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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 newly-built warehouses of the program. We found that farmers who exhibit stronger hyperbolic preferences are significantly more likely to participate in the warrantage system than other, otherwise similar, farmers. We interpret this result as evidence that farmers use warrantage as a means to commit to saving a portion of their crop until the lean season, which may improve their capacity to ensure the food security of their household.

Key Words: Commitment Savings, Inventory Credit, Hyperbolic Discounting.

JEL: D14, O12.

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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.

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.[5] 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.

[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).

[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.

[5] 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).

We implemented a warrantage system in Burkina Faso and investigated the possible link between farmers' risk and time preferences and participation in the system. This project was called 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 nation-wide organization of farmers, to implement a warrantage system in the western region of Burkina 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. The warrantage system continued to function in subsequent years.

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 contribution of this article is to offer a new rationale for the success of warrantage schemes, based on the demand for commitment.

In this article, 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. In this model, participation in warrantage provides the farmer with a means to constrain his futures selves. The model predicts that 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 - something that we actually observe in our data. The model moreover predicts a positive relationship between time-inconsistency and participation into the scheme.

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).[6] 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). For example, although present-biased individuals may prefer today to be patient enough in the future to save the harvest that they store on site, when the time comes they may nonetheless fail to do so when tempted to use their crop for immediate consumption. The point is that 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. Institutions can help solve self-control problems by providing such a commitment mechanism (Mullainathan, 2005; Bauer, Chytilova, and Morduch, 2012).[7] In this paper we argue that, 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.

Some recent empirical 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

[6]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).

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

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.[8]

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 credit constraint or social taxes. Section 8 concludes.

2 Context and FARMAF project

As part of the FARMAF project, we implemented a warrantage system in two administrative districts of Burkina Faso, the Tuy and Mouhoun provinces, in the western region of the country (Figure 1). The

[8]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.

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. Furthermore the warrantage system seems viable, as it has been implemented each year 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. Farmers who are able to repay the 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.[12] Farmers were also charged the cost of storage, which amounted

[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]In 2013, the interest rate was 0.7 percent in Magnimasso, 0.8 percent in Lopohin, 1 percent in Tankuy, 1.5 percent in

to 100 CFA 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.[13]

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

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.

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

market to get cash immediately is obviously more profitable than participating in an inventory credit system.

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 futures selves.

3.1 Model

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.[14] 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 $0 < r < 1$ 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:

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

[14] 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.

where δ_1 is the discount rate of the second-period self, applied to the utility stream that he receives 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, 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 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 $\frac{1}{1+\delta_2} < \left(\frac{1}{1+\delta_1}\right)^2$. Notice that this definition is quite general. 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 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:

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

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 in period 3 equals $\overline{p}$ with probability π and $\underline{p}$ with probability $1-\pi$.

3.2 Optimal warehouse storage

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,[15] i.e. $(1-\sigma)(1+\Delta) > 1+i$. For the sake of simplicity, we moreover focus on the cases where inequality (4) is binding, which occurs when h is higher than a certain threshold.[16] Proofs are relegated to Appendix B.1. We first look at the optimal warehouse storage and find the following result:

Proposition 1 [optimal warehouse storage]: *The optimal share of grain that the farmer decides to store in the warehouse is:*

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

where θ^* is the optimal loan rate.

[15]Even in the event of a small increase in grain prices, the condition still holds for very high (thus unlikely) values of σ.

[16]Establishing a full characterization of the optimal choice of the farmer for all possible values of h would be tedious because the optimization problem is not concave. This would require to compare the expected utility for the solution found in Proposition 1 to the solutions of the problem in the case where the inequality is not binding. In this case, however, several local extrema exist. For the ease of presentation, we do not provide these results.

This proposition leads to clear-cut predictions regarding the effects of time preferences on the optimal quantity of grain w^* that is stored as collateral. In particular we have:

Main Prediction [hyperbolic & optimal warehouse storage]: *The optimal quantity of grain w^* increases with the hyperbolic preference parameter h.*

This result arises because a farmer with sophisticated hyperbolic time preferences has the means to constrain his second-period self through warrantage. In other words, the first-period self can choose a quantity of grain w such that the optimal second-period consumption level is fully determined by the second-period budget constraint (inequality 4 is binding).

This proposition 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 play in various ways in the characterization of the optimal storage.[17]

3.3 Typology of participants

We then characterize the optimal loan rate, which allows us to highlight a typology of participants in the warrantage scheme. We get the following result:

Proposition 2 [typology]: *The optimal loan rate $\theta^* = l^* / w^*$ 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 $\underline{r} \leq r \leq \overline{r}$. Moreover, we have:*

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

- Case 3: *The farmer does not take 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 $\underline{r} = \frac{Ln\left[\frac{\pi}{1-\pi}\frac{[(1+\Delta)(1-\sigma)-(1+i)]}{(\sigma+i)}\right]}{Ln\left[\frac{(1+\Delta)(1-\sigma)-0.8(1+i)}{1-\sigma-0.8(1+i)}\right]}$.

[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.

This proposition 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 exclusively seeking a commitment feature in the proposed scheme, i.e. those farmers who have both sufficiently hyperbolic time preferences and are highly risk averse.

To better understand the characteristics of farmers who store grain but do not take out a loan, we examine the optimal loan rate θ^* in a model where the farmer has consistent time preferences. In such a model, inequality (4) may not be binding (contrary to the model with hyperbolic time preferences). For this reason, the solution differs from Proposition 1. Proofs are relegated to Appendix B.2. One important result arises from a comparison of the two models: whereas a time-consistent farmer will never choose to store grain in the warehouse without taking a loan, hyperbolic farmers will do so as long as they are sufficiently risk averse (i.e. $r > \overline{r}$), as stated in Propositions 1 and 2.

Proposition 2 moreover leads to the (standard) prediction that the optimal loan rate decreases with the risk aversion parameter.[18] In contrast, the loan rate θ^* is, perhaps surprisingly, 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 because the farmer has the means by which to smooth his consumption. He can for example, store grain at home (which will increase his wealth in the second period) or in the warehouse (which will increase his wealth in the third period).

In sum, this theoretical model highlights two important qualitative results regarding our understanding of farmers' decisions about whether or not to participate in a warrantage program. First, participants are likely to fall into three categories, defined according to the model parameters (π, Δ, σ, and i). In particular, we find that the group of risk averse farmers who store grain in the warehouse but do not take out a loan is comprised only of farmers with hyperbolic time preferences. Second, time preferences are likely to determine the optimal quantity of grain w^* that is stored as collateral. In particular, we find that the optimal quantity of grain w^* increases with the hyperbolic discounting

[18]We do not test this prediction using our data because it is a very standard result in the literature. Moreover, the relationship between the loan rate and the degree of risk aversion cannot be estimated using a simple reduced form model. This is 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. Here, we confront the standard problem of sample selection (Heckman, 1979).

parameter h. In what follows, we show to what extent our data are in line with these predictions.

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 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 3.3. 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).

Table 4 provides 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: the total cost of credit for the average farmer who stored 10 bags of maize in November and borrowed 42 percent of the value of the quantity stored, was 9,100 CFA francs. This amount includes 6,240 CFA for storage costs (100 CFA per bag and per month) and 2,860 CFA for loan interests (1 percent per month). Given that the price of grain rose by 25 percent between November 2013 and May 2014 in the seven villages participating in the study, the value of the collateral increased by 28,230 CFA, which is much more than the total cost of credit.[19]

In 2013, 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. This does not mean that participants have lost money doing warrantage (they may have invested the amount borrowed in a profitable activity), but this suggests that many households are willing to pay quite a lot for storing their own grain outside of their compound.

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

[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.

different pairs of lotteries, as illustrated in Table 5. Farmers were asked to choose either lottery A or lottery B. For example, the first row of Table 5 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. More information about the script used by the experimenters is provided in Appendix.

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 5, 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 5. 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:

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

[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.

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 multiple 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]

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

[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

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 7 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 8 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:

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

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.

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.

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 which indicates that 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 (Ashraf, Karlan,

[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.

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:

$$W_{it} = f(\delta_i, r_i, h_i, X_i, \eta_{tv}, \epsilon_{it}) \tag{7}$$

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:

$$\Pr(W_{it} = 1 | \delta_i, r_i, h_i, X_i) = \Pr(\lambda_0 + \lambda_1 \delta_i + \lambda_2 r_i + \lambda_3 h_i + X_i' \alpha_1 + \eta_{tv}' \alpha_2 + \epsilon_{it} > 0) \tag{8}$$

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 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 9 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 10 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

[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.

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 A.1 in Appendix).

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 9) 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 A.2 in Appendix).

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 Table A.3 in Appendix. Main results hold.

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 present-biased 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 A.4 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 A.4 in Appendix).

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.

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9 Figures and Tables

Figure 1: Location of participant villages

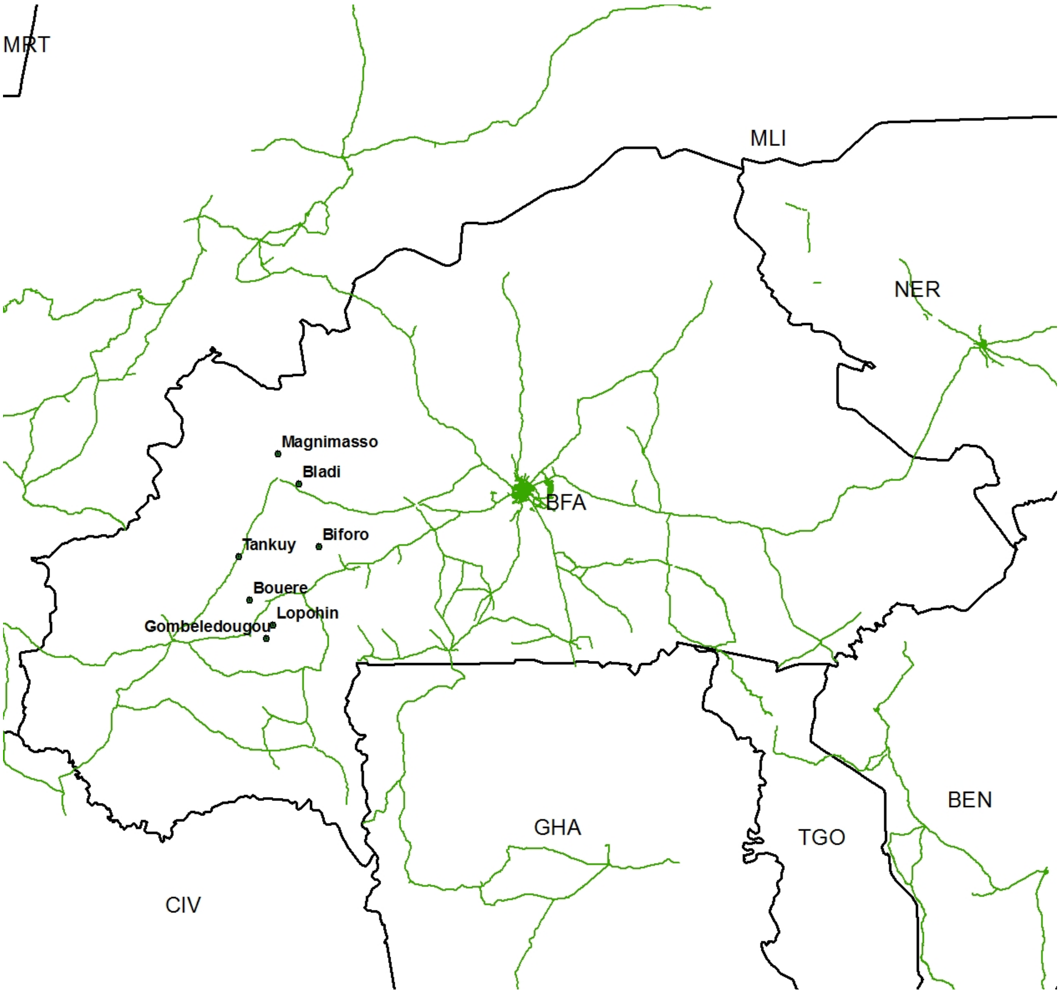

Figure 2: Agricultural Production and Warrantage Calendar in the Tuy and Mouhoun Provinces

	June	July	August	Sept	Oct	Nov	Dec	January to April	May
Grain production	Tilling	Sowing Fertilizing	Plant growing Weeding Fertilizing		Harvesting				
Cotton production	Tilling	Sowing Fertilizing	Plant growing Weeding Fertilizing			Harvesting			
Inventory Credit (or warrantage)						Storage Credit delivery			Credit repayment Collateral restitution

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

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 (%)	31.5	41.8	22.2	28.1
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

	no loan	< max.	=max.	
Participation in 2013	0%	]0%, 80%[	80%	All
Loan rate	0.00	0.43	0.8	0.60
Number of bags stored	6	19	14	14
Value of a bag	10,143	10,143	10,143	10,143
Storage costs	3,600	11,220	8,100	8,460
Loan interests	0	4,861	6,573	5,179
Total cost of warrantage	3,600	16,081	14,673	13,639
Price increase	0.03	0.03	0.03	0.03
Capital gain	1,826	5,690	4,108	4,290
Participation in 2015				
Loan rate	0.00	0.44	0.80	0.42
Number of bags stored	4	13	12	10
Value of a bag	10,857	10,857	10,857	10,857
Storage costs	2,160	7,800	7,380	6,240
Loan interests	0	3,766	6,410	2,860
Total cost of warrantage	2,160	11,566	13,790	9,100
Price increase	0.25	0.25	0.25	0.25
Capital gain	9,771	35,286	33,386	28,229

Note: This table compares the costs and returns of warrantage for maize. 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.

Table 5: 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 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: "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 8: “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 9: 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 10: 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).

A Robustness checks

Table A.1: 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 A.2: 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 A.3: 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 A.4: Robustness to income shocks

	(1)	(2)
Dep. Var	Participation	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.

B Proofs

B.1 Problem with hyperbolic 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

$$\overline{c}_3 = \underline{p}\left[(1+\Delta)(H-q_2) + \left[(\Delta - i)\theta - (1+\Delta)\sigma\right]w\right], \tag{9}$$

with probability π, and,

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

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:

$$\frac{\partial L_2}{\partial q_2} = \left(\underline{p}\right)^{1-r}[c_2]^{-r} - \frac{1}{1+\delta_1}\left(\pi\overline{p}\left[\overline{c}_3\right]^{-r} + (1-\pi)\underline{p}\left[\underline{c}_3\right]^{-r}\right) - \eta = 0, \tag{11}$$

$$\eta\left[H - q_2 - (1-\theta)w\right] = 0, \tag{12}$$

$$\eta \geq 0, \tag{13}$$

$$H - q_2 - (1-\theta)w \geq 0, \tag{14}$$

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

$$q_2^*(w,\theta) = H - (1-\theta)w. \tag{15}$$

If condition (14) is not binding, then $q_2^*(w,\theta) < H - (1-\theta)w$. In this latter case, condition (12) implies that $\eta = 0$. Hence, using condition (11) 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:

$$[c_2]^{-r} = \frac{1}{1+\delta_1}\left(\pi(1+\Delta)\left[\overline{c}_3\right]^{-r} + (1-\pi)\left[\underline{c}_3\right]^{-r}\right). \tag{16}$$

However, we can show that if the time preferences of the household are sufficiently hyperbolic, condition (14) is always binding. Indeed, $h = -\frac{1+\delta_2}{(1+\delta_1)^2} \geq -1$ and $\delta_2 \geq 0$, and then if h is large, then δ_1 has to be large too. Moreover, if δ_1 is large, condition (16) implies that c_2 is larger than $\underline{p}H$, which is impossible. We conclude that, if h is sufficiently large, then condition (14) is binding. Notice that having h sufficiently large is a sufficient (not necessary) condition for condition (14) 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:

$$\overline{c}_3(w,\theta) = \underline{p}\,[(1+\Delta)(1-\sigma) - \theta(1+i)]\, w, \tag{17}$$

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

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

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

$$\frac{\partial L_1}{\partial w} = -\frac{1-\theta}{1+\delta_1}[c_2]^{-r} + \frac{1}{1+\delta_2}\left(\pi\,[(1+\Delta)(1-\sigma) - \theta(1+i)]\left[\overline{c}_3\right]^{-r} + (1-\pi)\,[1-\sigma-\theta(1+i)]\left[\underline{c}_3\right]^{-r}\right) = 0, \tag{19}$$

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

$$\lambda\,[0.8-\theta] = 0;\ \lambda \geq 0;\ 0.8 \geq \theta, \tag{21}$$

$$\mu\theta = 0;\ \mu \geq 0;\ \theta \geq 0, \tag{22}$$

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

Using the expressions of the consumption levels and $\frac{1+\delta_2}{1+\delta_1} = -h(1+\delta_1)$, condition (19) can be rewritten as follows:

$$-h(1+\delta_1)\left[\frac{H}{w}-(1-\theta)\right]^{-r}=\left(\pi\left[(1+\Delta)(1-\sigma)-\theta(1+i)\right]^{1-r}+(1-\pi)\left[1-\sigma-\theta(1+i)\right]\right)^{1-r}, \tag{23}$$

or,

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

This condition characterizes the optimal warehouse storage level.

We then characterize the optimal loan rate. Multiplying condition (20) by $(1-\theta)$ and adding (19) times w, we find:

$$\frac{w}{1+\delta_2}\left[\pi\left[(1+\Delta)(1-\sigma)-(1+i)\right]\left[\overline{c}_3\right]^{-r}-(1-\pi)(\sigma+i)\left[\underline{c}_3\right]^{-r}\right]+\mu-\lambda=0. \tag{25}$$

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 (22), 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 (25) becomes:

$$\mu=\frac{w^{1-r}\left[\underline{p}(1-\sigma)\right]^{-r}}{1+\delta_2}\left[(1-\pi)(\sigma+i)-\pi\left[(1+\Delta)(1-\sigma)-(1+i)\right]\left[1+\Delta\right]^{-r}\right]. \tag{26}$$

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,

$$r>\frac{Ln\left[\frac{\pi}{1-\pi}\frac{(1+\Delta)(1-\sigma)-(1+i)}{\sigma+i}\right]}{Ln\left[1+\Delta\right]}. \tag{27}$$

If $\mu=0$ and $\lambda>0$, using condition (21), 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 (25) becomes:

$$\lambda=\frac{w}{1+\delta_2}\left[\pi\left[(1+\Delta)(1-\sigma)-(1+i)\right]\left[(1+\Delta)(1-\sigma)-0.8(1+i)\right]^{-r}-(1-\pi)(\sigma+i)\left[1-\sigma-0.8(1+i)\right]^{-r}\right]. \tag{28}$$

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

$$\frac{Ln\left[\frac{\pi}{1-\pi}\frac{\left[(1+\Delta)(1-\sigma)-(1+i)\right]}{(\sigma+i)}\right]}{Ln\left[\frac{(1+\Delta)(1-\sigma)-0.8(1+i)}{1-\sigma-0.8(1+i)}\right]}>r. \tag{29}$$

If $\mu=\lambda=0$, condition (25) becomes:

$$\frac{w^{1-r}\underline{p}^{-r}}{1+\delta_2}\left[\pi\left[(1+\Delta)(1-\sigma)-(1+i)\right]\left[(1+\Delta)(1-\sigma)-\theta(1+i)\right]^{-r}-(1-\pi)(\sigma+i)\left[1-\sigma-\theta(1+i)\right]^{-r}\right]=0, \tag{30}$$

or,

$$\left[\frac{\pi\left[(1+\Delta)(1-\sigma)-(1+i)\right]}{(1-\pi)(\sigma+i)}\right]^{\frac{1}{r}}=\frac{(1+\Delta)(1-\sigma)-\theta(1+i)}{1-\sigma-\theta(1+i)}, \tag{31}$$

or,

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

It remains to check that $0\leq\theta\leq 0.8$. Using (32), we find that this is equivalent to

$$\frac{Ln\left[\frac{\pi}{1-\pi}\frac{[(1+\Delta)(1-\sigma)-(1+i)]}{(\sigma+i)}\right]}{Ln\left[\frac{(1+\Delta)(1-\sigma)-0.8(1+i)}{1-\sigma-0.8(1+i)}\right]}\leq r\leq\frac{Ln\left[\frac{\pi}{1-\pi}\frac{(1+\Delta)(1-\sigma)-(1+i)}{\sigma+i}\right]}{Ln\left[1+\Delta\right]} \tag{33}$$

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.

B.2 Problem with time-consistent preferences

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

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

s.t. $q_2\leq H-(1-\theta)w$, $\theta\geq 0$ and $0.8\geq\theta$.

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 $\overline{c}_3\equiv\overline{p}(H+l-w-q_2+(1-\sigma)w)-(1+i)\underline{p}l$ 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:

$$\overline{c}_3=\underline{p}\left[(1+\Delta)(H-q_2)+\left[(\Delta-i)\theta-(1+\Delta)\sigma\right]w\right], \tag{34}$$

with probability π, and,

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

with probability $1-\pi$.

The Lagrangian of this problem is:

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

where $\widetilde{\eta}$, $\widetilde{\mu}$ and $\widetilde{\lambda}$ are the Lagrange multipliers associated with the inequality constraints $H-(1-\theta)w\geq q_2$, $\theta\geq 0$ and $0.8\geq\theta$, respectively.

The necessary conditions are given by:

$$\frac{\partial L}{\partial q_2} = [c_2]^{-r} - \frac{1}{1+\delta_1}\left(\pi(1+\Delta)\left[\overline{c}_3\right]^{-r} + (1-\pi)\left[\underline{c}_3\right]^{-r}\right) - \eta = 0, \tag{36}$$

$$\frac{\partial L}{\partial w} = \frac{1}{1+\delta_1}\left(\pi\left[(\Delta-i)\theta - (1+\Delta)\sigma\right]\left[\overline{c}_3\right]^{-r} - (1-\pi)\left[\sigma+\theta i\right]\left[\underline{c}_3\right]^{-r}\right) - (1-\theta)\eta = 0, \tag{37}$$

$$\frac{\partial L}{\partial \theta} = \frac{1}{1+\delta_1}\left(\pi\left[\Delta-i\right]\left[\overline{c}_3\right]^{-r} - (1-\pi)i\left[\underline{c}_3\right]^{-r}\right)w + w\eta + \mu - \lambda = 0, \tag{38}$$

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

$$\mu\theta = 0, \mu \geq 0, \theta \geq 0, \tag{40}$$

$$\lambda\left[0.8-\theta\right] = 0, \lambda \geq 0, 0.8-\theta \geq 0, \tag{41}$$

where $L = \underline{p}^r \widetilde{L}$, $\eta = \underline{p}^r \widetilde{\eta}$, $\mu = \underline{p}^r \widetilde{\mu}$, and $\lambda = \underline{p}^r \widetilde{\lambda}$.

The case where the farmer is time consistent and the grain constraint of Self 2 is binding corresponds to the specific case where $h = -1$ in Proposition 1 and Proposition 2. Thus, no additional proof is needed in this case. Indeed, recall that the proof of Propositions 1 and 2 is valid when the grain constraint of Self 2 is binding. Having h sufficiently large is a sufficient (not necessary) condition for this to be true.

It remains to consider the case where the grain constraint of Self 2 is not binding, i.e. $q_2 < H - (1-\theta)w$. Using condition (39), we have $\eta = 0$.
Notice that one cannot have $\mu > 0$ and $\lambda > 0$ (otherwise $\theta = 0 = 0.8$).

If $\mu > 0$ and $\lambda = 0$, we have $\theta = 0$. Condition (37) can be written as follows:

$$0 = \pi(1+\Delta)\left[\overline{c}_3\right]^{-r} + (1-\pi)\left[\underline{c}_3\right]^{-r}, \tag{42}$$

which is a contradiction. Thus, one cannot have both $\mu > 0$ and $\lambda = 0$.
If $\mu = 0$ and $\lambda > 0$, then using (41) we have $\theta = 0.8$. Thus we cannot have $\theta = 0 < w$ in this case.
If $\mu = 0$ and $\lambda = 0$, condition (38) can be rewritten as follows:

$$\left(\pi\left[\Delta-i\right]\left[\overline{c}_3\right]^{-r} - (1-\pi)i\left[\underline{c}_3\right]^{-r}\right)w = 0 \tag{43}$$

If $w > 0$, then

$$\pi\left[\Delta-i\right]\left[\overline{c}_3\right]^{-r} = (1-\pi)i\left[\underline{c}_3\right]^{-r}. \tag{44}$$

Using $\eta = 0$, condition (37) can be rewritten as follows:

$$\pi\left[(\Delta-i)\theta - (1+\Delta)\sigma\right]\left[\overline{c}_3\right]^{-r} = (1-\pi)\left[\sigma+\theta i\right]\left[\underline{c}_3\right]^{-r}. \tag{45}$$

Combining (44) and (45), we have $\frac{i}{\Delta-i} = \frac{\sigma+\theta i}{(\Delta-i)\theta-(1+\Delta)\sigma}$, or $\Delta\sigma(1+i) = 0$, which is a contradiction. Thus, one cannot have both $\mu = 0$ and $\lambda = 0$.

If $w = 0$, using $\eta = 0$ condition (36) can be written as follows:

$$[c_2]^{-r} = \frac{1}{1+\delta_1}\left(\pi(1+\Delta)\left[\overline{c}_3\right]^{-r} + (1-\pi)\left[\underline{c}_3\right]^{-r}\right). \tag{46}$$

Using the expressions of the consumption levels, condition (46) becomes

$$\left[\frac{H}{q_2} - 1\right]^r = \frac{1}{1+\delta_1}\left(\pi(1+\Delta)^{1-r} + 1 - \pi\right), \tag{47}$$

or,

$$\frac{q_2}{H} = \left[1 + \left[\frac{\pi(1+\Delta)^{1-r} + 1 - \pi}{1+\delta_1}\right]^{\frac{1}{r}}\right]^{-1}, \tag{48}$$

Using condition (48) and the expressions of the consumption values, we conclude that the value of the expected utility is given by:

$$EU^* = \frac{1}{(1+\delta_1)^2}\left[(1+\delta_1)^{\frac{1}{r}} + \left[\pi(1+\Delta)^{1-r} + 1 - \pi\right]^{\frac{1}{r}}\right]^r \frac{\left(\underline{p}H\right)^{1-r}}{1-r}. \tag{49}$$

In order to conclude, we need to exclude the possibility that the household prefers a solution such that the grain constraint is binding in period 2, with $\theta = 0$ and $w > 0$. Here again, the solution is given by replacing h by -1 in Propositions 1 and 2. The only subcase in which the optimal solution is $\theta^* = 0$ and $w^* > 0$ arises when $r > \overline{r}$. We find:

$$\frac{w^*}{H} = \frac{\left[\pi\left[(1+\Delta)(1-\sigma)\right]^{1-r} + (1-\pi)\left[1-\sigma\right]^{1-r}\right]^{\frac{1}{r}}}{\left[\pi\left[(1+\Delta)(1-\sigma)\right]^{1-r} + (1-\pi)\left[1-\sigma\right]^{1-r}\right]^{\frac{1}{r}} + \left[1+\delta_1\right]^{\frac{1}{r}}}. \tag{50}$$

Using $q_2^* = H - w^*$, we have

$$\frac{q_2^*}{H} = \frac{\left[1+\delta_1\right]^{\frac{1}{r}}}{\left[\pi\left[(1+\Delta)(1-\sigma)\right]^{1-r} + (1-\pi)\left[1-\sigma\right]^{1-r}\right]^{\frac{1}{r}} + \left[1+\delta_1\right]^{\frac{1}{r}}}. \tag{51}$$

Using the expressions of the consumption levels, $\theta^* = 0$ and $q_2^* = H - w^*$, we find

$$\overline{c}_3^* = \underline{p}(1-\sigma)(1+\Delta)\,w^*, \tag{52}$$

and,

$$\underline{c}_3^* = \underline{p}(1-\sigma)\,w^*. \tag{53}$$

Thus, the expected utility of the household is:

$$\widetilde{EU} = \frac{1}{(1+\delta_1)^2}\left[(1+\delta_1)(q_2^*/H)^{1-r} + \left[\pi(1+\Delta)^{1-r} + 1 - \pi\right](1-\sigma)^{1-r}(w^*/H)^{1-r}\right]\frac{\left(\underline{p}H\right)^{1-r}}{1-r}. \tag{54}$$

Using (50) and (51), we obtain:

$$\widetilde{EU} = \frac{1}{(1+\delta_1)^2}\left[(1+\delta_1)^{\frac{1}{r}} + \left[\pi(1+\Delta)^{1-r} + 1 - \pi\right]^{\frac{1}{r}}(1-\sigma)^{\frac{1-r}{r}}\right]^r \frac{\left(\underline{p}H\right)^{1-r}}{1-r}. \tag{55}$$

The right hand side in (55) decreases when σ increases. Moreover, when $\sigma = 0$ it is equal to the right hand side in (49). Since $\sigma > 0$, we conclude that $\widetilde{EU} < EU^*$. Thus, the household always strictly prefers not to participate rather than the solution where $\theta^* = 0$ and $w^* > 0$.

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