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Wait and Sell:
Farmers' individual preferences and crop storage in Burkina Faso

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Abstract

This paper investigates the reasons why African farmers differ in storage behavior and establishes a causal link between farmers' time and risk preferences and storage. We first provide a stylized onfarm storage model in which impatience and risk aversion interact in the storage decision process. We show that impatience decreases grain storage whereas risk aversion may increase or decrease the quantity of grain stored from the harvest season to the lean season. We then test these propositions using original data on agricultural decisions, which we have collected from 1,500 farmers in two regions of Burkina Faso, who were also asked hypothetical questions about risk aversion and time discounting. Parameterized to our data, the model predicts that stored quantities decrease with impatience and increase with risk aversion. We then turn to an econometric analysis and provide an identification strategy which tackles a sample selection issue in our data. Consistently with the model, we find a negative impact of impatience and a positive impact of risk aversion on the storage level. The effects are statistically significant and robust to various measures of time and risk preferences. This paper provides one of the first set of field evidence that links risk aversion and time discounting to observed agricultural decisions.

Key words: storage, discount rate, risk aversion, agriculture.
JEL: Q13, Q12, Q16, Q18, D03, D14.

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1 Introduction

Many developing countries experience significant seasonal price variability of food staple products (Colman, 1991; Barrett, 2007). In West-African countries, grain prices such as millet, maize and sorghum typically decline in September-December, reflecting increased supplies from ongoing harvests. For example, in rural markets in Burkina Faso where our study takes place, we observe that maize, millet, and sorghum prices decreased by 39, 33, and 38 percent respectively between August 2012 and December 2012 (Figure 1). This is close to what Aker (2008) reports for millet prices in Niger, where the average intra-seasonal price difference was 44 percent in the 2000s. Such large seasonal fluctuations in food staple prices offer substantial inter-temporal arbitrage opportunities. Yet many farmers appear not to take advantage of it as they would be expected to do through storage. As often documented in the literature, farmers often sell their output at low prices post-harvest and buy similar commodities several months later at prices that are far higher than those received post-harvest (Stephens and Barrett, 2011). This so-called "sell low, buy high puzzle" has been studied in a number of recent papers that examine the role of liquidity constraints in farmers' storage decisions. Barrett (2007) suggests that, if farmers have no other means to address temporary liquidity constraints, they might find it optimal to convert non-cash wealth in the form of grains into cash, even knowing that they will need to buy back grain later at a higher price. Stephens and Barrett (2011) moreover show that credit indeed seems to influence crop sales and purchase behaviors in the case of Kenya. Basu and Wong (2012) report results from a randomized experiment of food storage and food credit programs run in East Indonesia, which both increase economic well-being substantially. All these works are in line with the most obvious explanation of the "sell low, buy high puzzle", which is that many farmers are financially constrained and that only those who have marketable surplus and an appropriate storage technology[1] are able to take advantage of price increases. In this paper, we focus on observed heterogeneity in storage behavior among unconstrained farmers, namely those who are able to generate a marketable surplus. The fact that those farmers who face similar financial constraints and agro-ecological conditions differ in storage behavior is an additional puzzle to be solved. An assumption to be tested is that differences in agricultural decisions are also explained by individual preferences. Given financial constraints, farmers who have a stronger preference for present consumption may indeed store smaller grain quantities. This research question is directly linked to a central issue in development policies: should we provide African farmers with storage equipments? If farmers are too impatient to store, they may be reluctant to use development tools like new storage technologies.

Standard practice in inter-temporal welfare analyses is to assume that risk and time preferences are the same across farmers, when one would expect a priori that subjective time preferences differ across different individuals (Harrison, Humphrey, and Verschoor, 2010). For that reason, recent papers from the field experiment literature aimed at eliciting the value of risk aversion coefficients and discount rates for individuals.[2] More recently, a small number of studies attempted to go further

[1] Farmers in Burkina Faso store grain in traditional hand-shaped mud brick granaries or granaries made from braided straw.

[2] Harrison, Lau, and Williams (2002) elicit individual discount rates from a nationally representative sample of 268 Danish people. Using a sample of 253 Danish people as well, Andersen, Harrison, Lau, and Rutstrom (2008) make a joint elicitation of both discount rates and risk aversion coefficients, such approach providing lower estimates of discount rates compared to previous studies. Focusing on developing countries, Harrison, Humphrey, and Verschoor (2010) use data collected from risky choice experiments in Ethiopia, India and Uganda. Tanaka, Camerer, and Nguyen (2010) collect data from sample of

by assessing the extend to which individual preferences drive agricultural decisions. Ashraf, Karlan, and Yin (2006), Bauer, Chytilova, and Morduch (2012), and Dupas and Robinson (2013) have in common to show that present-bias preferences may explain individuals' choices of adopting saving or credit innovations in developing countries using data from field experiments. They construct time-inconsistency dummies from hypothetical time discounting questions that are then included in a probit model to analyze the decision to take up some innovative products. All of them conjecture from their results that time-inconsistency might be an important constraint for saving, whether at home or in a "self-help group" with microcredit purpose. In both studies, the results hold for women only.

Two additional empirical studies appear relevant to our study. Both of them elicit farmers' risk attitudes and use this measure to explain technology adoption decisions. Knight, Weir, and Woldehanna (2003) study technology adoption among Ethiopian farmers by dividing farmers into risk-averse and non-risk-averse groups depending on farmers' answer to a hypothetical question. Using a probit model where technology adoption is a dichotomous variable that equals one if a farmer has adopted at least one new agricultural input and one new crop and zero otherwise, they find that risk aversion is associated with lower probabilities of technology adoption. Liu and Huang (2013) investigate the importance of risk aversion as well. Using a Weibull model for duration of time to adoption, they show that risk aversion may affect farmers' choice of adopting genetically modified cotton in China. Related to those works, the question we aim to tackle here is whether individual preferences drive another crucial agricultural decision, which is that of storage.

We first provide a stylized onfarm storage model in which impatience and risk aversion interact in the storage decision process. As a result, we show that impatience decrease grain storage whereas risk aversion may increase or decrease the quantity of grain stored from the harvest season to the lean season. We then test the model's predictions using original data on agricultural decisions and hypothetical questions about risk aversion and time discounting, collected from 1,500 farmers in Burkina Faso. Parametrized with our data on farmers' preferences, the model predicts that stored quantities should decrease with impatience and increase with risk aversion. We then turn to an econometric analysis in order to check whether the evidence supports the theory. We provide an identification strategy which tackles a sample selection issue in our data. Consistent with the model, we find a negative impact of impatience and a positive impact of risk aversion on the storage level. The effects are statistically significant and robust to various measures of risk and time preferences. This paper presents one of the first set of field evidence that links individual preferences to observed decisions about storage and sales of grain.

Section 2 describes the theoretical model which links individual preferences and storage decisions. Section 3 describes the sample, the experimental design for eliciting individual risk aversion coefficients and discount rates, and the survey data. Section 4 explains the identification strategy for the causal relationship between storage decision and individual preferences. Section 5 displays the results and describes supporting evidence and alternative hypotheses. Section 6 concludes.

160 Vietnamese villagers and show that people living in wealthy villages are not only less risk averse but also more patient.

2 An onfarm storage model

2.1 Household optimization problem

We construct a two-period agricultural household model that allows for goods consumption smoothing between the two periods. The first period refers to the post-harvest season (subscript h) while the second period refers to the lean season (subscript l). Consider a household whose utility depends on the consumption of two goods – a quantity of grain, that we denote c^g, and a quantity of a generic good that is bought on the market, meat for example, which we denote c^m. The household harvests a quantity of grain (H) and generates some cash income from other agricultural or non-agricultural activities (B). The household can purchase and sell, at the market price, a quantity of grain denoted v^g . The price of the generic good is assumed to be constant and is normalized to one, while grain price increases from the post-harvest season ($\underline{p}$) to the lean season ($\overline{p}$). The household can save between the two seasons in the form of grain storage (s).[3] The generic good is not storable and is consumed immediately after purchase.[4]

The household purchases the generic good using the cash income derived from sales of grain as well as from other activities undertaken during both seasons, with b_h and b_l denoting cash spending at the post-harvest season and at the lean season, respectively, and $b_h + b_l \leq B$ (Equation 2). The household is moreover assumed to be credit constrained. She can borrow neither grain nor money so that s, b_h and b_l must be non-negative (Equation 3). At the harvest season, the stored quantity s, plus the sold quantity v_h^g, plus the consumed quantity c_h^g equals the harvested quantity H (Equation 4). The value of the purchased generic good must equal the value of grain sales $\underline{p}v_h^g$ plus cash spending b_h (Equation 5). At the lean season, the household allocates the quantity of stored grain s between consumption c_l^g and sales v_l^g (Equation 6). Again, the value of the purchased generic good must equal the value of grain sales $\overline{p}v_l^g$ plus cash spending b_l (Equation 7).

The household makes consumption, storage and marketing decisions each season to maximize the discounted utility. The crop season household's full optimization problem can be expressed as follows:[5]

$$\text{Maximize } U = \frac{1}{1-r}\left(\left(c_h^g\right)^{\sigma} c_h^m\right)^{1-r} + \frac{1}{1+\delta}\frac{1}{1-r}\left(\left(c_l^g\right)^{\sigma} c_l^m\right)^{1-r}, \tag{1}$$

s.t.

$$b_h + b_l \leq B \text{ (cash constraint)} \tag{2}$$

$$s \geq 0,\ b_h \geq 0,\ b_l \geq 0 \text{ (non negativity).} \tag{3}$$

$$c_h^g + v_h^g + s = H \text{ (harvest season grain balance),} \tag{4}$$

$$c_h^m = \underline{p}v_h^g + b_h \text{ (harvest season budget constraint)} \tag{5}$$

$$c_l^g + v_l^g = s \text{ (lean season grain balance)} \tag{6}$$

[3] It is commonly reported that grain may spoil due to pest or moisture. Adding a constant spoiling rate of grain is equivalent to considering a lower price increase, $\overline{p}/\underline{p}$.

[4] We may also consider that farmers store money and the generic good. However, in our context, grain storage is more profitable than money or generic good storage, i.e. $\overline{p}/\underline{p} > 1$. Since there is no uncertainty in our model, it is optimal not to store money or the generic good.

[5] See Park (2006) for a similar per-period utility function for consumption of grain and a generic good bought on the market.

$$c_l^m = \overline{p} v_l^g + b_l \text{ (lean season budget constraint)}, \tag{7}$$

Utility is assumed to be time separable with constant relative risk aversion parameter. Preferences are fully described by three parameters: $\sigma \geq 0$, which determines the relative share of grain and other consumed goods within the total expenditure ; r, which measures the relative risk aversion with respect to the consumption of the generic good; and δ, which is the discount rate. Relative risk aversion with respect to grain consumption is equal to $\sigma(r-1)+1$.[6] We assume that $r > \sigma/(1+\sigma)$, so that the utility function U is concave.

2.2 Optimal consumption, sales and storage decision

In this section, we solve the household's utility maximization problem focusing first on optimal levels of consumption and of storage. Proofs are relegated to Appendix A.

Proposition 1 [Consumption and Storage]: *At the harvest season, the optimal levels of the generic good consumption c_h^{m*} and of grain consumption c_h^{g*} are such that*[7]

$$c_h^{m*} = \underline{p}\frac{1}{1+\sigma}\left(H + \frac{B}{\underline{p}} - s^*\right) \text{ and } c_h^{g*} = \frac{\sigma}{1+\sigma}\left(H + \frac{B}{\underline{p}} - s^*\right).$$

At the lean season, the optimal levels of the generic good consumption c_l^{m*} and of grain consumption c_l^{g*} are such that

$$c_l^{m*} = \overline{p}\frac{1}{1+\sigma}s^* \text{ and } c_l^{g*} = \frac{\sigma}{1+\sigma}s^*.$$

The optimal quantity of stored grain s^* is

$$s^* = \frac{1}{1+\theta}\left(H + \frac{B}{\underline{p}}\right),$$

where $\theta = \left((1+\delta)\left(\overline{p}/\underline{p}\right)^{-(1-r)}\right)^{\frac{1}{(1+\sigma)r-\sigma}}$.

The optimal amount of cash spending in both seasons are such that

$$b_h^* = B \text{ and } b_l^* = 0.$$

The household spends all her cash income generated from non-grain activities within the post-harvest season because it is always more profitable for her to store grain than to store money, since the grain price increases between seasons.

The quantity $H + \frac{B}{\underline{p}}$ can be seen as an effective quantity of grain, part of which $\left(\frac{1}{1+\theta}\right)$ is stored at the post-harvest season and consumed at the lean season in the form of grain consumption, of grain

[6]For reasonable values of σ and r, the household is slightly more risk averse with respect to grain consumption than with respect to the consumption of the generic good. Indeed, assuming that $\sigma = 0.5$ and $r = 0.6$, we find $\sigma(r-1)+1 = 0.8 > r = 0.6$.

[7]We may relax the assumption that U is concave (i.e. $r > \sigma/(1+\sigma)$) and instead assume that U is quasi-concave. We then need to solve the household maximization problem for $r < \sigma/(1+\sigma)$. In this case, the optimal consumption level are still given by the expressions provided in Proposition 1. However, the optimal storage level becomes $s^* = 0$ if $\delta > \left(\overline{p}/\underline{p}\right)^{1-r} - 1$, $s^* = H + B/\underline{p}$ if $\delta < \left(\overline{p}/\underline{p}\right)^{1-r} - 1$, and $s^* \in \left[0, H + B/\underline{p}\right]$ if $\delta = \left(\overline{p}/\underline{p}\right)^{1-r} - 1$.

sales, and of generic good purchases. The share $\frac{1}{1+\theta}$ depends, in a non trivial way (see Propositions 3 and 4 below), on the discount rate δ, on the price ratio $\overline{p}/\underline{p}$, on the relative risk aversion parameter r, and on the grain preference parameter σ.

Note that the form chosen for the utility function in Equation 1 implies that the optimal consumption of each good is strictly positive. It also implies that the share of expenditures spent on grain, $\sigma/(1+\sigma)$, and the share of expenditures spent on the generic good, $1/(1+\sigma)$, are constant and sum to one, which contradicts Engel's law.[8] The utility function form also enables us to use explicit specification of the relative risk aversion parameter, the discount rate, and the consumption shares. Finally the utility function form implies that the share of the harvest H that is consumed by the household over the two seasons, $\left(c_h^{g*}+c_l^{g*}\right)/H$, is constant and equals $\sigma/1+\sigma$.

2.3 Cash income and sales

In order to apply our data to the model, we now have to shift our focus from the quantity of stored grain to the quantity of grain sold at the post-harvest season. In this section, we thus determine the optimal level of grain sold at the post-harvest season and we show that there is a theoretical equivalence between studying the effect of time and risk preferences on sales and studying the effect of time and risk preferences on storage.

Proposition 2 [Sales]: *At the harvest season, optimal grain sales are such that*

$$v_h^{g*}=\frac{1}{1+\sigma}\left(H+\frac{B}{\underline{p}}-s^*\right)-\frac{B}{\underline{p}},$$

and, at the lean season, they are such that

$$v_l^{g*}=\frac{1}{1+\sigma}s^*.$$

Note that, from the harvest season budget constraint (Equation 5), we have $v_h^{g*}+\frac{B}{\underline{p}}=\frac{c_h^{m*}}{\underline{p}}$, which indicates that the cash income generated from grain sales and cash income B are used together to purchase the generic good c_h^{m*}. Because all B is spent during the post-harvest season for generic good purchases ($b_h=B$), the household who wants to purchase additional generic goods to reach the optimal level c_h^{m*} has to make grain sales. There is thus a relationship between B and v_h^g, which we make explicit in Corollary 1:

Corollary 1 [Sales and Cash]: *Sales at the harvest decrease with the cash income B:*

$$\frac{\partial v_h^{g*}}{\partial B}=-\left(1-\frac{1}{1+\sigma}\frac{\theta}{1+\theta}\right)<0,$$

and, households having a small cash income B will sell rather than buy grain:

$$v_h^{g*}\geq 0\Longleftrightarrow \underline{p}\frac{\theta}{1+\sigma(1+\theta)}H\geq B.$$

[8] The elasticities of consumption with respect to $H+\frac{B}{\underline{p}}-s^*$ are constant and sum to one as well.

The intuition behind Corollary 1 is that the households with small cash income B have to sell grain at the post-harvest season if they prefer to purchase the generic good during the post-harvest season rather than storing grain to be sold at a higher price at the lean season. This result is at the heart of the identification strategy in the empirical analysis.

We then turn to the equivalence between v_h^g and s when examining the comparative static effects of some preference parameter x:

Corollary 2 [Equivalence]: *Preference parameter $x \in \{r, \delta\}$ affects sales at the harvest season and storage such that:*

$$\frac{\partial v_h^{g*}}{\partial x} = -\frac{\partial s^*}{\partial x}.$$

Corollary 2 states that the marginal effect of an increase in the preference x (either risk aversion or time preference parameters) on storage equals minus the marginal effect of an increase in the preference x on sales. This result will allow us to focus on grain sales rather than stored quantities in the empirical analysis.

2.4 Comparative static effects of time and risk preferences

In this section we determine the comparative static effects of time and risk preferences that will be estimated in the empirical analysis.

Proposition 3: [Discounting] *An increase in the discount rate, δ, always increases sales at the harvest season (then decreases grain storage):*

$$\frac{\partial v_h^{g*}}{\partial \delta} > 0.$$

Proposition 3 states that an increase in the household's discount rate always increases sales at the harvest season. Using Corollary 2, one can also conclude that an increase in the discount rate decreases grain storage, and using Proposition 1, that it increases the household's consumption of both grain and the generic good at the post-harvest season (c_h^{g*} and c_h^{m*}) whereas it decreases the household's consumption of both grain and the generic good at the lean season (c_l^{g*} and c_l^{m*}).

Proposition 4: [Risk Aversion] *Sales at the harvest season decrease with risk aversion if and only if the household is sufficiently impatient:*

$$\frac{\partial v_h^{g*}}{\partial r} < 0 \Leftrightarrow \left(\overline{p}/\underline{p}\right)^{\frac{1}{1+\sigma}} - 1 < \delta.$$

Proposition 4 states that the effect of a change in the relative risk aversion on the quantity of sold grain depends on the level of the discount rate. The intuition is as follows. If $\left(\overline{p}/\underline{p}\right)^{\frac{1}{1+\sigma}} - 1 < \delta$, i.e. if the household strongly discounts future utility and/or the price ratio is small enough, she tends to sell large quantities of grain during the post-harvest season, which means that she is likely to consume large quantities of the generic good during the post-harvest season. However, the more she is risk averse with respect to the generic good, the less she sells grain in the post-harvest season because she wants to smooth her consumption of the generic good between the two periods. In order to consume the generic good in the lean season, she has to store grain in the post-harvest season. As a result, grain sales at the post-harvest season decrease with risk aversion. Conversely, if the household does not strongly discount future utility and/or the price ratio is high enough, i.e. $\left(\overline{p}/\underline{p}\right)^{\frac{1}{1+\sigma}} - 1 \geq \delta$, she tends to store large quantities of grain. However, the more she is risk averse with respect to the generic good, the less she stores grain in the post-harvest season, again because she wants to smooth her consumption of the generic good. In order to consume more generic good in the post-harvest season, she has to sell more grain. For that reason, grain sales increase with risk aversion in that case.

This stylized model highlights that impatience is likely to decrease storage and that risk aversion is likely to increase storage among impatient farmers, and likely to decrease storage among patient farmers. The impact of risk aversion on storage behavior thus remain an empirical issue.

3 Data

In order to test the model's predictions as regards the effect of time and risk preferences on storage behavior, we use original data on agricultural decisions, collected from 1,500 farmers in two regions of Burkina Faso, who were also asked hypothetical time discounting and risk aversion questions.

3.1 Sampling

The survey design generated a representative sample of households in two administrative districts of Burkina Faso, Tuy and Mouhoun provinces. Those provinces are located in the west region of the country, which is the main maize production area. Data were collected in January 2013 in cooperation with the Confédération Paysanne du Faso (CPF), a nation-wide producer organization. A total number of 73 villages were randomly selected from the CPF list. In those villages, an average number of 20 households were selected following a door-to-door strategy in order to gather a random sample of households. With the help of the Burkinabe Agriculture Ministry, twenty investigators and two supervisors were recruited. A total number of 1,549 households were surveyed between January 21, 2013 and February 7, 2013. Surveys were conducted in Dioula language. The investigators had to interview the household head, defined as the person responsible for farming decisions. The survey included an experimental section that aimed at eliciting time and risk preferences and a household survey part that aimed at characterizing households and farming decisions.

3.2 Survey data

The household survey is a recall survey about what happen between January and February 2013. It is made of nine distinct sections: (i) socio-economic characteristics of the household and of the household's head; (ii) household's economic assets; (iii) crop production; (iv) crop sales; (v) fertilizer expenses: (vi) non agricultural activities undertaken by the household members; (vii) household's social expenses; (viii) household's loans and (ix) household's food expenses. Table 5 reports mean values for various farmer characteristics. On average, surveyed households have 13 members, 7 being working with farming activities. In almost all cases (98%), the household is headed by a man, who is 43 years old on average, has received a written education in 40% of cases and is very often (85% of cases) member of a producer organization, whatsoever CPF or another producer organization. In the Tuy and Mouhoun regions, main crops are cotton, maize, sorghum, millet and sesame. Millet and sorghum are traditionally consumed, while maize and sesame are sold as well.

Most households of the sample (73%) harvested maize during October or November while the others did it in December 2012. Maize is the most marketed grain but only one third of the sample sold maize during 2012. During the post-harvest season, i.e. between October 2012 and January 2013, 25% of households made one maize sale, 13% of them made two. Most of others did not sell maize at all. The quantity sold by those who made a unique sale over post-harvest season is one ton on average. This represents 23% of the harvest. Since the data were collected in January 2013, we do not observe the quantity of maize sold during the lean season of the studied crop season (2012-2013) but we do observe the quantity of maize sold during the lean season of previous crop season, i.e. between May 2012 and August 2012. Table 6 summarizes information on the quantity of maize sold at the post-harvest season, i.e. between October 2012 and January 2013 (v_h), and the quantity of maize sold at the previous lean season, i.e. between May 2012 and August 2012 (v_l). It appears that 67% of the households did not sell over the post-harvest season. Moreover, 52% of the households did not sell either during previous lean season, which suggests that they usually prefer to consume maize rather than to sell it. Unfortunately, data are missing on maize purchases.[9] This brings us to a sample selection problem in our data, which we deal with in Section 4.

3.3 Eliciting Risk and Time Preferences

In order to elicit households' time and risk preferences, we use an artefactual field experiment in the terminology of (Harrison and List, 2004).

3.3.1 Risk aversion

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

Low payoffs were chosen because they were in line with previous experiments of Holt and Laury (2002) and Andersen, Harrison, Lau, and Rutstrom (2008) as regards the ranges of the relative risk aversion parameter, and because they amount to approximately one day income for a non skilled worker in Burkina Faso (around 1,000 FCFA a day, i.e. 2 USD a day), which made sense to respondents. In the second experiment, farmers were asked to choose between lotteries with ten times higher payoffs. These offered payoffs were corresponding to an important amount of money, 10,000 FCFA (around 20 USD), corresponding to 10 days income for a non skilled worker or to the average price of one bag of 100 kg cereal at post-harvest season (Figure 1).

In practice, lotteries A and B were materialized by two bags of 10 marbles of different colors: green for 1000 FCFA, blue for 800 FCFA, black for 1925 FCFA and transparent for 50 FCFA. The composition

[9] In practice, it is almost impossible to collect reliable data from households who are asked to recall all crop purchases since the beginning of the year. On the contrary, it is much easier to collect data on sales, which are generally few over the period.

of the bags was revealed to the farmers but they had to choose between picking a marble in bag A or in bag B without seeing the marbles inside the bag (blind draw). As indicated in the last column of Table 1, risk neutral individuals ($r = 0$) are expected to switch from lottery A to lottery B at row 5, while 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.

In order to make our results comparable to previous studies, we assume a constant relative risk aversion (CRRA) utility function of the following form: $U(x) = x^{1-r}/(1-r)$, where x is the lottery prize and r is the parameter to be estimated and denotes the constant relative risk aversion of the individual. Expected utility is the probability weighted utility of each outcome in each row. An individual is indifferent between lottery A, with associated probability p to win a and probability $1-p$ to win b, and lottery B, with probability p to win c and probability $1-p$ to win d, if and only if his expected utilities are equal:

$$p.U(a) + (1-p).U(b) = p.U(c) + (1-p).U(d), \tag{8}$$

or,

$$p.\frac{a^{1-r}}{1-r} + (1-p).\frac{b^{1-r}}{1-r} = p.\frac{c^{1-r}}{1-r} + (1-p).\frac{d^{1-r}}{1-r} \tag{9}$$

which can be solved numerically in term of r (see last column of Table 1).

Because the lotteries were not played for actual stakes, there is concern that extreme responses are in fact non-responses. In our data, the options of never switching (always choosing lottery A) or switching at first row (always choosing lottery B) were chosen by 47% of participants in the low-payoff lottery and by 49% of participants in the high-payoff lottery. Given the sample size, one would expect a more normal distribution of the responses. We thus run a normalization procedure in order to get rid of noise in responses, by reshaping the distribution of the responses without dropping any observation. Just as in Holt and Laury (2002) and Andersen, Harrison, Lau, and Rutstrom (2008), we allow risk aversion to be a linear function of the observed households' characteristics. We consider six characteristics that we assumed unambiguously exogenous in driving risk preferences: gender, age, family size, education, village, and province. Elicited individual r coefficients are predicted values of the model, which we estimate using an interval regression, a generalization of censored regression for data where each observation represents interval data.[10] Intuitively, this amounts to estimate what would have been the response of those farmers who did not give real answers, had they played the game, given their characteristics. With this procedure, we loose some individual heterogeneity in coefficients because by construction farmers in the same village resemble each other in some extent. On the other hand, we get rid of noise that is likely to pollute the raw responses.[11] This method also has the advantage of providing an individual answer for each farmer in the sample, which is not possible when considering intervals only.

Figure 2 and Figure 3 display the distribution of the elicited risk aversion coefficients predicted from the low-payoff experiment and the high-payoff experiment respectively. Results from both experiments show that a minority of farmers exhibit a risk loving or risk neutrality behavior. Most of the

[10]Following Harrison, Lau, and Williams (2002), we refer to the constant relative risk aversion parameters that are predicted by the regression model as the elicited risk aversion coefficients. That is, some statistical analysis is needed to infer the constant relative risk aversion parameter that is implied by the raw response to the experimental instrument.

[11]The distribution of the gap between the interval midpoints that is implied by the raw response and the elicited coefficient is centered on zero (Figure 4.

farmers are risk averse, with an average of $r = 0.69$ in the low-payoff experiment and $r = 0.64$ in the high-payoff experiment (Table 2). This is in line with previous findings who suggest that farmers' risk aversion level is quite low (Binswanger and Sillers, 1983). Those average values are comparable to the ones obtained by Harrison, Humphrey, and Verschoor (2010) who used similar experiments in India, Ethiopia and Uganda.

3.3.2 Discount Rate

To our knowledge, there is no study that aims to elicit discount rates in developing countries. We thus built our time preference experiment on Harrison, Lau, and Williams (2002) and on Coller and Williams (1999), who respectively collected experimental data in Denmark and in the U.S.. However, we had to adapt the content in order to offer pay-offs that made sense to the respondents. To do so, we ran pre-tests of the experiment from a subset of farmers. We finally used two experiments to elicit farmers' time preferences, those experiments differing in the time delays offered to the respondents.

In the first experiment, farmers were invited to choose between receiving a given amount in one day time (option A) or receiving a bigger amount in five-days time (option B), and this choice has been repeated nine times, with increasing payoffs as option B. The amount of payment A (10,000 FCFA) corresponds to the average price of one bag of 100 kg of cereals at post-harvest season. Table 3 displays the experiment aiming to elicit this discount rate that we call "4 days-discount rate" hereafter. In the second experiment, farmers were invited to choose between receiving a given amount in one month-time (option A) or receiving a bigger amount in two-months time (option B), and this choice has been repeated eight times, with increasing payoffs as option B. Table 4 displays the experiment aiming to elicit this discount rate that we call "1 month-discount rate" hereafter. Again, in order to make our results comparable to other studies, we assume that farmers have additively time separable preferences with a per-period CRRA utility function of the following form: $U(x) = x^{1-r}/(1-r)$, where x is the lottery prize and r 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:

$$U(w + M_t) + \frac{1}{1+\delta}U(w) = U(w) + \frac{1}{1+\delta}U(w + M_{t+1}) \tag{10}$$

where w is his background consumption and δ accounts for the discount rate which is the parameter to be estimated. Using the CRRA per period utility and assuming no background consumption ($w = 0$), this writes:

$$\frac{M_t^{1-r}}{1-r} = \frac{1}{1+\delta}\frac{M_{t+1}^{1-r}}{1-r}, \tag{11}$$

from which we can explicitly solve for δ as a function of risk aversion r:

$$\delta = \left[\frac{M_{t+1}}{M_t}\right]^{1-r} - 1 \tag{12}$$

We take the sample mean of the elicited risk aversion coefficient ($r = 0.69$). to calculate the interval bounds. Then, as we did for the risk aversion coefficient r, we allow δ to be a linear function of exogenous covariates (gender, age, family size, education, village, and province). The elicited individual δ coefficients are predicted values of a linear model, which we estimate using an interval regression again. Figure5 displays the elicited 4 days and 1 month discount rates.

Results show that most of the farmers are rather impatient, with an average value of 120 percent per month for the 4 days-discount rate and 24 percent per month for the 1 month-discount rate (Table 2). Those results call for two comments. Firstly, even when considering the lowest mean value of δ, we fall well above previous estimates of discount rates that have been elicited for selected segments of populations in developed countries, which range between one percent and three percent per month (Harrison, Lau, and Williams, 2002). This is not particularly surprising insofar as we do not expect Danish people and Burkinabe farmers to have similar preferences. Secondly, the elicited 4-days discount rate differs a lot from the one-month discount rate[12] in a way that suggests hyperbolic preferences, the one-month discount rate being much smaller than the 4-days discount rate. Although in line with previous studies, this result is not of great interest for our analysis, which is carried out in a two-period framework.

3.4 Expected effects of impatience and risk aversion

At this stage, we are able to discuss potential impacts of time and risk preferences from Proposition 3 and Proposition 4, using the sample means of r and δ along with secondary data on σ, $\overline{p}$, and $\underline{p}$.

In order to make predictions on the effect of impatience on the quantity of grain sold at the post-harvest season, we first check our assumption that $r > \sigma/(1+\sigma)$. To do so, we use data on the share of the harvest that is consumed by the household, $\frac{\sigma}{1+\sigma}$, from the 2010/2011 Enquête Permanente Agricole (EPA) of Burkina Faso run by the Ministry of Agriculture. The average value for $\frac{\sigma}{1+\sigma}$ appears to be 0.53, which is much lower than the sample mean of r (0.81 or 0.87, depending on whether low or high payoffs were offered in the experiments). Then, according to Proposition 3, we expect that the effect of impatience on the quantity of grain sold at the harvest season is positive.

In order to make predictions on the effect of risk aversion, we need to compare the threshold $\left(\underline{p}/\overline{p}\right)^{\frac{1}{1+\sigma}}$ to the household discount factor $\left(\frac{1}{1+\delta}\right)^{\Delta T}$ where ΔT is the time interval between the harvest and the lean season (Proposition 4). To do so, we use data from the Market Information System of Burkina Faso, the SONAGESS, which collects and provides data on grain prices on several local markets throughout the country. Considering data over 2005-2012 in the regions of Tuy and Mouhoun, we observe that maize prices increase by 44% (on average) between the post-harvest season and the lean season. The average annual price ratio is then $\underline{p}/\overline{p} = 1/1.44$, where $\underline{p}$ refers to the October-January period and $\overline{p}$ refers to the May-August period. Using data on the share of the harvest that is consumed by the household from the EPA, we know that $\sigma = 1.13$, we thus have $\left(\underline{p}/\overline{p}\right)^{\frac{1}{1+\sigma}} = \left(\frac{1}{1.44}\right)^{\frac{1}{1+1.13}} \simeq 0.84$. Then, assuming a three-month interval between the post-harvest season and the lean season ($\Delta T = 3$), we have $\left(\frac{1}{1+\delta}\right)^{\Delta T} = \left(\frac{1}{1+0.24}\right)^{3} \simeq 0.52$ or $\left(\frac{1}{1+1.2}\right)^{3} \simeq 0.09$, depending on the time delay considered in the experiment. These values are unambiguously below the 0.84 threshold. Using Proposition 4, we thus conclude that the expected effect of risk aversion on the quantity of grain sold at the harvest season is negative.[13] In what follows, we provide an econometric analysis that enable us to check whether the evidence supports our theoretical results.

[12]We ran a test of the equality of the distributions and a test of equality of the means and the null hypothesis was rejected in both cases.

[13]This is all the more true that the storage costs are large. On the contrary, this prediction would be reversed if, for instance, one assumes that the price of maize doubles between the post-harvest season and the lean season and the household self-consumption falls below 40%. In such a case, we would have $(\underline{p}/\overline{p})^{\frac{1}{1+\sigma}} \leq 0.52$.

4 Identification strategy

In order to properly estimate the causal relationship between storage decision and individual preferences, we have to tackle a missing data issue. This problem is in all respects similar to the standard selection problem, where one who wants to estimate the effect of education on women's wages has to deal with a missing data issue, women who do not work having virtually a zero wage (Heckman, 1979).

4.1 Equation to be estimated

We derive the equation to be estimated from Proposition 2:

$$v_h^{g*} = \frac{1}{1+\theta}\frac{1}{1+\sigma}\left(H + \frac{B}{\underline{p}}\right) - \frac{B}{\underline{p}} \tag{13}$$

where $\theta = \left((1+\delta)\left(\overline{p}/\underline{p}\right)^{-(1-r)}\right)^{\frac{1}{(1+\sigma)r-\sigma}}$

We then use a linear approximation of v_h^{g*} in order to write the regression equation that will be estimated:

$$v_h^{g*} \simeq \beta_0 + \beta_1 r + \beta_2 \delta + \beta_3 H + \beta_4 \sigma + \beta_5 B \tag{14}$$

Our estimates will enable us to validate the comparative static results as regards the effects of r and of δ on the quantity of maize sold at the post-harvest season.[14] The objective of the econometric analysis is to recover consistent and unbiased estimates of the unknown coefficients β_1 and β_2 using our data. Our data consist of two measures of variable r (the elicited risk aversion coefficients that we infer from the experiments), two measures of variable δ (the elicited discount rates that we infer from the experiments), a measure of v_h^{g*} that is the quantity of maize sold between October 2012 and January 2013, and a measure of H that is the harvested quantity of maize in 2012. We do not directly observe cash availability B. However, we have data that are likely to provide some measurement of the cash that can be made available by the farmer: the harvested quantities of sorghum, millet, rice, groundnut and cotton, the total number of cattle and of poultry (Table 8). All other potential sources of cash like non-agricultural income remain unobserved, as well as the relative preference for grain σ. We thus write the regression model as follows:

$$v_{hi} = \mu_0 + \beta_1 r_i + \beta_2 \delta_i + \beta_3 H_i + \beta_6 X_i + \epsilon_i,$$

where v_{hi} is the quantity of maize sold by household i during the post-harvest period. This household has risk and time preferences r_i and δ_i respectively, and she harvests a quantity H_i of maize. Proxy variables for cash availability (B_i) are stored in vector X_i, and ϵ_i is an error term.

[14] There is interest in considering the regression slope coefficients because they will tell us whether the evidence is consistent with the theory, although it does not provide us with a sense of the strength of the relationship between v_h^{g*} and δ, since the conditional mean function, $E(v_h^{g*}|\delta)$, is nonlinear in δ. As pointed by Reiss and Wolak (2007), since we do not know the joint distribution of v_h^{g*} and δ, we do not know how good the linear approximation is.

4.2 Selection problem

Applying ordinary least squares (OLS) to the regression equation for the sample of available data would yield biased estimates of the βs. Indeed, a selection problem arises in that the sample consists only of households who sell maize (we observe v_{hi} only when $v_{hi} > 0$) and these households may differ in important unmeasured ways from those who do not. For example, some households may get into the sample of sellers not because they are impatient but because they need cash (see Corollary 2 in Section 2.3), which is unobservable to us. The problem is that whether or not time preference is correlated with cash availability in the overall population, these two variables will be correlated in the selected sample. Then, applying OLS to the regression model, one would underestimate the effect of δ on v_{hi} .[15]

We thus turn to a sample selection model to describe our estimation problem:

$$v_{hi} = \begin{cases} \gamma_0 + \gamma_1 r_i + \gamma_2 \delta_i + \gamma_3 H_i + \gamma_4 X_i + \eta_i & \text{if } \widetilde{V_i} > 0 \\ - & \text{if } \widetilde{V_i} \leq 0 \end{cases} \tag{15}$$

where household i sells maize only if $\widetilde{V_i}$ is positive. The selection equation for participating in the market in order to sell maize might be:

$$\widetilde{V_i} = \lambda_0 + \lambda_1 r_i + \lambda_2 \delta_i + \lambda_3 H_i + \lambda_4 Z_i + u_i \tag{16}$$

where $\widetilde{V_i}$ represents the household's utility to sell maize. Z_i includes explanatory variables that do not appear in the outcome equation. u_i is assumed to be jointly normally distributed with η_i. We do not observe $\widetilde{V_i}$ but we observe a dichotomous variable V_i that equals one if the farmer sells maize ($\widetilde{V_i} > 0$) and zero otherwise.

There are two approaches to estimating the sample selection model under the bivariate normality assumption: the two-step procedure of Heckman (1979) and the maximum likelihood estimation (MLE). In this paper we use both. Heckman estimator consists in estimating the selection equation as the usual Probit model in order to get an estimate of the inverse Mills ratio. This requires to have some instruments, which are stored in Z_i. There are two good candidates in our database: a dummy that equals one if the household's head is member of a producers' organization and zero elsewhere (a variable that we denote PO), and a dummy that equals one if the household sold some maize during previous lean season (a variable that we denote v_{lean}). All variables used in the estimations are described in Table 9.

5 Results

5.1 Estimated effects of impatience and risk aversion

Main results are presented in Table 10. Column (1) displays the results we get applying the Heckman two-step (H2S) consistent estimator to our data, while Columns (2) to (5) display the results we get applying the MLE. Comparing Column (1) and Column (2), both estimators provide very close results.

[15] The selection effect seems to appear in our data. While one would expect sellers to be more impatient than non-sellers, data indicate, on the contrary, that they are slightly more patient (see Table 7). This might due to a large number of patient households needing cash.

In the case of MLE, we report standard errors that are clustered at the village level.[16] The likelihood-ratio test (χ^2) provided at the bottom of Table 10 justifies the use of the Heckman selection model with our data.[17] In accordance, other tests reject the independence of the two equations (15 and 16) as well: we reject the hypothesis that the inverse hyperbolic tangent of ρ equals zero[18] (this estimate is reported as atanhρ in the bottom of the table), as well as the hypothesis that $\lambda = 0$, where $\lambda = \sigma\rho$ (this estimate is reported in the bottom of the table).

Overall, the results appear very stable. Risk aversion affects the quantity of maize sold during the post-harvest season at standard levels of significance, with the expected negative sign. The result hold whatever the measure used. The results indicate that a one standard deviation increase in relative risk aversion decreases the quantity of maize sold by 147 kg, which corresponds to a 11% decrease from the mean value. In the case of time preference, estimates are even more precise (most of times we can reject the null at the 1% significance level). The results indicate that a one standard deviation increase in impatience increases the quantity of maize sold by 274 kg, which corresponds to a 20% increase from the mean value.[19]

Since some households of the sample sell sorghum, the staple crop of Burkina Faso, we increase the sample size and consider the quantities of maize and of sorghum sold at the post-harvest season altogether. In order to take into account crop specificities, we include a dummy variable that takes on value one for maize transactions and zero for sorghum in the set of control variables. The results are reported in Table 13. They look similar to those we get from the maize sample.

Finally, in order to complete the discussion as regards the sample selection issue, we provide our results when we apply the ordinary least square estimator to the maize sample (Table 16). As expected, the effects are smaller compared to those we obtain with the Heckman selection model. In the case of risk aversion, the bias appears to be very large, since a one standard deviation increase in relative risk aversion translates into a 1% decrease (from the mean value) in the quantity of maize sold, while the decrease is more than ten times larger when we apply the Heckman selection procedure. In the case of time preferences, a one standard deviation increase in the discount rate increases the quantity of maize sold at the post-harvest season by 131 kg, i.e. a 10% increase only, while we estimate a 20% increase when we apply the Heckman selection procedure. These results clearly show that taking the selection issue related to unobserved cash needs into account has a large impact on our estimates.

5.2 Discussion

In this section we tackle a potential limitation of our specification. Since we include village dummies in the model used to estimate the households risk and time preferences, we cannot include dummies for villages in the sample selection model, because this would generate a problem of multicollinearity. We thus cannot take the effect of village specificities in marketing decisions into account,

[16] Since the predicted values for preferences are generated from a prior regression, we also compute standard errors using bootstrap techniques to obtain standard errors that explicitly take into account the presence of generated regressors (Pagan, 1984). Those results are provided in Table 11 and Table 12.

[17] The reported likelihood-ratio test is an equivalent test for $\rho = 0$, where ρ is the correlation between η_i and u_i, and is computationally the comparison of the joint likelihood of an independent probit model for the selection equation 16 and an OLS regression model on the observed $v_h i$ data against the Heckman model likelihood.

[18] The reported test for atanh$\rho = 0$ is equivalent to the test for $\rho = 0$.

[19] The coefficient is larger for the discount rate elicited from the one-month-delay experiment than for the discount rate elicited from the 4-day-delay experiment. This does not mean that the impact is larger for the former.

outside the effect that goes through the time and risk preferences. Omitting village fixed effects may cast doubt on the interpretation of the results, because transaction costs that are incurred to reach the market in order to sell maize may affect the quantities of maize sold at the post-harvest season. This would be an issue if, for instance, the most impatient household lived in villages that are closer to the market. In this case, we would not be able to disentangle the effect of impatience and of the distance to the market.

We believe that this is very unlikely to be the case. Firstly, there is no (economic) reason for the more impatient households to live closer to the market, and such correlation does not appear in our data. Secondly, when we substitute village dummies to risk and time preferences in the model, only two villages appear to be associated with larger quantities of maize sold at the post-harvest season.[20] Thus, we provide regression results leaving out all farmers living in those two villages (Table 14). Results remain unchanged.[21] Finally, we provide our estimates when we include communal dummies in the set of controls (Table 15). The results remain unchanged. Although communal dummies may not perfectly capture the transaction costs, these results suggest that the confounding effect hypothesis can be rejected.

6 Conclusion

Grain buffer stocks are an important consumption smoothing asset in developing countries and storage decisions vary a lot across households from a given region. Most studies show that many farmers who are expected to store often choose to sell their grain instead because they need cash. We have gone further by examining the role of individual preferences in storage decisions. Taking into account the fact that most farmers who choose to sell grain in the post-harvest season are liquidity constrained, we have provided evidence that impatience and risk aversion affect the quantity of grain sold. To do so, we have developed a dynamic model of household grain management that explicitly takes into account the household preference for risk, for time, and also for grain with respect to other goods. We have shown that impatience decreases grain storage whereas risk aversion may increase or decrease the quantity of grain stored, depending on the level of impatience. Parameterized to our data, the model has predicted that stored quantities decrease with impatience and increase with risk aversion. We have then tested these propositions using original data on agricultural decisions, which we have collected from 1,500 farmers in two regions of Burkina Faso, who were also asked hypothetical questions about risk aversion and time discounting. We have found a statistically significant impact of risk and time preferences on storage behavior. Overall, the results are very stable. Both time and risk preference affect storage decision at standard levels of significance, with the expected sign. Results are robust to various measures of risk and time preferences.

This paper contributes to the field experiment literature that aimed at eliciting the value of risk aversion coefficients and discount rates for individuals in developing countries. Although the potential gains from doing economic research using field experiments is high, it is often quite difficult to implement such methods in developing countries. For practical reasons, we chose to ask hypo-

[20]Regression results are available from authors upon request.

[21]Our interpretation of these results is that the transactions costs that are incurred to reach the market in order to sell maize are fixed costs rather than variable costs. This may be the reason why we fail to detect a significant link between villages dummies in the outcome equation, while most of village dummies have a significant effect in the selection equation.

thetical questions to a large number of farmers rather than to present lotteries that would had been played-out for real money to a small number of participants. Although some statistical analysis has been needed to infer the risk aversion coefficients and the discount rates that were implied by the raw responses, we have been able to elicit parameters whose value is actually very close to what can be found in the field experiment literature. Moreover, we have been able to link these data to observed agricultural decisions, which reinforces our belief that our survey measures brought relevant information on individual preferences (see Vieider et al. (2013) for further discussion).

This paper has provided, foremost, evidence that individual preferences may strongly affect the effectiveness of development programs that support warehouse receipt initiatives. Warehouse Receipt Systems (WRS) that are developing in Africa are designed to provide a reliable source of credit for farmers who are allowed to use their grain as collateral for a loan. A key outstanding question is whether farmers who are able to generate a marketable surplus will participate in WRS or not. Obviously these systems are likely to be of great interest for farmers under liquidity constraint. We have found evidence that it will be all the more true if borrowers are moreover patient people.

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Tables and Figures

Table 1: The paired lottery-choice decisions with low payoffs

	lottery A				lottery B					
	p	gain a	$1-p$	gain b	p	gain c	$1-p$	gain d	range of r	
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 2: Elicited risk and time preferences (whole sample)

	Obs	Mean	Std. Dev.	Min	Max
r (low payoffs)	1524	0.69	0.63	-3.21	3.25
r (high payoffs)	1524	0.64	0.73	-3.06	4.14
δ (1 month)	1524	0.24	0.25	-0.60	1.03
δ (4 days)	1524	1.20	1.25	-1.00	9.44

Table 3: “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 4: “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 5: Sample characteristics

Characteristics	Unit	Obs	Mean	Std. Dev.	Min	Max
Family size	number	1549	12.69	8.83	1	70
Labor force	number	1549	7.10	5.38	1	48
Sex	yes=man	1549	0.98	0.13	0	1
Age	years	1548	42.88	12.66	14	90
Education	yes=1	1549	0.39	0.49	0	1
Producer organization	yes=1	1549	0.85	0.35	0	1
Cattle (none)	yes=1	1549	0.21	0.41	0	1
Cattle (more than 10)	yes=1	1549	0.62	0.48	0	1
Cattle (less than 10)	yes=1	1549	0.17	0.37	0	1
Plow	number	1549	2.01	1.73	0	18
Poultry	number	1549	21.33	27.13	0	300
Cultivated areas						
Cotton	ha	1549	3.95	4.61	0	45
Maize	ha	1549	2.06	3.28	0	35
Sorghum	ha	1549	1.84	2.20	0	30
Millet	ha	1549	0.89	1.55	0	25
Sesam	ha	1549	0.50	1.07	0	12
Groundnut	ha	1549	0.29	0.48	0	5.5
Rice	ha	1549	0.13	0.43	0	8
Production levels						
Cotton	ton	1543	4.45	10.87	0	272160
Maize	ton	1544	3.63	7.10	0	97500
Sorghum	ton	1546	1.34	1.95	0	26520
Millet	ton	1547	0.54	1.00	0	14400
Sesam	ton	1540	0.11	0.26	0	3948
Groundnut	ton	1535	0.19	0.41	0	5232
Rice	ton	1544	0.19	0.76	0	17280
Maize marketing						
Sales (post-harv)	yes=1	1549	0.34	0.47	0	1
Sales (lean)	yes=1	1549	0.31	0.46	0	1
Quantity sold (post-harv)	kg	521	1442.94	2084.94	16.3	19200
Quantity sold (lean)	kg	245	2410.61	4450.73	24	43875

Table 6: Maize sales over the two periods

	current $v_h = 0$	current $v_h > 0$	total
previous $v_l = 0$	796	257	1053
previous $v_l > 0$	230	241	471
total	1026	498	1524

Note: Previous v_l refers to maize sales that occur between January 2012 and September 2012. Current v_h refers to maize sales that occur between October 2012 and January 2013.

Table 7: Elicited risk and time preferences by groups

Non-sellers ($v_h <= 0$)	Obs	Mean	Std. Dev.	Min	Max
r low payoffs	1012	0.61	0.63	-3.18	3.25
r high payoffs	1012	0.55	0.73	-3.00	4.14
δ (1 month)	1012	0.28	0.24	-0.60	1.03
δ (4 days)	1010	1.41	1.29	-0.85	8.57
Sellers ($v_h > 0$)					
r low payoffs	489	0.87	0.61	-3.21	3.22
r high payoffs	489	0.81	0.71	-3.06	3.95
δ (1 month)	489	0.15	0.23	-0.60	0.99
δ (4 days)	487	0.82	0.94	-0.81	5.43

Table 8: Farmers' characteristics by groups

Characteristics	Unit	Non-sellers ($v_h <= 0$) Obs	Mean	Std. Dev.	Sellers ($v_h > 0$) Obs	Mean	Std. Dev.
Family size	number	1028	12.39	8.58	521	13.26	9.28
Labor force	number	1028	6.65	5.12	521	7.98	5.76
Sex	yes=man	1028	0.98	0.14	521	0.98	0.12
Age	years	1028	43.39	12.86	520	41.85	12.20
Education	yes=1	1028	0.34	0.47	521	0.49	0.50
Producer organization	yes=1	1028	0.81	0.39	521	0.93	0.25
Cattle (none)	yes=1	1028	0.24	0.43	521	0.14	0.35
Cattle (more than 10)	yes=1	1028	0.59	0.49	521	0.69	0.46
Cattle (less than 10)	yes=1	1028	0.16	0.37	521	0.17	0.38
Plow	number	1028	1.82	1.67	521	2.40	1.78
Poultry	number	1028	19.18	23.69	521	25.56	32.48
Cultivated areas							
Cotton	ha	1028	3.21	4.13	521	5.41	5.13
Maize	ha	1028	1.24	2.37	521	3.68	4.13
Sorghum	ha	1028	2.20	2.32	521	1.13	1.74
Millet	ha	1028	1.13	1.71	521	0.42	1.02
Sesam	ha	1028	0.51	1.13	521	0.47	0.95
Groundnut	ha	1028	0.25	0.43	521	0.36	0.56
Rice	ha	1028	0.09	0.28	521	0.23	0.63
Production levels							
Cotton	ton	1022	3.82	10.72	521	5.69	11.05
Maize	ton	1025	2.08	5.60	519	6.68	8.61
Sorghum	ton	1028	1.59	2.13	518	0.84	1.41
Millet	ton	1026	0.68	1.11	521	0.27	0.68
Sesam	ton	1024	0.11	0.28	516	0.10	0.22
Groundnut	ton	1020	0.15	0.31	515	0.26	0.56
Rice	ton	1027	0.11	0.44	517	0.35	1.14
Maize marketing							
Sales (post-harv)	yes=1	1028	0.00	0.00	521	1.00	0.00
Sales (lean)	yes=1	1028	0.22	0.42	521	0.47	0.50
Quantity sold (post-harv)	kg	0	.	.	521	1442.94	2084.94
Quantity sold (lean)	kg	230	3141.35	7934.83	245	2410.61	4450.73

Table 9: Description of variables of the model

Label	Unit	Description
risk aversion (r)	none	risk aversion coefficient
discount rate (δ)	none	discount rate
maize harvest (H)	tons	maize harvest
cattle>= 10	dummy	equals one if the farmer has more than 10 oxen (none is the reference)
cattle< 10	dummy	equals one if the farmer has less than 10 oxen (none is the reference)
poultry	number	chickens, turkeys, ducks, and geese
sorgho harvest	tons	quantity of sorgho harvested in 2012
millet harvest	tons	quantity of millet harvested in 2012
gnut harvest	tons	quantity of groundnut harvested in 2012
rice harvest	tons	quantity of rice harvested in 2012
cotton harvest	tons	quantity of cotton harvested in 2012
PO	dummy	equals one if the farmer is member of a producer organization
v_{lean}	dummy	equals one if the farmer sold maize during previous lean season
maize	dummy	equals one if the farmer sold maize and zero if sorgho

Table 10: Heckman two-step and ML estimates (maize sample)

	(1)		(2)		(3)		(4)		(5)	
Outcome Eq.	H2S		MLE		MLE		MLE		MLE	
risk aversion (r)	-238.06	*	-250.99	*	-201.72	*	-311.16	**	-238.50	*
	140.63		*141.80*		*121.25*		*146.87*		*125.53*	
discount rate (δ)	1183.69	***	1163.38	**	1191.02	**	2817.06	***	2748.23	***
	398.55		*459.59*		*484.68*		*981.09*		*1047.95*	
maize harvest (H)	102.33	***	119.30	***	117.76	***	117.84	***	115.58	***
	14.58		*31.40*		*31.30*		*30.82*		*30.82*	
Select. Eq.										
risk aversion (r)	0.29	***	0.29	***	0.25	***	0.34	***	0.28	***
	0.06		*0.11*		*0.09*		*0.12*		*0.10*	
discount rate (δ)	-0.87	***	-0.83	**	-0.87	**	-2.47	***	-2.41	***
	0.16		*0.39*		*0.39*		*0.78*		*0.80*	
maize harvest (H)	0.03	***	0.06	**	0.06	**	0.06	***	0.06	***
	0.01		*0.02*		*0.02*		*0.02*		0.02	
PO	0.54	***	0.45	***	0.45	***	0.45	**	0.45	**
	0.12		*0.17*		*0.17*		*0.18*		*0.18*	
v_{lean}	0.31	***	0.18	°	0.18	°	0.18	°	0.19	°
	0.08		*0.12*		*0.12*		*0.12*		*0.12*	
λ	-1254.72	***								
	452.60									
atanhρ			-0.94	***	-0.93	**	-0.94	***	-0.94	**
			0.36		*0.37*		*0.36*		*0.37*	
χ_2			6.69	***	6.43	**	6.71	***	6.48	**
Nb. obs.	1501		1501		1501		1501		1501	
Censored	1012		1012		1012		1012		1012	
Uncensored	489		489		489		489		489	
Payoffs	low		low		high		low		high	
Time delay	1 month		1 month		1 month		4 days		4 days	

Note: Standard errors are in italics. Three asterisks *** (resp. **, *, °) denote rejection of the null hypothesis at the 1% (resp. 5%, 10%, 15%) significance level. Both equations also includes the harvested quantities of sorghum, millet, rice, groundnut, rice, and cotton, the total number of cattle and of poultry. Standard errors are clustered at village level. λ, atanhρ, and χ_2 are statistics of three tests of the null hypothesis $\rho = 0$, where ρ is the correltation between the error terms of the two equations.

Table 11: Heckman two-step estimates with bootstrapped standard-errors

Outc. Eq.	(1)		(2)		(3)		(4)	
risk aversion (r)	-238.06		-194.18		-296.09	°	-223.49	°
	187.67		*139.80*		*205.47*		*155.13*	
discount rate (δ)	1183.69	**	1216.60	**	2760.67	**	2657.73	*
	522.01		*505.36*		*1475.38*		*1458.16*	
maize harvest (H)	102.33	***	100.80	**	101.74	**	99.96	**
	39.39		*39.57*		*40.53*		*40.32*	
Select. Eq.								
risk aversion (r)	0.29	**	0.26	**	0.34	***	0.28	**
	0.13		*0.11*		*0.13*		*0.12*	
discount rate (δ)	-0.87	**	-0.92	**	-2.55	***	-2.52	***
	0.42		*0.41*		*0.98*		*0.96*	
maize harvest (H)	0.03	**	0.04	**	0.04	**	0.04	**
	0.02		*0.02*		*0.02*		*0.02*	
PO	0.54	***	0.54	***	0.54	***	0.54	***
	0.16		*0.16*		*0.17*		*0.17*	
v_{lean}	0.31	***	0.32	***	0.32	***	0.33	***
	0.12		*0.12*		*0.12*		*0.12*	
Nb. obs.	1501		1501		1501		1501	
Censored	1012		1012		1012		1012	
Uncensored	489		489		489		489	
Payoffs	low		high		high		low	
Time delay	1 month		1 month		4 days		4 days	

Note: Standard errors are in italics. Three asterisks *** (resp. **, *, °) denote rejection of the null hypothesis at the 1% (resp. 5%, 10%, 15%) significance level. Both equations also includes the harvested quantities of sorghum, millet, rice, groundnut, rice, and cotton, the total number of cattle and of poultry. Standard errors are bootstrapped and clustered at village level. λ, atanhρ, and χ_2 are statistics of three tests of the null hypothesis $\rho = 0$, where ρ is the correltation between the error terms of the two equations.

Table 12: ML estimates with bootstrapped standard-errors

Outc. Eq.	(1)		(2)		(3)		(4)	
risk aversion (r)	-250.99		-201.72		-311.16		-238.50	
	223.27		*163.48*		*254.72*		*186.97*	
discount rate (δ)	1163.38	*	1191.02	**	2817.06	°	2748.23	*
	670.26		*597.78*		*1939.46*		*1758.93*	
maize harvest (H)	119.30	***	117.76	***	117.84	***	115.58	***
	34.48		*34.11*		*34.00*		*33.96*	
Select. Eq.								
risk aversion (r)	0.29	**	0.25	**	0.34	***	0.28	**
	0.12		*0.11*		*0.13*		*0.12*	
discount rate (δ)	-0.83	**	-0.87	**	-2.47	***	-2.41	**
	0.42		*0.41*		*0.95*		*0.94*	
maize harvest (H)	0.06	**	0.06	**	0.06	**	0.06	**
	0.02		*0.02*		*0.02*		*0.02*	
PO	0.45	**	0.45	**	0.45	**	0.45	**
	0.18		*0.18*		*0.19*		*0.19*	
v_{lean}	0.18		0.18	°	0.18	°	0.19	°
	0.12		*0.12*		*0.12*		*0.12*	
Nb. obs.	1501		1501		1501		1501	
Censored	1012		1012		1012		1012	
Uncensored	489		489		489		489	
Payoffs	low		high		low		high	
Time delay	1 month		1 month		4 days		4 days	

Note: Standard errors are in italics. Three asterisks *** (resp. **, *, °) denote rejection of the null hypothesis at the 1% (resp. 5%, 10%, 15%) significance level. Both equations also includes the harvested quantities of sorghum, millet, rice, groundnut, rice, and cotton, the total number of cattle and of poultry. Standard errors are bootstrapped and clustered at village level.

Table 13: Heckman two-step and ML estimates (maize and sorgho sample)

	(1)		(2)		(3)		(4)		(5)	
Outcome Eq.	H2S		MLE		MLE		MLE		MLE	
risk aversion (r)	-83.99		-157.06	*	-133.53	*	-174.75	**	-136.78	*
	101.69		94.01		82.27		83.80		72.60	
discount rate (δ)	506.16	*	694.07	**	712.00	**	1521.81	***	1480.80	***
	285.81		274.74		288.19		512.96		535.02	
maize harvest (H)	117.06	***	114.64	***	113.61	***	112.76	***	111.41	***
	10.57		26.24		26.07		25.78		25.69	
sorgho harvest	52.67	°	61.79		60.45		62.56		62.42	
	35.99		52.91		51.61		53.30		51.85	
maize dummy	436.20	°	120.77		131.52		112.85		119.76	
	287.41		217.42		217.19		219.67		219.72	
Select. Eq.										
risk aversion (r)	0.21	***	0.21	***	0.18	***	0.23	***	0.19	***
	0.04		0.07		0.06		0.06		0.05	
discount rate (δ)	-0.54	***	-0.53	*	-0.57	*	-1.50	***	-1.48	***
	0.12		0.29		0.30		0.55		0.55	
maize harvest (H)	0.02	***	0.02	***	0.02	***	0.02	***	0.02	***
	0.00		0.01		0.01		0.01		0.01	
sorgho harvest	0.00		0.00		0.00		0.00		0.00	
	0.02		0.02		0.02		0.02		0.02	
maize dummy	0.61	***	0.62	***	0.62		0.62	***	0.62	***
	0.06		0.16		0.16		0.17		0.16	
PO	0.11		0.11		0.11		0.10		0.10	
	0.08		0.11		0.11		0.12		0.12	
v_{lean}	0.31	***	0.28	***	0.29	***	0.28	***	0.29	***
	0.06		0.09		0.09		0.09		0.09	
	0.10		0.17		0.17		0.17		0.17	
λ	-111.20									
	488.58									
atanhρ			-0.53	**	-0.51	**	-0.53	**	-0.52	**
			0.24		0.24		0.23		0.24	
χ_2			4.96	**	4.6	**	5.16	**	4.82	**
Nb. obs.	3001		3001		3001		3001		3001	
Censored	2310		2310		2310		2310		2310	
Uncensored	691		691		691		691		691	
Payoffs	low		low		high		low		high	
Time delay	1 month		1 month		1 month		4 days		4 days	

Note: Standard errors are in italics. Three asterisks *** (resp. **, *, °) denote rejection of the null hypothesis at the 1% (resp. 5%, 10%, 15%) significance level. Both equations also includes the harvested quantities of sorghum, millet, rice, groundnut, rice, and cotton, the total number of cattle and of poultry. Standard errors are clustered at village level. λ, atanhρ, and χ_2 are statistics of three tests of the null hypothesis $\rho = 0$, where ρ is the correltation between the error terms of the two equations.

Table 14: Heckman two-step and ML estimates (maize sample - two villages dropped)

	(1)		(2)		(3)		(4)		(5)	
Outcome Eq.	H2S		MLE		MLE		MLE		MLE	
risk aversion (r)	-198.45	*	-199.13	*	-140.80	°	-257.26	**	-175.40	*
	122.21		*106.17*		*89.14*		*108.34*		*90.73*	
discount rate (δ)	879.85	**	849.73	***	859.94	***	2261.66	***	2158.68	***
	348.55		*259.77*		*275.01*		*606.42*		*675.03*	
maize harvest (H)	94.53	***	104.62	***	103.17	***	103.66	***	101.54	***
	12.79		*23.71*		*23.83*		*23.14*		*23.39*	
Select. Eq.										
risk aversion (r)	0.29	***	0.29	***	0.26	***	0.35	***	0.28	***
	0.06		*0.10*		*0.09*		*0.12*		*0.10*	
discount rate (δ)	-0.88	***	-0.87	**	-0.91	**	-2.51	***	-2.46	***
	0.16		*0.39*		*0.39*		*0.79*		*0.81*	
maize harvest (H)	0.03	***	0.05	***	0.05	***	0.05	***	0.05	***
	0.01		*0.02*		*0.02*		*0.02*		*0.02*	
PO	0.53	***	0.48	***	0.49	***	0.48	***	0.48	***
	0.12		*0.16*		*0.16*		*0.16*		*0.16*	
v_{lean}	0.32	***	0.21	*	0.21	*	0.21	*	0.22	*
	0.09		*0.11*		*0.11*		*0.12*		*0.12*	
	0.14		*0.19*		*0.18*		*0.19*		*0.18*	
λ	-949.48	**								
	397.37									
atanhρ			-0.75	***	-0.74	***	-0.74	***	-0.74	***
			0.18		*0.18*		*0.18*		*0.18*	
χ_2			17.42	***	17.42	***	17.29	***	16.80	***
Nb.obs.	1482		1482		1482		1482		1482	
Censored	1005		1005		1005		1005		1005	
Uncensored	477		477		477		477		477	
Payoffs	low		low		high		low		high	
Time delay	1 month		1 month		1 month		4 days		4 days	

Note: Standard errors are in italics. Three asterisks *** (resp. **, *, °) denote rejection of the null hypothesis at the 1% (resp. 5%, 10%, 15%) significance level. Both equations also includes the harvested quantities of sorghum, millet, rice, groundnut, rice, and cotton, the total number of cattle and of poultry. Standard errors are clustered at village level. λ, atanhρ, and χ_2 are statistics of three tests of the null hypothesis $\rho = 0$, where ρ is the correltation between the error terms of the two equations.

Table 15: Heckman two-step and ML estimates (maize sample - communal dummies)

	(1)		(2)		(3)		(4)		(5)	
Outcome Eq.	H2S		MLE		MLE		MLE		MLE	
risk aversion (r)	-155.48		-172.40		-124.75		-229.01	*	-158.11	*
	138.36		*121.50*		*90.33*		*126.68*		*86.58*	
discount rate (δ)	917.50	***	884.68	***	870.23	***	2342.30	***	2223.41	***
	348.25		*296.20*		*306.25*		*638.37*		*670.00*	
maize harvest (H)	115.79	***	120.36	***	119.27	***	120.30	***	119.02	***
	12.41		*32.21*		*32.51*		*31.79*		*32.23*	
Select. Eq.										
risk aversion (r)	0.08		0.07		0.07		0.17	**	0.15	**
	0.07		*0.10*		*0.07*		*0.08*		*0.06*	
discount rate (δ)	-0.08		-0.05		-0.07		-1.57	***	-1.53	***
	0.20	***	*0.24*		*0.25*		*0.46*		*0.43*	
maize harvest (H)	0.02		0.04	*	0.04	*	0.03	**	0.03	*
	0.01		*0.02*		*0.02*		*0.02*		*0.02*	
PO	0.65		0.59	***	0.59	***	0.59	***	0.59	***
	0.13		*0.22*		*0.22*		*0.22*		*0.22*	
$v_{\text{lean}} > 0$	0.07		0.00		0.00		0.01		0.01	
	0.09		*0.10*		*0.10*		*0.10*		*0.10*	
λ	-537.67									
	608.28									
atanhρ			-0.68	*	-0.67	**	-0.65	*	-0.65	*
			0.39		*0.39*		*0.36*		*0.36*	
χ_2			3.02	*	3.00	*	3.28	*	3.27	*
Nb. obs.	1501		1501		1501		1501		1501	
Censored	1012		1012		1012		1012		1012	
Uncensored	489		489		489		489		489	
Payoffs	low		low		high		low		high	
Time delay	1 month		1 month		1 month		4 days		4 days	

Note: Standard errors are in italics. Three asterisks *** (resp. **, *, °) denote rejection of the null hypothesis at the 1% (resp. 5%, 10%, 15%) significance level. Both equations also includes the harvested quantities of sorghum, millet, rice, groundnut, rice, and cotton, the total number of cattle and of poultry and communal dummies. Standard errors are clustered at village level. λ, atanhρ, and χ_2 are statistics of three tests of the null hypothesis $\rho = 0$, where ρ is the correltation between the error terms of the two equations.

Table 16: OLS estimates (maize sample)

	(1)		(2)		(3)		(4)	
Outcome Eq.	OLS		OLS		OLS		OLS	
risk aversion (r)	-43.27		-19.03		-72.77		-34.76	
	88.81		*67.45*		*105.41*		*72.83*	
discount rate (δ)	574.99	*	570.44	*	1091.81	*	1037.93	*
	293.90		297.20		581.56		566.03	
maize harvest (H)	126	****	125	***	125	***	124	***
	27.6		28.0		27.5		28.1	
sorghum harvest	8.31		9.81		9.78		12.2	
	72.9		70.6		73.8		71.0	
millet harvest	-159	*	-158	*	-143	°	-140	°
	90.8		91.1		86.2		86.5	
rice harvest	12.3		12.0		6.74		6.48	
	163		162		162		162	
cotton harvest	-12.2	*	-12.2	*	-12.9	*	56.8	
	7.15		7.17		7.60		211	
gnut harvest	54.2		55.3		55.0		-12.9	*
	212		212		210		7.64	
cattle (<10)	415.15	***	413.35	***	394.24	**	390.74	***
	138.56		137.27		136.61		134.25	
cattle (>10)	169.19		168.42		157.20		154.68	
	272.45		272.45		273.65		272.20	
poultry	7.57	*	7.58	*	7.57	*	7.57	*
	4.13		4.11		4.11		4.10	
cons	33.82		14.88		101.06		74.19	
	149.41		133.92		135.35		114.15	
Nb. obs.	489		489		489		489	
Payoffs	low		high		high		low	
Time delay	1 month		1 month		4 days		4 days	

Note: Standard errors are in italics. Three asterisks *** (resp. **, *, °) denote rejection of the null hypothesis at the 1% (resp. 5%, 10%, 15%) significance level. Both equations also includes the harvested quantities of sorghum, millet, rice, groundnut, rice, and cotton, the total number of cattle and of poultry. Standard errors are clustered at village level.

Figure 1: Wholesale price of cereals in Mouhoun (FCFA/100 kg - Source: SONAGESS)

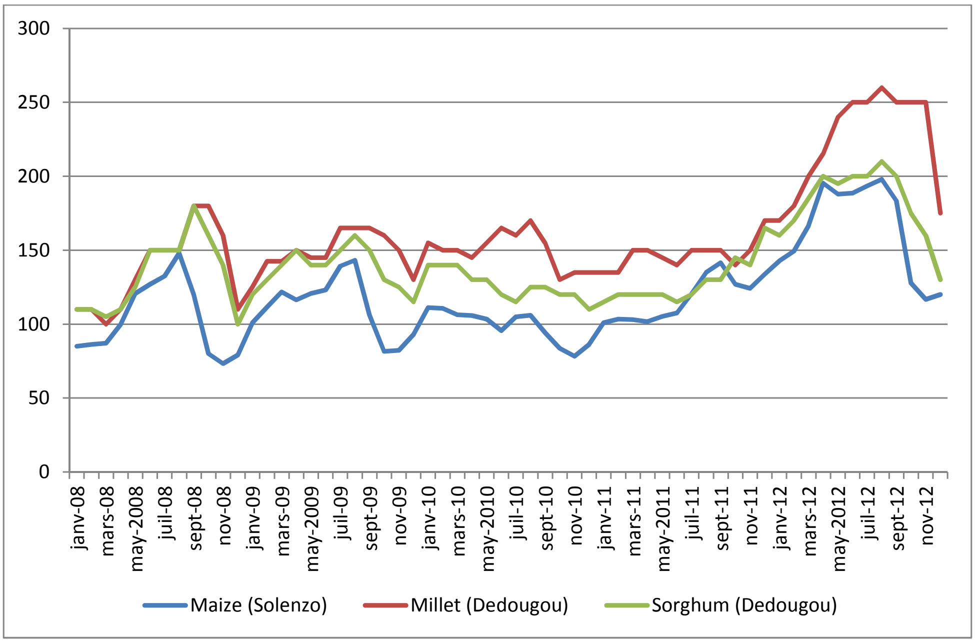


Figure 2: Elicited risk aversion coefficients (low payoffs)

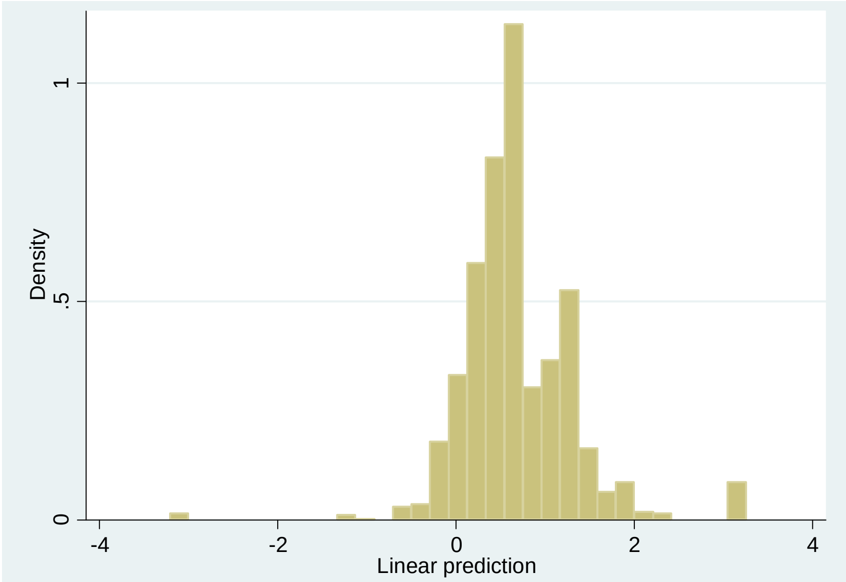


Figure 3: Elicited risk aversion coefficients (high payoffs)

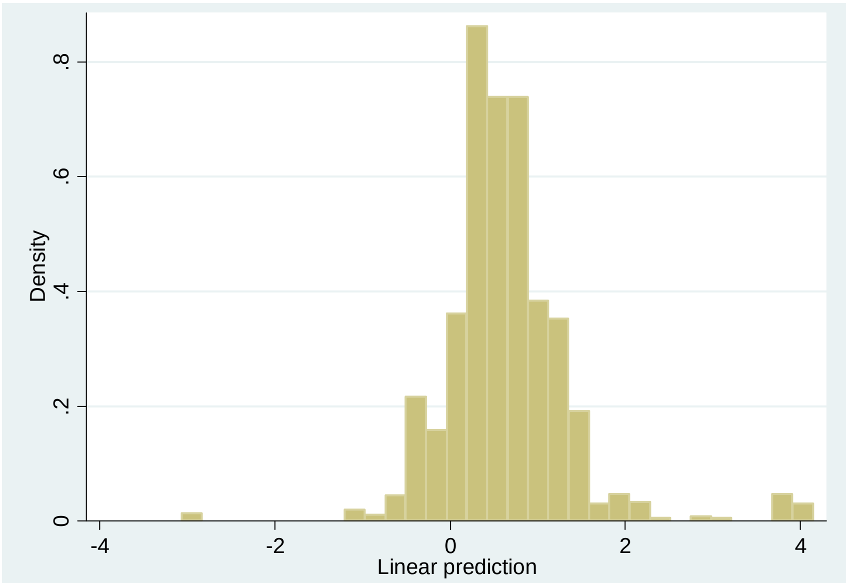


Figure 4: Gap between the interval midpoints and the elicited risk aversion coefficients (low payoffs)

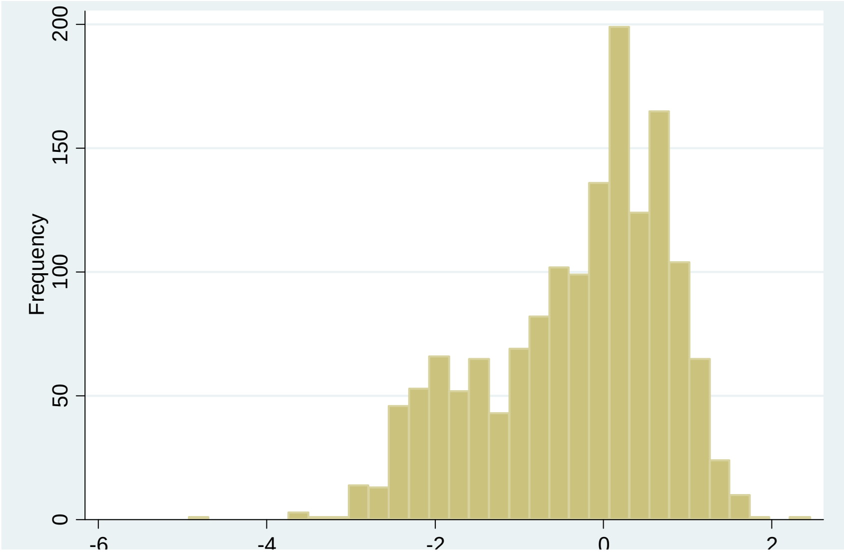
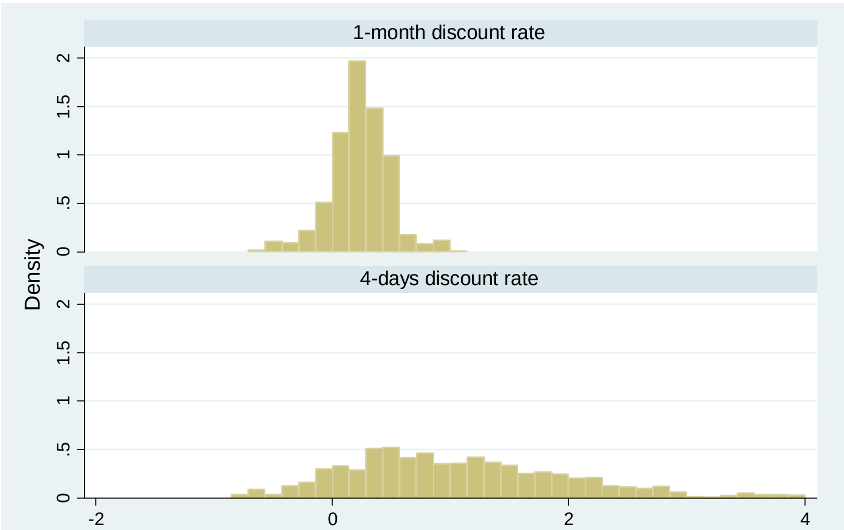


Figure 5: Comparison of elicited discount rates (δ)



Appendix A: Proofs

Proof of Proposition 1 and 2: Notice that the cash constraint is necessarily saturated, i.e. $b_h + b_l = B$. Using this condition and conditions (5) and (7) and substituting c_h^m, c_l^m and b_l, the optimization problem (1) can be solved by considering the following simplified optimization problem (we will check that the ignored non negativity constraint hold):

$$\underset{\{c_h^g, v_h^g, c_l^g, v_l^g\}}{\text{Maximize}}\ U = \frac{1}{1-r}\left(\left(c_h^g\right)^{\sigma}\left(\underline{p}v_h^g + b_h\right)\right)^{1-r} + \frac{1}{1+\delta}\frac{1}{1-r}\left(\left(c_l^g\right)^{\sigma}\left(\overline{p}v_l^g + B - b_h\right)\right)^{1-r}, \tag{17}$$

such that:

$$c_h^g + v_h^g + c_l^g + v_l^g = H, \tag{18}$$

and,

$$b_h \leq B. \tag{19}$$

Let the Lagrange multipliers associated with the constraints (18) and (19) be λ and μ. The Lagrangian is given by

$$L = U + \lambda\left[H - c_h^g - v_h^g - c_l^g - v_l^g\right] + \mu\left(B - b_h\right), \tag{20}$$

such that $\lambda \geq 0$, $\mu \geq 0$, $\lambda\left[H - c_h^g - v_h^g - c_l^g - v_l^g\right] \geq 0$ and $\mu\left(B - b_h\right) \geq 0$.

The first order conditions include:

$$\frac{\partial L}{\partial c_h^g} = \sigma\left(c_h^g\right)^{\sigma(1-r)-1}\left(\underline{p}v_h^g + b_h\right)^{1-r} - \lambda = 0, \tag{21}$$

$$\frac{\partial L}{\partial v_h^g} = \underline{p}\left(c_h^g\right)^{\sigma(1-r)}\left(\underline{p}v_h^g + b_h\right)^{-r} - \lambda = 0, \tag{22}$$

$$\frac{\partial L}{\partial c_l^g} = \frac{\sigma}{1+\delta}\left(c_l^g\right)^{\sigma(1-r)-1}\left(\overline{p}v_l^g + B - b_h\right)^{1-r} - \lambda = 0, \tag{23}$$

$$\frac{\partial L}{\partial v_l^g} = \frac{1}{1+\delta}\overline{p}\left(c_l^g\right)^{\sigma(1-r)}\left(\overline{p}v_l^g + B - b_h\right)^{-r} - \lambda = 0, \tag{24}$$

$$\frac{\partial L}{\partial b_h} = \left(c_h^g\right)^{\sigma(1-r)}\left(\underline{p}v_h^g + b_h\right)^{-r} - \frac{1}{1+\delta}\left(c_l^g\right)^{\sigma(1-r)}\left(\overline{p}v_l^g + B - b_h\right)^{-r} - \mu = 0 \tag{25}$$

and (18).

Let us first show that $\mu > 0$. Suppose the contrary, i.e $\mu = 0$. Then, (25) becomes

$$\left(\frac{c_h^g}{c_l^g}\right)^{\sigma(1-r)} = \frac{1}{1+\delta}\left(\frac{\overline{p}v_l^g + B - b_h}{\underline{p}v_h^g + b_h}\right)^{-r}.$$

Combining (22) and (24), we obtain

$$\left(\frac{c_h^g}{c_l^g}\right)^{\sigma(1-r)} = \frac{\overline{p}}{\underline{p}}\frac{1}{1+\delta}\left(\frac{\overline{p}v_l^g + B - b_h}{\underline{p}v_h^g + b_h}\right)^{-r}.$$

We then must have $\overline{p} = \underline{p}$, which is a contradiction. We then have $\mu > 0$ and $b_h = B$.

Combining (21), (22), (23), and (24), we find,

$$\sigma\left(v_h^g+\frac{B}{\underline{p}}\right) = c_h^g \tag{26}$$

$$\sigma v_l^g = c_l^g \tag{27}$$

$$v_l^g = \frac{1}{\theta}\left(v_h^g+\frac{B}{\underline{p}}\right), \tag{28}$$

where $\theta=\left((1+\delta)\left(\overline{p}/\underline{p}\right)^{-(1-r)}\right)^{\frac{1}{(1+\sigma)r-\sigma}}$.

Using (18), we obtain

$$v_h^g=\frac{1}{1+\sigma}\frac{\theta}{1+\theta}\left(H+\frac{B}{\underline{p}}\right)-\frac{B}{\underline{p}}, \tag{29}$$

and then, we have

$$c_h^g = \frac{\sigma}{1+\sigma}\frac{\theta}{1+\theta}\left(H+\frac{B}{\underline{p}}\right), \tag{30}$$

$$c_l^g = \frac{\sigma}{1+\sigma}\frac{1}{1+\theta}\left(H+\frac{B}{\underline{p}}\right), \tag{31}$$

$$v_l^g = \frac{1}{1+\sigma}\frac{1}{1+\theta}\left(H+\frac{B}{\underline{p}}\right), \tag{32}$$

and, using (5) and (7), we also have

$$c_h^m=\underline{p}\frac{1}{1+\sigma}\frac{\theta}{1+\theta}\left(H+\frac{B}{\underline{p}}\right), \tag{33}$$

and,

$$c_l^m=\overline{p}\frac{1}{1+\sigma}\frac{1}{1+\theta}\left(H+\frac{B}{\underline{p}}\right). \tag{34}$$

The Lagrange multipliers are such that

$$\lambda=(\sigma)^{\sigma(1-r)}\left(\underline{p}\right)^{1-r}\left(\frac{1}{1+\sigma}\frac{\theta}{1+\theta}\left(H+\frac{B}{\underline{p}}\right)\right)^{\sigma(1-r)-r}>0,$$

and,

$$\mu=\left(\overline{p}\right)^{-r}\frac{\sigma^{\sigma(1-r)}}{1+\delta}\left(\frac{1}{1+\sigma}\frac{1}{1+\theta}\left(H+\frac{B}{\underline{p}}\right)\right)^{\sigma(1-r)-r}\left(\frac{\overline{p}}{\underline{p}}-1\right)>0.$$

□

Proof of Corollary 1: Omitted.

Proof of Corollary 2: Sales at the harvest season are non negative if and only if

$$\underline{p}\frac{\frac{1}{1+\sigma}\frac{\theta}{1+\theta}}{1-\frac{1}{1+\sigma}\frac{\theta}{1+\theta}}H\geq B,$$

or,

$$\underline{p}\frac{\theta}{1+\sigma(1+\theta)}H \geq B.$$

□

Proof of Proposition 3: The derivative of v_h^{g*} with respect to δ is positive as long as $r > \frac{\sigma}{1+\sigma}$.□

Proof of Proposition 4: The derivative of v_h^{g*} with respect to r is given by

$$\frac{\partial v_h^{g*}}{\partial r} = -\frac{s^*\left(H+\frac{B}{\underline{p}}-s^*\right)}{\left(H+\frac{B}{\underline{p}}\right)(r-\sigma+r\sigma)^2}\ln\left((1+\delta)^{1+\sigma}\,\underline{p}/\overline{p}\right), \tag{35}$$

which is positive only if

$$(1+\delta)^{1+\sigma}\left(\underline{p}/\overline{p}\right) \geq 1, \tag{36}$$

or,

$$\frac{1}{1+\delta} \leq \left(\underline{p}/\overline{p}\right)^{\frac{1}{1+\sigma}}. \tag{37}$$

□

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