The coefficient and standard error of the interactive term in Col.(3) are computed as recommended in Ai and Norton (2003). The p-values calculated by using the score method after clustering standard errors at the village level are into brackets (Kline and Santos, 2012).

Table 8: Quantity stored as collateral: tobit regression

	(1)	(2)	(3)	(4)	(5)
Risk aversion (r)	-0.014	-0.021	-0.021	0.007	-0.049
	(0.028)	(0.028)	(0.028)	(0.029)	(0.045)
Time discounting (δ)	-0.242	0.063	0.053	0.132	-0.007
	(0.174)	(0.190)	(0.192)	(0.207)	(0.278)
Hyperbolic pref. (h)		0.986**	1.152**	0.862**	1.003$^{\diamond}$
		(0.440)	(0.503)	(0.366)	(0.631)
Hyperbolic pref. x 2015			-0.292		
			(0.548)		
Village-by-Year FE	yes	yes	yes	yes	yes
Nb. obs.	1,138	1,138	1,138	653	485
Survey	2013 & 2015	2013 & 2015	2013 & 2015	2013	2015
Controls					
Plow	0.008	0.006	0.006	-0.001	0.009
	(0.024)	(0.024)	(0.024)	(0.024)	(0.037)
Labor force	-0.018*	-0.018*	-0.018*	-0.014*	-0.018
	(0.009)	(0.009)	(0.009)	(0.008)	(0.013)
Education	0.225**	0.232**	0.232**	0.162***	0.261*
	(0.098)	(0.100)	(0.100)	(0.053)	(0.154)
Age	-0.004*	-0.004*	-0.004*	-0.002*	-0.005$^{\diamond}$
	(0.002)	(0.002)	(0.002)	(0.002)	(0.003)
Sex	-0.016	-0.092	-0.091	0.020	-0.210
	(0.177)	(0.184)	(0.182)	(0.230)	(0.263)
Total land area	0.037***	0.037***	0.037***	0.027***	0.040**
	(0.012)	(0.012)	(0.012)	(0.006)	(0.017)
Cattle (less than 10)	0.216***	0.222***	0.223***	0.189**	0.221*
	(0.083)	(0.083)	(0.083)	(0.080)	(0.118)
Cattle (more than 10)	0.164	0.177$^{\diamond}$	0.178$^{\diamond}$	0.190$^{\diamond}$	0.119
	(0.115)	(0.116)	(0.116)	(0.118)	(0.177)
Poultry	-0.001	-0.001	-0.001	0.000	-0.002
	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)

Note: This table displays tobit regressions where the left-censored dependent variable is the fraction of harvest stored in the warehouse. Three asterisks *** (resp. **, *, $^{\diamond}$) denote rejection of the null hypothesis of no impact at the 1% (resp. 5%, 10%, 15%) significance level. Robust standard errors in parentheses. The coefficient and standard error of the interactive term in Col.(3) are computed as recommended in Ai and Norton (2003).

Supplementary Material

Figures and Tables

Table S1: Paired Lottery-choice Decisions with Low Payoffs

	lottery A				lottery B				range of r	
	p	gain a	$1-p$	gain b	p	gain c	$1-p$	gain d		
1	0.1	1000	0.9	800	0.1	1925	0.9	50	$-\infty$	-1.71
2	0.2	1000	0.8	800	0.2	1925	0.8	50	-1.71	-0.95
3	0.3	1000	0.7	800	0.3	1925	0.7	50	-0.95	-0.49
4	0.4	1000	0.6	800	0.4	1925	0.6	50	-0.49	-0.14
5	0.5	1000	0.5	800	0.5	1925	0.5	50	-0.14	0.15
6	0.6	1000	0.4	800	0.6	1925	0.4	50	0.15	0.41
7	0.7	1000	0.3	800	0.7	1925	0.3	50	0.41	0.68
8	0.8	1000	0.2	800	0.8	1925	0.2	50	0.68	0.97
9	0.9	1000	0.1	800	0.9	1925	0.1	50	0.97	1.37
10	1	1000	0	800	1	1925	0	50	1.37	$+\infty$

Note: Last column was not shown to respondents.

Table S2: "Would you prefer to get A in one day or B in five days?"

	A	B	range of δ	
1	10000	10400	0	0.016
2	10000	10700	0.016	0.027
3	10000	11000	0.027	0.039
4	10000	11500	0.039	0.057
5	10000	12000	0.057	0.076
6	10000	13000	0.076	0.111
7	10000	14000	0.111	0.144
8	10000	17000	0.144	0.236
9	10000	20000	0.236	0.320

Note: Column "range of δ" indicates the associated interval for monthly δ for a respondent who switches from A to B.

Table S3: “Would you prefer to get A in one month or B in two months?”

	A	B	range of δ	
1	10000	12000	0	0.06
2	10000	15000	0.06	0.13
3	10000	18000	0.13	0.19
4	10000	20000	0.19	0.23
5	10000	23000	0.23	0.28
6	10000	29000	0.28	0.38
7	10000	48000	0.38	0.60
8	10000	75000	0.60	0.83

Note: Column “range of δ” indicates the associated interval for monthly δ for a respondent who switches from A to B.

Table S4: Participation in warrantage: probit regression (only farmers with a loan)

	(1)	(2)	(3)	(4)	(5)
Risk aversion (r)	0.005	-0.008	-0.008	0.013	-0.030
	(0.057)	(0.058)	(0.058)	(0.080)	(0.086)
Time discounting (δ)	-0.457	0.144	0.102	0.121	0.069
	(0.330)	(0.407)	(0.408)	(0.603)	(0.559)
Hyperbolic pref. (h)		2.065***	2.457**	2.440**	1.774*
		(0.753)	(1.056)	(1.124)	(0.964)
Hyperbolic pref. x 2015			-0.064		
			(0.125)		
Village-by-Year FE	yes	yes	yes	yes	yes
Nb. obs.	1,101	1,101	1,101	643	452
Survey	2013 & 2015	2013 & 2015	2013 & 2015	2013	2015
χ^2-test of $r = \delta = h$		9.42	5.67	5.54	4.44
		(p=0.009)	(p=0.059)	(p=0.063)	(p=0.109)
z-test of $h = 0$		2.74	2.33	2.17	1.84
		(p=0.006)	(p=0.020)	(p=0.030)	(p=0.066)
Controls					
Plow	-0.024	-0.028	-0.028	-0.045	-0.011
	(0.048)	(0.048)	(0.048)	(0.069)	(0.068)
Labor force	-0.023$^\diamond$	-0.023$^\diamond$	-0.023$^\diamond$	-0.032	-0.016
	(0.015)	(0.015)	(0.015)	(0.023)	(0.020)
Education	0.393***	0.403***	0.406***	0.453***	0.359**
	(0.105)	(0.106)	(0.106)	(0.149)	(0.151)
Age	-0.007*	-0.006$^\diamond$	-0.006$^\diamond$	-0.006	-0.006
	(0.004)	(0.004)	(0.004)	(0.006)	(0.005)
Sex	0.486	0.400	0.387	0.081	na
	(0.522)	(0.512)	(0.511)	(0.535)	(na)
Total land area	0.073***	0.073***	0.073***	0.069***	0.079***
	(0.012)	(0.012)	(0.012)	(0.016)	(0.018)
Cattle (less than 10)	0.599***	0.630***	0.630***	0.589***	0.647***
	(0.156)	(0.158)	(0.158)	(0.224)	(0.222)
Cattle (more than 10)	0.525**	0.566**	0.565**	0.672**	0.429
	(0.234)	(0.237)	(0.237)	(0.328)	(0.340)
Poultry	0.000	0.000	0.000	0.001	-0.002
	(0.003)	(0.003)	(0.003)	(0.004)	(0.004)

Note: This table displays probit regressions where the dependent variable is a dummy variable that equals one if the farmers participated in the warrantage system and zero elsewhere. The sample excludes the farmers who chose to store some grain in the warehouse without taking any loan. Three asterisks *** (resp. **, *, $^\diamond$) denote rejection of the null hypothesis of no impact at the 1% (resp. 5%, 10%, 15%) significance level. Robust standard errors in parentheses. The coefficient and standard error of the interactive term are computed as recommended in Ai and Norton (2003).

Table S5: Participation in warrantage: probit regression (interactive term for risk-loving)

	(1)	(2)	(3)	(4)	(5)
Risk aversion (r)	0.085	0.063	0.063	0.063	0.062
	(0.067)	(0.073)	(0.073)	(0.103)	(0.101)
Time discounting (δ)	-0.393	0.148	0.139	0.255	0.108
	(0.310)	(0.373)	(0.374)	(0.557)	(0.500)
Hyperbolic pref. (h)		1.846**	2.066**	2.610*	1.462
		(0.913)	(1.055)	(1.436)	(1.093)
Hyperbolic pref. x 2015			-0.004		
			(0.083)		
Hyperbolic pref. x risk lover		-0.193	-0.220	-1.073	0.381
		(1.092)	(1.071)	(1.756)	(1.323)
Village-by-Year FE	yes	yes	yes	yes	yes
Nb. obs.	1,149	1,149	1,149	653	496
Survey	2013 & 2015	2013 & 2015	2013 & 2015	2013	2015
χ^2-test of $r = \delta = h$		3.84	3.62	3.08	1.68
		(p=0.147)	(p=0.164)	(p=0.215)	(p=0.433)
z-test of $h = 0$		2.02	1.96	1.82	1.34
		(p=0.043)	(p=0.050)	(p=0.069)	(p=0.181)
Controls					
risk lover	0.395**	0.166	0.135	-0.826	0.832
	(0.190)	(1.203)	(1.180)	(1.894)	(1.494)
Plow	-0.023	-0.027	-0.027	-0.014	-0.040
	(0.046)	(0.046)	(0.046)	(0.066)	(0.064)
Labor force	-0.021$^\diamond$	-0.021$^\diamond$	-0.021$^\diamond$	-0.032$^\diamond$	-0.011
	(0.014)	(0.014)	(0.014)	(0.022)	(0.019)
Education	0.412***	0.423***	0.424***	0.444***	0.407***
	(0.100)	(0.101)	(0.101)	(0.146)	(0.139)
Age	-0.006*	-0.006*	-0.006*	-0.006	-0.006
	(0.004)	(0.004)	(0.004)	(0.005)	(0.005)
Sex	-0.052	-0.179	-0.179	0.098	-0.383
	(0.323)	(0.326)	(0.325)	(0.546)	(0.445)
Total land area	0.071***	0.071***	0.071***	0.072***	0.071***
	(0.012)	(0.012)	(0.012)	(0.016)	(0.017)
Cattle (less than 10)	0.438***	0.454***	0.455***	0.542***	0.406**
	(0.142)	(0.143)	(0.143)	(0.207)	(0.197)
Cattle (more than 10)	0.273	0.298	0.299	0.515$^\diamond$	0.123
	(0.223)	(0.225)	(0.225)	(0.315)	(0.315)
Poultry	0.001	0.001	0.001	0.001	0.000
	(0.002)	(0.002)	(0.002)	(0.004)	(0.003)

Note: This table displays probit regressions where the dependent variable is a dummy variable that equals one if the farmers participated in the warrantage system and zero elsewhere. Three asterisks *** (resp. **, *, $\diamond$) denote rejection of the null hypothesis of no impact at the 1% (resp. 5%, 10%, 15%) significance level. Robust standard errors in parentheses. The coefficient and standard error of the interactive term are computed as recommended in Ai and Norton (2003).

Table S6: Participation in warrantage: probit regression (using dummy variables for quintiles)

	(1)	(2)	(3)	(4)	(5)
Risk aversion (r) q1	-0.381	-0.228	-0.224	-0.276	-0.164
	(0.289)	(0.314)	(0.314)	(0.436)	(0.451)
Risk aversion (r) q2	-0.615**	-0.493*	-0.486$^\diamond$	-0.645$^\diamond$	-0.333
	(0.277)	(0.298)	(0.297)	(0.415)	(0.427)
Risk aversion (r) q3	-0.157	-0.026	-0.017	-0.102	0.085
	(0.272)	(0.286)	(0.284)	(0.404)	(0.402)
Risk aversion (r) q4	-0.292	-0.192	-0.190	-0.191	-0.179
	(0.203)	(0.223)	(0.222)	(0.317)	(0.313)
Time discounting (δ) q1	-0.466$^\diamond$	-0.285	-0.275	-0.278	-0.295
	(0.304)	(0.327)	(0.326)	(0.459)	(0.462)
Time discounting (δ) q2	-0.231	-0.026	-0.017	-0.035	-0.014
	(0.263)	(0.294)	(0.293)	(0.304)	(0.417)
Time discounting (δ) q3	-0.105	0.078	0.080	0.149	-0.009
	(0.178)	(0.215)	(0.216)	(0.304)	(0.307)
Time discounting (δ) q4	-0.040	0.092	0.096	0.046	0.115
	(0.147)	(0.178)	(0.179)	(0.254)	(0.255)
Hyperbolic pref. (h) q1		-0.562**	-0.591*	-0.570*	-0.595$^\diamond$
		(0.246)	(0.332)	(0.342)	(0.368)
Hyperbolic pref. (h) q2		-0.670***	-0.608*	-0.593*	-0.768**
		(0.257)	(0.334)	(0.354)	(0.386)
Hyperbolic pref. (h) q3		-0.677**	-0.534$^\diamond$	-0.605$^\diamond$	-0.770*
		(0.270)	(0.344)	(0.379)	(0.396)
Hyperbolic pref. (h) q4		-0.536**	-0.520$^\diamond$	-0.578$^\diamond$	-0.520
		(0.267)	(0.343)	(0.378)	(0.391)
Hyperbolic pref. X 2015 q1			0.041		
			(0.500)		
Hyperbolic pref. X 2015 q2			-0.132		
			(0.491)		
Hyperbolic pref. X 2015 q3			-0.283		
			(0.489)		
Hyperbolic pref. X 2015 q4			-0.046		
			(0.480)		
Village-by-Year FE	yes	yes	yes	yes	yes
Controls	yes	yes	yes	yes	yes
Nb. obs.	1,149	1,149	1,149	653	496
Survey	2013 & 2015	2013 & 2015	2013 & 2015	2013	2015

Note: This table displays probit regressions where the dependent variable is a dummy variable that equals one if the farmers participated in the warrantage system and zero elsewhere. The four regressions include four binary variables for the quintiles of each of the variable of interest (r, δ, and h). For all the three variables, q5 (the fifth quintile) is the reference dummy. Three asterisks *** (resp. **, *, $^\diamond$) denote rejection of the null hypothesis of no impact at the 1% (resp. 5%, 10%, 15%) significance level. Robust standard errors are in parentheses.

Table S7: Quantity stored as collateral: tobit regression (using dummy variables for quintiles)

	(1)	(2)	(3)	(4)	(5)
Risk aversion (r) q1	-0.137	-0.004	0.010	-0.152	0.229
	(0.162)	(0.164)	(0.164)	(0.166)	(0.267)
Risk aversion (r) q2	-0.221	-0.113	-0.098	-0.263*	0.151
	(0.171)	(0.164)	(0.161)	(0.157)	(0.261)
Risk aversion (r) q3	-0.031	0.130	0.141	-0.060	0.388$^\diamond$
	(0.136)	(0.156)	(0.156)	(0.150)	(0.264)
Risk aversion (r) q4	-0.129	-0.064	-0.059	-0.125	0.037
	(0.109)	(0.107)	(0.106)	(0.120)	(0.159)
Time discounting (δ) q1	-0.165	-0.013	-0.004	-0.116	0.136
	(0.166)	(0.168)	(0.167)	(0.173)	(0.270)
Time discounting (δ) q2	-0.051	0.108	0.117	-0.026	0.268
	(0.140)	(0.159)	(0.158)	(0.158)	(0.257)
Time discounting (δ) q3	-0.019	0.126	0.122	0.154	0.160
	(0.100)	(0.130)	(0.127)	(0.121)	(0.195)
Time discounting (δ) q4	-0.026	0.144	0.143	0.041	0.228
	(0.083)	(0.135)	(0.132)	(0.099)	(0.226)
Hyperbolic pref. (h) q1		-0.439*	-0.309*	-0.226*	-0.639$^\diamond$
		(0.235)	(0.174)	(0.125)	(0.412)
Hyperbolic pref. (h) q2		-0.535*	-0.381**	-0.252*	-0.803$^\diamond$
		(0.297)	(0.191)	(0.130)	(0.532)
Hyperbolic pref. (h) q3		-0.488*	-0.257$^\diamond$	-0.203$^\diamond$	-0.749$^\diamond$
		(0.267)	(0.180)	(0.140)	(0.462)
Hyperbolic pref. (h) q4		-0.407*	-0.265$^\diamond$	-0.252*	-0.527$^\diamond$
		(0.239)	(0.175)	(0.138)	(0.404)
Hyperbolic pref. X 2015 q1			-0.276		
			(0.395)		
Hyperbolic pref. X 2015 q2			-0.317		
			(0.420)		
Hyperbolic pref. X 2015 q3			-0.455		
			(0.415)		
Hyperbolic pref. X 2015 q4			-0.292		
			(0.385)		
Village-by-Year FE	yes	yes	yes	yes	yes
Controls	yes	yes	yes	yes	yes
Nb. obs.	1,138	1,138	1,138	653	485
Survey	2013 & 2015	2013 & 2015	2013 & 2015	2013	2015

Note: This table displays probit regressions where the dependent variable is a dummy variable that equals one if the farmers participated in the warrantage system and zero elsewhere. The four regressions include four binary variables for the quintiles of each of the variable of interest (r, δ, and h). For all the three variables, q5 (the fifth quintile) is the reference dummy. Three asterisks *** (resp. **, *, $^\diamond$) denote rejection of the null hypothesis of no impact at the 1% (resp. 5%, 10%, 15%) significance level. Robust standard errors are in parentheses.

Table S8: Robustness to income shocks

Dep. Var	(1) Participation	(2) Quantities
Risk aversion (r)	-0.019	-0.042
	(0.076)	(0.046)
Time discounting (δ)	0.190	0.017
	(0.513)	(0.281)
Hyperbolic pref. (h)	1.666**	1.014$^{\diamond}$
	(0.805)	(0.640)
Village-by-Year FE	yes	yes
Nb. obs.	496	496
Survey	2015	2015
χ^2-test of $r = \delta = h$	4.89	1.50
	(p=0.087)	(p=0.224)
z-test of $h = 0$	2.07	1.59
	(p=0.039)	(p=0.114)
Controls		
Harvest	0.340$^{\diamond}$	0.165$^{\diamond}$
	(0.210)	(0.103)
Plow	-0.017	0.018
	(0.064)	(0.037)
Labor force	-0.016	-0.020
	(0.019)	(0.013)
Education	0.373***	0.259*
	(0.140)	(0.157)
Age	-0.006	-0.005
	(0.005)	(0.003)
Sex	-0.371	-0.200
	(0.440)	(0.261)
Total land area	0.055***	0.033*
	(0.018)	(0.017)
Cattle (less than 10)	0.366*	0.203*
	(0.195)	(0.119)
Cattle (more than 10)	0.017	0.074
	(0.305)	(0.175)
Poultry	-0.001	-0.002
	(0.003)	(0.002)

Note: This table displays a probit regression where the dependent variable is a dummy variable that equals one if the farmers participated in the warrantage system and zero elsewhere (Col. 1) and a tobit regression where the left-censored dependent variable is the fraction of harvest stored in the warehouse (Col. 2). Three asterisks *** (resp. **, *, $^{\diamond}$) denote rejection of the null hypothesis of no impact at the 1% (resp. 5%, 10%, 15%) significance level. Robust standard errors in parentheses.

Proof A – Problem with hyperbolic time preferences (Proof of Propositions 1 and 2)

We proceed backward to solve the game between Self 1 and Self 2 (Self 3 consumes all his wealth because the game ends at period 3). The problem of the second-period Self is:

$$Max_{(q_2)} \frac{[c_2]^{1-r}}{1-r} + \frac{1}{1+\delta_1}\frac{1}{1-r}\left(\pi\left[\overline{c}_3\right]^{1-r} + (1-\pi)\left[\underline{c}_3\right]^{1-r}\right)$$

s.t. $q_2 \leq H-(1-\theta)w$,

where the grain consumption level in period 2 is $c_2 = \underline{p}q_2$, the grain consumption level in period 3 when the price of grain increases up to $\overline{p}$ is $\overline{c}_3 \equiv \overline{p}(H-(1-\theta)w - q_2 + (1-\sigma)w) - \underline{p}(1+i)\theta w$ and the grain consumption level in period 3 when the price does not increase is $\underline{c}_3 \equiv \underline{p}(H-(1-\theta)w - q_2 + (1-\sigma)w) - \underline{p}(1+i)\theta w$. The consumption level in period 3 is thus

$$\overline{c}_3 = \underline{p}\left[(1+\Delta)(H-q_2) + \left[(\Delta - i)\theta - (1+\Delta)\sigma\right]w\right], \tag{10}$$

with probability π, and,

$$\underline{c}_3 = \underline{p}\left[H - q_2 - [\sigma + \theta i]\,w\right], \tag{11}$$

with probability $1-\pi$.

The Lagrangian of this problem is:

$$L_2 = \frac{(c_2)^{1-r}}{1-r} + \frac{1}{1+\delta_1}\frac{1}{1-r}\left(\pi\left[\overline{c}_3\right]^{1-r} + (1-\pi)\left[\underline{c}_3\right]^{1-r}\right) + \eta\left[H - q_2 - (1-\theta)w\right]$$

where η is the Lagrange multiplier associated with the inequality constraint $q_2 \leq H-(1-\theta)w$.

The necessary conditions are given by:

$$\frac{\partial L_2}{\partial q_2} = \left(\underline{p}\right)^{1-r}[c_2]^{-r} - \frac{1}{1+\delta_1}\left(\pi\overline{p}\left[\overline{c}_3\right]^{-r} + (1-\pi)\underline{p}\left[\underline{c}_3\right]^{-r}\right) - \eta = 0, \tag{12}$$

$$\eta\left[H - q_2 - (1-\theta)w\right] = 0, \tag{13}$$

$$\eta \geq 0, \tag{14}$$

$$H - q_2 - (1-\theta)w \geq 0, \tag{15}$$

There are two cases to consider. If the grain constraint is binding, then the optimal grain consumption of the self of period 2 is characterized by

$$q_2^*(w,\theta) = H - (1-\theta)w. \tag{16}$$

If condition (15) is not binding, then $q_2^*(w,\theta) < H-(1-\theta)w$. In this latter case, condition (13) implies that $\eta = 0$. Hence, using condition (12) and $1+\Delta = \overline{p}/\underline{p}$, we conclude that the optimal grain consumption of the self of period 2 in this case, $q_2^*(w,\theta)$, is the level q_2 that solves:

$$1+\delta_1 = [c_2]^r\left(\pi(1+\Delta)\left[\overline{c}_3\right]^{-r} + (1-\pi)\left[\underline{c}_3\right]^{-r}\right). \tag{17}$$

Using this condition, we can show that if the time preferences of the household are sufficiently present biased, condition (15) is always binding. Using (10) and (11), we have that the right hand side in (17) is an increasing function of q_2 and it does not depend on time preferences. The left hand side does not depend on q_2. Notice that $h = -\frac{1+\delta_2}{(1+\delta_1)^2} \geq -1$ and $\delta_2 \geq 0$. Hence, h tends to its upper bound, which is 0, only when δ_1 goes to $+\infty$. Moreover, when δ_1 goes to $+\infty$, condition (17) implies that q_2 should be as high as possible, i.e. such that the budget constraint of self 2 is binding, which is a contradiction. We conclude that, if h is sufficiently large, then condition (15) is binding. Notice that having h sufficiently large is a sufficient (not necessary) condition for condition (15) to be binding.

Assuming that h is sufficiently large, we now go backward and consider the choice of Self 1. The optimization problem is the following:

$$Max_{(w,\theta)} \frac{1}{1+\delta_1}\frac{[c_2(w,\theta)]^{1-r}}{1-r} + \frac{1}{1+\delta_2}\frac{1}{1-r}\left(\pi\left[\overline{c}_3(w,\theta)\right]^{1-r} + (1-\pi)\left[\underline{c}_3(w,\theta)\right]^{1-r}\right)$$

s.t. $\theta \geq 0$ and $0.8 \geq \theta$,

where the grain consumption in period 2 is $c_2(w,\theta) = \underline{p}q_2^*(w,\theta)$, the grain consumption in period 3 when the price increases is $\overline{c}_3(w,\theta) \equiv \underline{p}\left[(1+\Delta)(H-q_2^*(w,\theta)) + [(\Delta-i)\theta-(1+\Delta)\sigma]\,w\right]$ and the grain consumption in period 3 when the price does not increase is $\underline{c}_3(w,l) \equiv \underline{p}\left[H-q_2^*(w,\theta)-[\sigma+\theta i]\,w\right]$. The Lagrangian of this problem is:

$$\widetilde{L}_1 = \frac{1}{1+\delta_1}\frac{(c_2(w,\theta))^{1-r}}{1-r} + \frac{1}{1+\delta_2}\frac{1}{1-r}\left(\pi\left[\overline{c}_3(w,\theta)\right]^{1-r} + (1-\pi)\left[\underline{c}_3(w,\theta)\right]^{1-r}\right) + \tilde{\mu}\theta + \tilde{\lambda}\,(0.8-\theta),$$

where $\tilde{\mu}$ and $\tilde{\lambda}$ are the Lagrange multipliers associated with the inequality constraints $\theta \geq 0$ and $0.8 \geq \theta$, respectively.

Since $q_2^*(w,\theta) = H-(1-\theta)\,w$, the consumption level in period 2 is $c_2(w,\theta) = \underline{p}\,[H-(1-\theta)\,w]$, the consumption level in period 3 when the price increases is:

$$\overline{c}_3(w,\theta) = \underline{p}\,[(1+\Delta)(1-\sigma)-\theta(1+i)]\,w, \tag{18}$$

and the consumption level in period 3 when the price does not increase is:

$$\underline{c}_3(w,\theta) = \underline{p}\,[1-\sigma-\theta(1+i)]\,w. \tag{19}$$

The necessary conditions are given by (we omit the arguments of the consumption level functions):

$$\frac{\partial L_1}{\partial w} = -\frac{1-\theta}{1+\delta_1}[c_2]^{-r} + \frac{1}{1+\delta_2}\left(\pi\,[(1+\Delta)(1-\sigma)-\theta(1+i)]\left[\overline{c}_3\right]^{-r} + (1-\pi)\,[1-\sigma-\theta(1+i)]\left[\underline{c}_3\right]^{-r}\right) = 0, \tag{20}$$

$$\frac{\partial L_1}{\partial \theta} = \left[\frac{1}{1+\delta_1}[c_2]^{-r} - \frac{(1+i)}{1+\delta_2}\left(\pi\left[\overline{c}_3\right]^{-r} + (1-\pi)\left[\underline{c}_3\right]^{-r}\right)\right]w + \mu - \lambda = 0, \tag{21}$$

$$\lambda\,[0.8-\theta] = 0;\ \lambda \geq 0;\ 0.8 \geq \theta, \tag{22}$$

$$\mu\theta = 0;\ \mu \geq 0;\ \theta \geq 0, \tag{23}$$

where $L_1 = \widetilde{L}_1/\underline{p}$, $\mu = \tilde{\mu}/\underline{p}$ and $\lambda = \widetilde{\lambda}/\underline{p}$.

Using the expressions of the consumption levels and $\frac{1+\delta_2}{1+\delta_1} = -h(1+\delta_1)$, condition (20) can be rewritten as follows:

$$-h(1+\delta_1)(1-\theta)\left[\frac{H}{w}-(1-\theta)\right]^{-r} = \left(\pi\left[(1+\Delta)(1-\sigma)-\theta(1+i)\right]^{1-r}+(1-\pi)\left[1-\sigma-\theta(1+i)\right]\right)^{1-r}, \quad (24)$$

or,

$$\frac{w}{H} = \left[1-\theta+\left[\frac{-h(1+\delta_1)(1-\theta)}{\pi\left[(1+\Delta)(1-\sigma)-\theta(1+i)\right]^{1-r}+(1-\pi)\left[1-\sigma-\theta(1+i)\right]^{1-r}}\right]^{\frac{1}{r}}\right]^{-1}. \quad (25)$$

This condition characterizes the optimal warehouse storage level.

We then characterize the optimal loan rate. Multiplying condition (21) by $(1-\theta)$ and adding (20) times w, we find:

$$\frac{w}{1+\delta_2}\left[\pi\left[(1+\Delta)(1-\sigma)-(1+i)\right]\left[\overline{c}_3\right]^{-r}-(1-\pi)(\sigma+i)\left[\underline{c}_3\right]^{-r}\right]+\mu-\lambda=0. \quad (26)$$

Notice that this condition implies that θ depends neither on δ_1 nor on δ_2. Indeed, if $\mu=\lambda=0$ then θ is such that the term in brackets in the left hand side equals 0. If $\mu>0$, then $\theta=0$ and if $\lambda>0$ then $\theta=0.8$.

Notice that $\mu>0$ and $\lambda>0$ is impossible (otherwise $\theta=0=0.8$).

If $\mu>0$ and $\lambda=0$, using condition (23), we must have $\theta=0$. Hence, $c_2=\underline{p}(H-w)$, $\overline{c}_3=\underline{p}(1+\Delta)(1-\sigma)w$ and $\underline{c}_3=\underline{p}(1-\sigma)w$. Moreover, condition (8) becomes:

$$\mu=\frac{w^{1-r}\left[\underline{p}(1-\sigma)\right]^{-r}}{1+\delta_2}\left[(1-\pi)(\sigma+i)-\pi\left[(1+\Delta)(1-\sigma)-(1+i)\right]\left[1+\Delta\right]^{-r}\right]. \quad (27)$$

Since $w>0$, $\mu>0$ holds if and only if $(1-\pi)(\sigma+i)-\pi\left[(1+\Delta)(1-\sigma)-(1+i)\right]\left[1+\Delta\right]^{-r}>0$, or,

$$r>\frac{Ln\left[\frac{\pi}{1-\pi}\frac{(1+\Delta)(1-\sigma)-(1+i)}{\sigma+i}\right]}{Ln\left[1+\Delta\right]}. \quad (28)$$

If $\mu=0$ and $\lambda>0$, using condition (22), we must have $\theta=0.8$. Hence $\overline{c}_3=\underline{p}\left[(1+\Delta)(1-\sigma)-0.8(1+i)\right]w$ and $\underline{c}_3=\underline{p}\left[1-\sigma-0.8(1+i)\right]w$. Moreover, condition (8) becomes:

$$\lambda=\frac{w}{1+\delta_2}\left[\pi\left[(1+\Delta)(1-\sigma)-(1+i)\right]\left[(1+\Delta)(1-\sigma)-0.8(1+i)\right]^{-r}-(1-\pi)(\sigma+i)\left[1-\sigma-0.8(1+i)\right]^{-r}\right]. \quad (29)$$

Hence, $\lambda>0$ holds if and only if

$$\frac{Ln\left[\frac{\pi}{1-\pi}\frac{\left[(1+\Delta)(1-\sigma)-(1+i)\right]}{(\sigma+i)}\right]}{Ln\left[\frac{(1+\Delta)(1-\sigma)-0.8(1+i)}{1-\sigma-0.8(1+i)}\right]}>r. \quad (30)$$

If $\mu=\lambda=0$, condition (8) becomes:

$$\frac{w^{1-r}\underline{p}^{-r}}{1+\delta_2}\left[\pi\left[(1+\Delta)(1-\sigma)-(1+i)\right]\left[(1+\Delta)(1-\sigma)-\theta(1+i)\right]^{-r}-(1-\pi)(\sigma+i)\left[1-\sigma-\theta(1+i)\right]^{-r}\right]=0, \quad (31)$$

or,

$$\left[\frac{\pi\left[(1+\Delta)(1-\sigma)-(1+i)\right]}{(1-\pi)(\sigma+i)}\right]^{\frac{1}{r}}=\frac{(1+\Delta)(1-\sigma)-\theta(1+i)}{1-\sigma-\theta(1+i)}, \tag{32}$$

or,

$$\theta=\frac{1-\sigma}{1+i}\frac{\left[\frac{\pi[(1+\Delta)(1-\sigma)-(1+i)]}{(1-\pi)(\sigma+i)}\right]^{\frac{1}{r}}-(1+\Delta)}{\left[\frac{\pi[(1+\Delta)(1-\sigma)-(1+i)]}{(1-\pi)(\sigma+i)}\right]^{\frac{1}{r}}-1}. \tag{33}$$

It remains to check that $0\leq\theta\leq 0.8$. Using (33), we find that this is equivalent to

$$\frac{Ln\left[\frac{\pi}{1-\pi}\frac{[(1+\Delta)(1-\sigma)-(1+i)]}{(\sigma+i)}\right]}{Ln\left[\frac{(1+\Delta)(1-\sigma)-0.8(1+i)}{1-\sigma-0.8(1+i)}\right]}\leq r\leq\frac{Ln\left[\frac{\pi}{1-\pi}\frac{(1+\Delta)(1-\sigma)-(1+i)}{\sigma+i}\right]}{Ln\left[1+\Delta\right]} \tag{34}$$

We now show that θ decreases when r increases. Notice that $x\mapsto\frac{x-(1+\Delta)}{x-1}$ increases when x increases. Since $r>0$, the case where $\mu=\lambda=0$ exists only when $\frac{\pi}{1-\pi}\frac{(1+\Delta)(1-\sigma)-(1+i)}{\sigma+i}>1$. Hence, $\left[\frac{\pi[(1+\Delta)(1-\sigma)-(1+i)]}{(1-\pi)(\sigma+i)}\right]^{\frac{1}{r}}$ decreases when r increases. Thus, θ decreases when r increases.

Proof B – Problem with time-consistent preferences (Proof of Proposition 3)

The problem of the farmer with time-consistent preferences can be written as follows:

$$Max_{(w,l,q_2)}\frac{[c_2]^{1-r}}{1-r}+\frac{1}{1+\delta_1}\frac{1}{1-r}\left(\pi\left[\overline{c}_3\right]^{1-r}+(1-\pi)\left[\underline{c}_3\right]^{1-r}\right)$$

s.t. $q_2\leq H-w-l$, $l\geq 0$ and $0.8w\geq l$.

where l is the loan ($l=\theta w$), the grain consumption level in period 2 is $c_2=\underline{p}q_2$, the grain consumption level in period 3 when the price of grain increases up to $\overline{p}$ is $\overline{c}_3\equiv\overline{p}(H+l-w-q_2+(1-\sigma)w)-(1+i)\underline{p}l$ and the grain consumption level in period 3 when the price does not increase is $\underline{c}_3\equiv\underline{p}(H+l-w-q_2+(1-\sigma)w)-(1+i)\underline{p}l$. The consumption level in period 3 is thus:

$$\overline{c}_3=\underline{p}\left[(1+\Delta)(H-q_2)+\left[(\Delta-i)\theta-(1+\Delta)\sigma\right]w\right], \tag{35}$$

with probability π, and,

$$\underline{c}_3=\underline{p}\left[H-q_2-\left[\sigma+\theta i\right]w\right], \tag{36}$$

with probability $1-\pi$.

The Lagrangian of this problem is:

$$\widetilde{L}=\frac{[c_2]^{1-r}}{1-r}+\frac{1}{1+\delta_1}\frac{1}{1-r}\left(\pi\left[\overline{c}_3\right]^{1-r}+(1-\pi)\left[\underline{c}_3\right]^{1-r}\right)+\widetilde{\eta}\left[H-q_2-w-l\right]+\widetilde{\mu}l+\widetilde{\lambda}\left[0.8w-l\right]$$

where $\widetilde{\eta}$, $\widetilde{\mu}$ and $\widetilde{\lambda}$ are the Lagrange multipliers associated with the inequality constraints $H-w-l\geq q_2$, $l\geq 0$ and $0.8w\geq l$, respectively.

Assume that the farmer does not take the maximal loan, i.e. $l<0.8w$. We then must have $\widetilde{\lambda}=0$. A simple inspection of the Langrangian and the consumption functions reveals that, in this case, the Lagrangian is strictly decreasing when the collateral w increases. The farmer thus has incentives to chooses the smallest possible collateral w, i.e. such that $w = l/0.8$, i.e. $\theta = 0.8$.

Proof C – Problem under price certainty ($\pi = 1$)

Problem of Self 2:

The problem of self 2 is:

$$Max_{(q_2)} \frac{[c_2]^{1-r}}{1-r} + \frac{1}{1+\delta_1} \frac{[c_3]}{1-r}^{1-r}$$

s.t. $q_2 \leq H - (1-\theta) w$,

where the consumption level in period 2 is $c_2 = \underline{p} q_2$, the consumption level in period 3 is $c_3 \equiv \overline{p}(H + l - w - q_2 + (1-\sigma) w) - (1+i)\underline{p} l$, or

$$c_3 = \underline{p} \left[(1+\Delta)(H - q_2) + [(\Delta - i)\theta - (1+\Delta)\sigma] \, w \right], \tag{37}$$

The Lagrangian of this problem is:

$$\widetilde{L} = \frac{[c_2]^{1-r}}{1-r} + \frac{1}{1+\delta_1} \frac{[c_3]^{1-r}}{1-r} + \widetilde{\eta} \left[H - q_2 - (1-\theta) w \right]$$

where $\widetilde{\eta}$, is the Lagrange multiplier associated to the inequality constraint $H - (1-\theta) w \geq q_2$.

The necessary conditions are given by:

$$\frac{\partial L}{\partial q_2} = [c_2]^{-r} - \frac{1+\Delta}{1+\delta_1} [c_3]^{-r} - \eta = 0, \tag{38}$$

$$\eta \left[H - q_2 - (1-\theta) w \right] = 0, \eta \geq 0, H - q_2 - (1-\theta) w \geq 0, \tag{39}$$

where $\eta = \underline{p} \widetilde{\eta}$.

If $\eta > 0$, then $q_2 = H - (1-\theta) w$. Using condition (38), we obtain:

$$w/H > \frac{\left[\frac{1+\Delta}{1+\delta_1} \right]^{\frac{1}{r}}}{(1+\Delta)(1-\sigma) - \theta \left[1 + i + \left(\frac{1+\Delta}{1+\delta_1} \right)^{\frac{1}{r}} \right] + \left[\frac{1+\Delta}{1+\delta_1} \right]^{\frac{1}{r}}}. \tag{40}$$

If $\eta = 0$, using condition (2), we know that the optimal grain consumption of the self of period 2, $q_2^* (w, \theta)$, is the level q_2 that solves:

$$[c_2]^{-r} = \frac{1}{1+\delta_1} (1+\Delta) \left[\overline{c}_3 \right]^{-r}. \tag{41}$$

Solving for q_2, we find:

$$q_2^* (w, \theta) = \frac{(1+\Delta) H + [(\Delta - i)\theta - (1+\Delta)\sigma] \, w}{\left[\frac{1+\Delta}{1+\delta_1} \right]^{\frac{1}{r}} + 1 + \Delta}. \tag{42}$$

In this case, using (42), the budget constraint of the self of period 2 becomes:

$$w/H \leq \frac{\left[\frac{1+\Delta}{1+\delta_1}\right]^{\frac{1}{r}}}{(1+\Delta)(1-\sigma)-\theta\left[1+i+\left(\frac{1+\Delta}{1+\delta_1}\right)^{\frac{1}{r}}\right]+\left[\frac{1+\Delta}{1+\delta_1}\right]^{\frac{1}{r}}} \tag{43}$$

Problem of Self 1:

We now go backward and consider the choice of Self 1.

The optimization problem is the following:

$$Max_{(w,\theta)} \frac{1}{1+\delta_1}\frac{[c_2(w,\theta)]^{1-r}}{1-r}+\frac{1}{1+\delta_2}\frac{[c_3(w,\theta)]^{1-r}}{1-r}$$

s.t. $\theta \geq 0$ and $0.8 \geq \theta$,

where the grain consumption in period 2 is $c_2(w,\theta) = \underline{p}q_2^*(w,\theta)$ and the grain consumption in period 3 is $c_3(w,\theta) \equiv \underline{p}\left[(1+\Delta)(H-q_2^*(w,\theta))+[(\Delta-i)\theta-(1+\Delta)\sigma]\,w\right]$.
The Lagrangian of this problem is:

$$\widetilde{L}_1 = \frac{1}{1+\delta_1}\frac{(c_2(w,\theta))^{1-r}}{1-r}+\frac{1}{1+\delta_2}\frac{1}{1-r}[c_3(w,\theta)]^{1-r}+\tilde{\mu}\theta+\tilde{\lambda}(0.8-\theta).$$

Case 1: $\eta > 0$ **(the budget constraint of self 2 is binding)**

In this case, the budget constraint of self 2 is binding, i.e. $q_2 = H-(1-\theta)w$ and the consumption level in period 3 is $c_3(w,\theta) = \underline{p}\,[(1+\Delta)(1-\sigma)-\theta(1+i)]\,w$.
The necessary conditions are (we omit the arguments of the consumption level functions):

$$\frac{\partial L_1}{\partial w} = -\frac{1-\theta}{1+\delta_1}[c_2]^{-r}+\frac{1}{1+\delta_2}[(1+\Delta)(1-\sigma)-\theta(1+i)]\,[c_3]^{-r} = 0, \tag{44}$$

$$\frac{\partial L_1}{\partial \theta} = \left[\frac{1}{1+\delta_1}[c_2]^{-r}-\frac{(1+i)}{1+\delta_2}[c_3]^{-r}\right]w+\mu-\lambda = 0, \tag{45}$$

$$\lambda\,[0.8-\theta] = 0;\ \lambda \geq 0;\ 0.8 \geq \theta, \tag{46}$$

$$\mu\theta = 0;\ \mu \geq 0;\ \theta \geq 0, \tag{47}$$

where $L_1 = \widetilde{L}_1/\underline{p}$, $\mu = \widetilde{\mu}/\underline{p}$ and $\lambda = \widetilde{\lambda}/\underline{p}$.

Using the expressions of the consumption levels and $\frac{1+\delta_2}{1+\delta_1} = -h(1+\delta_1)$, condition (44) can be rewritten as follows:

$$-h(1+\delta_1)(1-\theta)\left[\frac{H}{w}-(1-\theta)\right]^{-r} = [(1+\Delta)(1-\sigma)-\theta(1+i)]^{1-r}$$

or,

$$\frac{w}{H} = \left[1-\theta+\left[\frac{-h(1+\delta_1)(1-\theta)}{[(1+\Delta)(1-\sigma)-\theta(1+i)]^{1-r}}\right]^{\frac{1}{r}}\right]^{-1}. \tag{48}$$

We then characterize the optimal loan rate. Multiplying condition (45) by $(1-\theta)$ and adding (44) times w, we find:

$$\frac{w}{1+\delta_2}\left[(1+\Delta)(1-\sigma)-(1+i)\right][c_3]^{-r}+\mu(1-\theta)-\lambda(1-\theta)=0.$$

Since $(1+\Delta)(1-\sigma)-(1+i)>0$, μ cannot be strictly positive, thus $\theta>0$ and $\mu=0$ and $\lambda>0$, thus $\theta=0.8$.

We need to check that $\eta>0$, ie. that inequality (40) holds. We find that it holds if and only if:

$$h>\tilde{h}\equiv-\frac{(1-\sigma)(1+\Delta)-0.8(1+i)}{(1+\Delta)0.2} \tag{49}$$

Case 2: $\eta=0$

In this case, using conditions (41) and (42), the Lagrangian of the optimization problem of self 1 becomes:

$$\widetilde{L}_1=\frac{\underline{p}^{1-r}}{1+\delta_1}\frac{1}{1-r}\left[1+\frac{(1+\Delta)^{\frac{1-r}{r}}}{-h(1+\delta_1)^{\frac{1}{r}}}\right]\left(\frac{(1+\Delta)H+\left[(\Delta-i)\theta-(1+\Delta)\sigma\right]w}{\left[\frac{1+\Delta}{1+\delta_1}\right]^{\frac{1}{r}}+1+\Delta}\right)^{1-r}+\tilde{\mu}\theta+\tilde{\lambda}\,(0.8-\theta). \tag{50}$$

First suppose that $w>0$. If $\lambda=0$, then the Lagrangian increases when θ increases, and then $\theta=0.8$. If $\lambda>0$, we also have $\theta=0.8$. If $(\Delta-i)0.8>(1+\Delta)\sigma$, then w goes to infinity and the budget constraint of self 2 cannot hold, which is a contradiction. If $(\Delta-i)0.8<(1+\Delta)\sigma$, then $w=0$, which is a contradiction.

We thus have $w=0$. This solution holds as long as the Lagrangian is decreasing when w increases, which is true when $\theta\leq\frac{(1+\Delta)\sigma}{\Delta-i}$.

In order to conclude the proof, one needs to compare the expected utility of the farmer for the optimal solution when $\eta>0$ (i.e. $\theta=0.8$ and w characterized by (48)) and the optimal solution when $\eta=0$ (i.e. $w=0$) for the case where $h>-\frac{1-\sigma}{0.2}+\frac{0.8(1+i)}{(1+\Delta)0.2}$. The expected utility of self 1 when $\eta=0$ is:

$$EU_1|_{\eta=0}=\frac{\left(\underline{p}H\right)^{1-r}}{1+\delta_1}\frac{1}{1-r}\left(\frac{1+\Delta}{\left[\frac{1+\Delta}{1+\delta_1}\right]^{\frac{1}{r}}+1+\Delta}\right)^{1-r}\left[1+\frac{(1+\Delta)^{\frac{1-r}{r}}}{-h(1+\delta_1)^{\frac{1}{r}}}\right], \tag{51}$$

and the expected utility of self 1 when $\eta>0$ is:

$$EU_1|_{\eta>0}=\frac{\left(\underline{p}H\right)^{1-r}}{1+\delta_1}\frac{1}{1-r}\left[1+\frac{\left(\frac{(1-\sigma)(1+\Delta)-0.8(1+i)}{0.2}\right)^{\frac{1-r}{r}}}{\left[-h(1+\delta_1)\right]^{\frac{1}{r}}}\right]^{r}, \tag{52}$$

The solution with $\eta>0$ is preferred to the solution with $\eta=0$ if and only if $EU_1|_{\eta>0}\geq EU_1|_{\eta=0}$, which is equivalent to:

$$\frac{1}{1-r}\left((-h)^{\frac{1}{r}}+\frac{\left(\frac{(1-\sigma)(1+\Delta)-0.8(1+i)}{0.2}\right)^{\frac{1-r}{r}}}{(1+\delta_1)^{\frac{1}{r}}}\right)^{r}\geq\frac{1}{1-r}\left[-h+\frac{(1+\Delta)^{\frac{1-r}{r}}}{(1+\delta_1)^{\frac{1}{r}}}\right]\left(\frac{1+\Delta}{\left[\frac{1+\Delta}{1+\delta_1}\right]^{\frac{1}{r}}+1+\Delta}\right)^{1-r} \tag{53}$$

When $h=-1$, condition (53) is equivalent to $0.8(\Delta-i)-(1+\Delta)\sigma\geq 0$. When $h\to 0$, condition (53) is equivalent to

$$\frac{(1-\sigma)(1+\Delta)-0.8(1+i)}{0.2(1+\Delta)}\geq\frac{(1+\Delta)^{\frac{1-r}{r}}}{(1+\Delta)^{\frac{1-r}{r}}+(1+\delta_1)^{\frac{1}{r}}}. \tag{54}$$

Since $h=-\frac{1+\delta_2}{1+\delta_1}$ and $\delta_2\geq 0$ we must have $\delta_1\to+\infty$. Hence, when $h\to 0$, condition (53) is equivalent to $\frac{(1-\sigma)(1+\Delta)-0.8(1+i)}{0.2(1+\Delta)}\geq 0$, which is always true.

Now let us study how condition (53) changes when h varies. The left hand side in (53) is convex with respect to h while the right hand side is linear. Both the left hand side and the right hand side increase when h increases (respectively decrease) when $r>1$ (respectively $r<1$).

The level of h that minimizes the difference between the left hand side and the right hand side in (53) is such that the derivative of this difference with respect to h is null. We find that it is given by:

$$\check{h}=-(-\widetilde{h})^{1-r}=-\left[\frac{(1-\sigma)(1+\Delta)-0.8(1+i)}{0.2(1+\Delta)}\right]^{1-r} \tag{55}$$

If $0.8(\Delta-i)-(1+\Delta)\sigma\geq 0$, then $\check{h}\leq -1$ and $\widetilde{h}\leq -1$ and then the difference between the left hand side and the right hand side in (53) is always increasing. Moreover, we know that (53) holds when $h=-1$. Hence, (53) holds whatever the value of h in $[-1,0]$.

If $0.8(\Delta-i)-(1+\Delta)\sigma<0$, then $\check{h}<\widetilde{h}$. Hence, the difference between the left hand side and the right hand side in (53) is always increasing. We know that (53) does not hold when $h=-1$ in this case while it holds when $h\to 0$. Hence, condition (53) holds if and only if $h\geq\hat{h}$ where $\hat{h}$ is the unique value of h in $]-1,0[$ such that inequality (53) is binding.

The reasoning above leads to the following result:

Result [threshold]: *When the price increases with certainty, i.e.* $\pi=1$, *there is a threshold* $\underline{h}$ *such that the budget constraint of Self 2 is binding in equilibrium if and only if the farmer' present bias is larger than this threshold, i.e.* $h>\underline{h}$. *It is such that:*
(i) $\underline{h}=-1$ *if* $0.8(\Delta-i)-(1+\Delta)\sigma\geq 0$, *and*
(ii) $\underline{h}$ *is the unique solution to* $\left((-h)^{\frac{1}{r}}+\frac{\left(\frac{(1-\sigma)(1+\Delta)-0.8(1+i)}{0.2}\right)^{\frac{1-r}{r}}}{(1+\delta_1)^{\frac{1}{r}}}\right)^{r}=\left[-h+\frac{(1+\Delta)^{\frac{1-r}{r}}}{(1+\delta_1)^{\frac{1}{r}}}\right]\left(\frac{1+\Delta}{\left[\frac{1+\Delta}{1+\delta_1}\right]^{\frac{1}{r}}+1+\Delta}\right)^{1-r}$ *where* $-1<h<0$, *if* $0.8(\Delta-i)-(1+\Delta)\sigma<0$.

This result states that, in case (i), Self 1 will always find it optimal to choose a storage quantity and a loan such that the budget constraint of Self 2 is binding, whatever his level of present bias. In case (ii), this will be the optimal strategy of Self 1 only if he is sufficiently present biased.

In the case where the risk aversion parameter equals 0.5 (i.e. the median value in our sample), we can solve for the explicit formula of the threshold. In this case, we find:

$$\underline{h} = -1 + \sqrt{\frac{(1+\Delta)\sigma - 0.8(\Delta - i)}{0.2(1+\Delta)}\left(1 + \frac{1+\Delta}{(1+\delta_1)^2}\right)}. \tag{56}$$

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Contact : laurent.garnier@inra.fr/ 04 99 61 31 21

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