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# DOCUMENT de RECHERCHE

« Farmer Impatience and Grain  
Storage for the Hunger Season »

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# Farmer Impatience and Grain Storage for the Hunger Season

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## Abstract

In African countries, food security greatly depends on farmers' propensity to store grain until the lean season. Using original data collected from 1,500 farmers in Burkina Faso in 2013, we show that individual risk and time preferences play a central role in grain storage decisions. We use a sample selection model as well as a structural estimation approach and find that both lead to very similar results. Specifically, we find that a one-standard-deviation increase in the discount rate (resp. risk aversion) results in a large decrease (resp. increase) in grain storage of about 45% (resp. 25%). We simulate a grain price stabilisation policy and show that half of farmers in our sample would benefit from such a policy.

Key Words: Storage, Food Security, Time Discounting, Risk Aversion, Price Stabilisation Policy.

JEL: D13, D14, D91, O12.

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# 1 Introduction

In African countries, many grain farmers suffer from starvation during the lean season when the value of their product reaches a peak.<sup>1</sup> This occurs because farmers either consume or sell their entire harvest when the price of grain is lowest. Given that grain storage can be used to increase food security, why don't farmers store some of their harvest until the lean season? The most common reason why farmers are thought not to take advantage of seasonal price fluctuations through storage is that they face temporary liquidity constraints that force them to convert their grain into cash, even though they know that they may need to buy back more grain later at a higher price (Stephens and Barrett, 2011; Van Campenhout, Lecoutere, and D'Exelle, 2015). Another explanation is that risk aversion and impatience limit storage.<sup>2</sup> At first glance, the role of impatience in the African context is not obvious: given the typically large increase in grain prices between the harvest and the lean season,<sup>3</sup> this second explanation would hold only if farmers were extremely impatient. This paper highlights the role of impatience in driving African farmers' agricultural behaviour. We use original data from Burkina Faso to study this issue empirically. Taking into account the fact that farmers who choose to sell grain in the harvest season may be liquidity constrained, we provide evidence that heterogeneity in storage behaviour is largely explained by individual risk attitudes and time preferences. To do so, we develop a stylized on-farm storage model that explicitly takes into account the household preference for risk, time, and grain relative to other goods. Parameterized to our data, the model predicts that stored quantities decrease with impatience and increase with risk aversion. In order to test these predictions and quantify these effects, we use original data on agricultural decisions that we have collected from 1,500 farmers who were also asked hypothetical questions about risk aversion and time discounting.

Risk and time preferences have long been recognized by theoretical models of storage as an important factor in the storage decision-making process (Newbery, 1989; Deaton and Laroque, 1992). However, the extent to which they play a role in storage decisions is less understood from an empirical perspective. Identifying the effects of individual preferences on agricultural decisions is a difficult task for at least two reasons. First, eliciting risk and time preferences requires implementing artefactual field experiments (in the terminology of Harrison and List (2004)), which is more difficult than running declarative surveys, for practical reasons. We built our risk aversion experiments following Holt and Laury (2002) and our time preference experiments following Harrison, Lau, and Williams (2002). However, we had to adapt the content of the experiments in order to offer hypothetical payoffs that made sense to the respondents. We then follow the same approach as Andersen, Harrison, Lau, and Rutstrom (2008) in order to infer the risk aversion coefficients and the discount rates implied by the raw responses. In our sample, most of the farmers appear risk averse at levels that are comparable to those obtained by Harrison, Humphrey, and Verschoor (2010), who used similar experiments in India, Ethiopia, and Uganda. Our estimates of the time preference parameter fall well above previous estimates of discount rates that have been elicited for selected segments of populations in more

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<sup>1</sup>In West-African countries, the price of grains such as millet, maize, and sorghum typically declines during the harvest season, reflecting an increased supply of grain from ongoing harvests, and increases thereafter with the onset of the lean season.

<sup>2</sup>A third explanation concerns limits to storage technology. In our context, this is less of an issue as farmers have access to traditional storage methods at low costs.

<sup>3</sup>For example, during the 2012-2013 season, in rural markets in Burkina Faso where our study takes place, we observe that maize prices increased by 40 % between the harvest season and the lean season (Figure 1).

developed countries.<sup>4</sup> These results are consistent with how farmers live in Burkina Faso and with recent papers from the field experiment literature showing that people living in wealthier areas are not only less risk averse but also more patient.

Second, we generally cannot collect all of the information on household behaviour that we need to make causal inference using simple econometric models. While it is possible to collect data on grain quantities that are sold over a season, it is much more difficult to collect data on grain quantities that are purchased because these transactions are much smaller in magnitude and more numerous in quantity. This generates missing data problems. In this paper, we first address this issue by estimating a sample selection model. This approach yields results that are consistent with theoretical predictions. Our estimated effects are statistically significant and robust to various measures of time and risk preferences. Despite the fact that farmers appear to have hyperbolic time preferences, we do not find evidence that this feature significantly affects storage decisions. Because the validity of the exclusion restriction in a selection model cannot be tested, we then turn to a more structural approach. Using this approach, we obtain results that are very similar in size. We find that a one-standard-deviation increase in the discount rate (resp. risk aversion) appears to result in a large decrease (resp. increase) in storage of about 45% (resp. 25%). We moreover find that quantities of grain sold, as predicted by the model, fall close to the quantities actually sold by the farmers in the sample over the period under study. This suggests that our model performs quite well in reproducing the observed data. We further use the theoretical model to simulate a public policy aiming to smooth inter-seasonal price variability.<sup>5</sup> We use the theoretical results derived from our on-farm storage model to simulate a grain price stabilisation policy, and we quantify farmers' willingness to accept not implementing it. We show that half of farmers who sell grain would benefit from such a policy. We moreover show that the amount of cash that would compensate the median farmer for not implementing the policy is about 1,200 CFA francs. This value does not exceed per capita storage costs associated with the policy.

This paper presents one of the first field evidence that directly links elicited individual preferences to observed agricultural decisions. Other recent studies address similar topics, but they do not focus on grain storage decisions, use experimental methods to elicit individual preferences, nor provide a theoretical framework that could be used to simulate public policies. Ashraf, Karlan, and Yin (2006), Bauer, Chytilova, and Morduch (2012), and Dupas and Robinson (2013) implement randomized controlled trials to show that present-bias preferences measured using a survey instrument may explain individuals' choices of adopting savings or credit innovations in the Philippines, India, and Kenya respectively. They construct time-inconsistency dummies from hypothetical time discounting questions that are then used in a probit model to analyse the decision to take up innovative products. All of these authors conjecture from their results that time-inconsistency may be an important constraint

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<sup>4</sup>Harrison, Lau, and Williams (2002) elicit individual discount rates from a nationally representative sample of 268 Danish people. Also using a sample of 253 Danish people, Andersen, Harrison, Lau, and Rutstrom (2008) jointly elicits both discount rates and risk aversion coefficients, an approach that provided 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 a sample of 160 Vietnamese villagers. Bauer, Chytilova, and Morduch (2012) collect data from a sample of 570 women in rural India.

<sup>5</sup>In countries with a large number of poor living without safety nets, food price spikes often force governments to implement food price stabilisation policies in the form of direct interventions like public stocks (Abbott, 2010; World Bank, 2012; Jayne, 2012; Gouel, 2014) Based on data collected from 81 countries, for example, Demeke, Pangrazio, and Maetz (2009) show that 35 countries released public stocks at subsidised prices during the 2007-2008 food crisis.

for savings activity, whether at home or in a microcredit “self-help group”. Liu (2013) conducted a field experiment to elicit the risk preferences of Chinese farmers. She shows that risk aversion may affect farmers’ decisions regarding the adoption of genetically modified cotton. In summary, existing empirical studies that link individual preferences with observed agricultural decisions remain very scarce. To our knowledge, there is no existing empirical evidence to suggest that impatience drives important agricultural decisions such as storage. The present paper thus contributes to a better understanding of the decision mechanisms that drive development.

This paper proceeds as follows. Section 2 describes the theoretical model linking individual preferences to storage decisions. Section 3 describes the sample, the experimental design for eliciting individual risk aversion coefficients, discount rates and hyperbolic discounting parameters, and the survey data. Section 4 provides expected results using secondary data. Section 5 displays the results of the causal relationship between storage decision and risk and time preferences when using a sample selection model. Section 6 provides the results from the structural estimation of the theoretical model. Section 7 provides the results of a counterfactual experiment which simulates a grain price stabilisation policy. Section 8 concludes.

## 2 Theoretical Framework

### 2.1 An On-farm Storage Model

We construct a two-period agricultural household model that allows for goods consumption smoothing between the two periods. The first period refers to the 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 and non-agricultural activities ( $B$ ). The household can purchase and sell, at the market price, a quantity of grain denoted  $q^g$ . The price of the generic good is assumed to be constant and is normalized to one,<sup>6</sup> while grain price increases from the harvest season ( $p$ ) to the lean season ( $\bar{p}$ ).<sup>7</sup> Between the two seasons, the household has the opportunity to save in the form of grain storage ( $s$ ).<sup>8</sup> The generic good cannot be stored and is consumed immediately after purchase.<sup>9</sup>

The household purchases the generic good using the cash income derived from the sale of grain

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<sup>6</sup>This assumption is not crucial. Assuming that the price of the generic good varies from  $p_h^m$  in the harvest season to  $p_l^m$  does not affect our results qualitatively. In Proposition 1, Proposition 2, and Corollary 1 that follow,  $\theta$  is replaced by  $\bar{\theta} = \left( (1 + \delta) \left( p_h^m \bar{p} / p_l^m p \right)^{-(1-r)} \right)^{\frac{1}{(1+\sigma)r-\sigma}}$ . Corollary 2 and Proposition 3 are not modified. The formal statement in Proposition 4 becomes:  $\frac{\partial q_h^{g*}}{\partial r} < 0 \Leftrightarrow \left( \bar{p} p_h^m / p p_l^m \right)^{\frac{1}{1+\sigma}} - 1 < \delta$ , which implies that the condition is more easily met only if the price of the generic good increases between the two seasons.

<sup>7</sup>For simplicity, we assume that, in the harvest season, the household knows with certainty the price of grain in the lean season. In Appendix B, we show how our results can be extended to a situation in which, at the harvest season, the household is uncertain about the exact level of the price of grain of the lean season.

<sup>8</sup>It is commonly reported that grain may spoil due to pests or moisture. Adding a constant spoiling rate of grain is equivalent to considering a lower price ratio,  $\bar{p}/p$ .

<sup>9</sup>We may consider that farmers also store money and the generic good. However, in our context, grain storage is more profitable than either money or generic good storage because  $\bar{p}/p > 1$ . Since there is no uncertainty in our model, it is optimal to store neither money nor the generic good. See Appendix B for an extension of the model including price uncertainty.

as well as from other activities, with  $b_h$  and  $b_l$  denoting cash spending during the harvest season and during the lean season, respectively, and  $b_h + b_l \leq B$  (Equation 2). The household is moreover assumed to be credit constrained. As a result, the household 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  $q_h^g$ , plus the consumed quantity  $c_h^g$  equals the harvested quantity  $H$  (Equation 4). The value of the generic good purchased must equal the value of grain sales  $\underline{p}q_h^g$  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  $q_l^g$  (Equation 6). Again, the value of the purchased generic good must equal the value of grain sales  $\bar{p}q_l^g$  plus cash spending  $b_l$  (Equation 7).

The household makes consumption, storage, and marketing decisions each season to maximize discounted utility. The household's full optimization problem during the year can be expressed as follows:<sup>10</sup>

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

s.t.

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

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

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

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

$$c_l^g + q_l^g = s \text{ (lean season grain balance),} \quad (6)$$

$$c_l^m = \bar{p}q_l^g + b_l \text{ (lean season budget constraint).} \quad (7)$$

Utility is assumed to be time separable with a constant relative risk aversion parameter. Preferences are fully described by three parameters:  $\sigma \geq 0$ , which determines the relative share of grain and of the generic good within the total expenditure;  $r$ , which measures relative risk aversion with respect to the consumption of the generic good; and  $\delta$ , which is the discount rate. Relative risk aversion with respect to grain consumption is equal to  $\sigma(r-1) + 1$ . We assume that  $r > \sigma/(1+\sigma)$ , so that the utility function  $U$  is concave.<sup>11</sup>

## 2.2 Optimal Consumption, Sales and Storage Decision

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

**Proposition 1 [Consumption and Storage]:** *At the harvest season, the optimal levels of generic good*

<sup>10</sup>See Park (2006) for a similar per-period utility function for consumption of grain and a generic good bought on the market.

<sup>11</sup>We may relax the assumption that  $U$  is concave (i.e.  $r > \sigma/(1+\sigma)$ ) and instead assume that  $U$  is quasi-concave. We must then solve the household maximization problem for  $r < \sigma/(1+\sigma)$ . In this case, the optimal consumption levels provided by Proposition 1 remain unchanged. However, the optimal storage level becomes  $s^* = 0$  if  $\delta > (\bar{p}/\underline{p})^{1-r} - 1$ ,  $s^* = H + B/\underline{p}$  if  $\delta < (\bar{p}/\underline{p})^{1-r} - 1$ , and  $s^* \in [0, H + B/\underline{p}]$  if  $\delta = (\bar{p}/\underline{p})^{1-r} - 1$ .

consumption  $c_h^{m*}$  and of grain consumption  $c_h^{g*}$  are such that

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

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

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

where the optimal quantity of stored grain,  $s^*$ , is

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

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

The optimal amount of cash spending in each season is such that

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

The household spends all its cash income  $B$  during the harvest season because it is always more profitable 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,  $\frac{1}{1+\theta}$ , is stored during the harvest season and then consumed in the lean season in the form of grain consumption, grain sales, and generic good purchases. The share  $\frac{1}{1+\theta}$  depends, in a non trivial way, on the discount rate  $\delta$ , the relative risk aversion parameter  $r$ , and the grain preference parameter  $\sigma$ .<sup>12</sup> Moreover, it increases with the price ratio, given  $r > \sigma/(1+\sigma)$ .

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.<sup>13</sup> The form of the utility function also enables us to explicitly specify the relative risk aversion parameter, discount rate, and consumption shares.

### 2.3 Cash Income and Sales

In order to apply our data to the model, we must now shift our focus from the quantity of stored grain to the quantity of grain sold during the harvest season. In this section, we thus determine the optimal level of grain sold during the 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.

<sup>12</sup>An increase in the grain preference parameter  $\sigma$  increases grain storage only if the household is sufficiently impatient and risk averse, i.e.  $(1+\delta)^{(r-1)} \left( \bar{p}/\underline{p} \right)^{(r-1)^2} \geq 1$ . The underlying intuition is that an increase in  $\sigma$  increases household risk aversion with respect to grain consumption only if  $r \geq 1$ . Assume, for instance, that  $r \geq 1$ . Thus, an increase in  $\sigma$  increases risk aversion with respect to grain, and, if the household is sufficiently impatient (preferring to consume relatively large quantities during the harvest season), it increases grain storage in order to smooth its consumption. The opposite holds for  $r \leq 1$ .

<sup>13</sup>The elasticities of consumption with respect to  $H + \frac{B}{\underline{p}} - s^*$  are constant and sum to one, as well.

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

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

*and, in the lean season, they are such that*

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

From the harvest season budget constraint (Equation 5), we have  $q_h^{g*} + \frac{B}{\underline{p}} = \frac{c_h^{m*}}{\underline{p}}$ , which indicates that the cash income generated from grain sales and cash income  $B$  are used together to purchase the generic good  $c_h^{m*}$ .<sup>14</sup> Because all  $B$  is spent during the harvest season for generic good purchases ( $b_h^* = B$ ), the household that would like to purchase additional generic goods to reach the optimal level  $c_h^{m*}$  must sell grain. There is thus a relationship between  $B$  and  $q_h^g$ , which we make explicit in Corollary 1:

**Corollary 1 [Sales and Cash]:** *Grain sales (resp. grain purchases) decrease (resp. increase) with cash income  $B$  in the harvest season:*

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

*and, households having a small cash income  $B$  will sell rather than purchase grain:*

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

The intuition behind Corollary 1 is that households with small cash income  $B$  must sell grain during the harvest season if they would like to purchase some of the generic good during the harvest season. This result is at the heart of the identification strategy in the empirical analysis that follows.

We now turn to the equivalence between  $q_h^{g*}$  and  $s^*$  when examining the comparative static effects of some preference parameter  $x$ :

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

$$\frac{\partial q_h^{g*}}{\partial x} = - \frac{1}{1+\sigma} \frac{\partial s^*}{\partial x}.$$

Corollary 2 states that the marginal effect of an increase in the preference  $x$  (either risk aversion or time preference parameters) on storage is proportional to the marginal effect of an increase in the preference  $x$  on post-harvest sales. Corollary 2 implies that, provided we are able to empirically estimate the impact of preferences on post-harvest sales, we are able to derive the impact of preferences on storage levels as well. Corollary 2 also implies that the size of the marginal effect of a preference parameter is always larger for storage than for post-harvest sales:

$$\left| \frac{\partial q_h^{g*}}{\partial x} \right| < \left| \frac{\partial s^*}{\partial x} \right|, x \in \{r, \delta\}. \quad (8)$$

<sup>14</sup>If  $q_h^g \leq 0$ , Equation (5) means that the cash income  $B$  is used to buy the generic good and also some grain.

## 2.4 Comparative Static Effects of Preferences

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

**Proposition 3: [Discounting]** *An increase in the discount rate,  $\delta$ , always increases post-harvest sales:*<sup>15</sup>

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

The formula is given by:

$$\frac{\partial q_h^{g*}}{\partial \delta} = \frac{\theta}{(1+\theta)^2} \frac{1}{1+\sigma} \frac{1}{1+\delta} \frac{H+B/\underline{p}}{(1+\sigma)r-\sigma} > 0. \quad (9)$$

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 in the harvest season ( $c_h^{g*}$  and  $c_h^{m*}$ ) and decreases the household's consumption of both grain and the generic good in the lean season ( $c_l^{g*}$  and  $c_l^{m*}$ ).<sup>16</sup>

**Proposition 4: [Risk Aversion]** *Post-harvest sales decrease with risk aversion if and only if the household is sufficiently impatient:*

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

Proposition 4 states that the effect of a change in the relative risk aversion with respect to the quantity of grain sold depends on the level of the discount rate.<sup>17</sup> The formula is given by:

$$\frac{\partial q_h^{g*}}{\partial r} = -\frac{1}{1+\sigma} \frac{\theta}{(1+\theta)^2} \frac{H+B/\underline{p}}{(r-\sigma+r\sigma)^2} \ln\left((1+\delta)^{1+\sigma} \underline{p}/\bar{p}\right). \quad (10)$$

The intuition of Proposition 4 is as follows. If  $\left(\bar{p}/\underline{p}\right)^{\frac{1}{1+\sigma}} - 1 < \delta$ , i.e. if the household strongly discounts future utility and/or the price ratio is small enough, it tends to consume large quantities of grain and the generic good during the harvest season. However, the more it is risk averse with respect to the generic good, the less grain the household sells in the harvest season because it seeks to smooth its consumption of the two goods between the two periods. In order to consume the two goods in the lean season, it must store grain in the harvest season. As a result, grain sales in the 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.  $\left(\bar{p}/\underline{p}\right)^{\frac{1}{1+\sigma}} - 1 \geq \delta$ , it tends to store large quantities of grain. However, the more the household is risk averse with respect to the generic good, the less it stores

<sup>15</sup>This is true for  $r > \sigma/(1+\sigma)$ . If  $r < \sigma/(1+\sigma)$ , post-harvest sales do not depend on impatience,  $\frac{\partial q_h^{g*}}{\partial \delta} = 0$ .

<sup>16</sup>We assume that there is no link between the amount of cash  $B$  and the discount rate  $\delta$ . Alternatively, one could assume that  $B$  is negatively correlated to  $\delta$ , that is  $B \equiv B(\delta)$  with  $B'(\delta) < 0$ . Defining sales  $q_h^{g*}$  as a function of  $\delta$  and  $B(\delta)$ , condition (9) would then write:

$$\frac{dq_h^{g*}}{d\delta} = \frac{\partial q_h^{g*}}{\partial \delta} + \frac{\partial q_h^{g*}}{\partial B} B'(\delta) > \frac{\partial q_h^{g*}}{\partial \delta} > 0,$$

which means that the effect of impatience on sales would actually be stronger.

<sup>17</sup>This is true for  $r > \sigma/(1+\sigma)$ . If  $r < \sigma/(1+\sigma)$ , sales at the time of harvest season do not depend on risk aversion,  $\frac{\partial q_h^{g*}}{\partial r} = 0$ .

grain in the harvest season, again because it seeks to smooth its consumption. In order to consume more of the generic good in the harvest season, it must sell more grain. For this reason, grain sales increase with risk aversion in that case.<sup>18</sup>

In summary, this stylized model highlights the fact that impatience is likely to decrease storage among all farmers and that risk aversion is likely to increase storage among impatient farmers and decrease storage among patient farmers.

## 2.5 Grain Price Stabilisation Policy and Welfare

In this section, we provide a framework for studying a price stabilisation policy aiming to smooth fluctuations in domestic grain prices over the two seasons. We then derive the expression determining a farmer's willingness to accept such a policy, which is equal to the amount of cash income that would exactly compensate him if the policy were not implemented.

We consider a scenario in which the government chooses the grain quantity  $G^*$  to be bought at the harvest season and sold at the lean season,<sup>19</sup> such that the equilibrium market price  $p^*$  is the same over both seasons ( $\underline{p} = \bar{p} = p^*$ ).<sup>20</sup> In order to determine  $G^*$  and  $p^*$ , we first write the aggregate supply and demand functions, assuming as before that households consume self-produced grain.<sup>21</sup> We then define the market clearing conditions. On the supply side, we derive from the two-period household model the aggregate supply of grain at the harvest season as well as the aggregate supply of grain at the lean season. Both supplies depend on the price of grain at the harvest season and the price of grain at the lean season. Formally, letting  $N_h$  denote the set of farmers who sell grain at the harvest season ( $q_h^{g^*} > 0$ ), the aggregate supply of grain at the harvest season,  $S_h(\underline{p}, \bar{p})$ , is given by:

$$S_h(\underline{p}, \bar{p}) = \sum_{N_h} q_h^{g^*}, \quad (11)$$

where  $q_h^{g^*}$  is the quantity of grain sold by the farmer at the harvest season defined by Proposition 2 in Section 2.3. Similarly, letting  $N_l$  denote the set of farmers who sell grain at the lean season ( $q_l^{g^*} > 0$ ), the aggregate supply of grain at the lean season,  $S_l(\underline{p}, \bar{p})$ , is given by:

$$S_l(\underline{p}, \bar{p}) = \sum_{N_l} q_l^{g^*}, \quad (12)$$

where  $q_l^{g^*}$  is the quantity of grain sold by the farmer at the lean season (as before, see Proposition 2 in Section 2.3).

For the sake of simplicity, we assume that the demand function,  $D(p)$ , which is a decreasing func-

<sup>18</sup>We assume that there is no link between the amount of cash  $B$  and the risk aversion parameter  $r$ . Alternatively, one could assume that  $B$  is negatively correlated to  $r$ , that is  $B \equiv B(r)$  with  $B'(r) < 0$ . Defining sales  $q_h$  as a function of  $\delta$  and  $B(r)$ , condition (10) would then write:

$$\frac{dq_h^{g^*}}{dr} = \frac{\partial q_h^{g^*}}{\partial r} + \frac{\partial q_h^{g^*}}{\partial B} B'(r) > \frac{\partial q_h^{g^*}}{\partial r},$$

which means that the effect of risk aversion on sales would actually be weaker (given that, if the household is sufficiently impatient, the right hand side is negative, see Proposition 4).

<sup>19</sup>We assume that all available maize is locally produced. According to the Burkina Faso Annual Agricultural Survey, Burkina Faso produces sufficient quantities of maize to satisfy national demand.

<sup>20</sup>We assume that the government does not discount time between the two seasons.

<sup>21</sup>In this, we differ from the standard models proposed by Newbery (1989) who considers a two-period model, or more recently by Gouel (2013), who considers a rational expectation infinite horizon model.

tion of the price, is identical in both seasons. We are then able to define  $(G^*, p^*)$  which solves the two market clearing conditions:

$$D(p^*) + G^* = S_h(p^*, p^*) \quad (13)$$

$$D(p^*) = S_l(p^*, p^*) + G^* \quad (14)$$

Condition (13) is the market clearing condition at the harvest season: the demand plus the quantity bought by the government must equal the quantity supplied by the farmers. Condition (14) is the market clearing condition at the lean season: the demand must equal the quantity supplied by the farmers plus the quantity supplied by the government. Solving (13)-(14) yields an expression of  $G^*$  and of  $p^*$ . We then compute their value from our data.

Following this, we study the welfare effect of the price stabilisation policy. To do so, we define the amount of cash that exactly compensates the farmer for not implementing this policy. Let  $V(\underline{p}, \bar{p}, \sigma, B)$  be the indirect utility of the farmer, i.e. the level of utility he derives from the optimal levels of consumption, storage, cash spending, and sales (Section 2.1). The farmer's willingness to accept (WTA) is characterized by:

$$V(\underline{p}, \bar{p}, \sigma, B + \text{WTA}) = V(p^*, p^*, \sigma, B), \quad (15)$$

The expression of WTA derived from equality (15) shows that, provided we are able to estimate the value of  $B$ , of  $\sigma$  and of  $p^*$ , we are also able to quantify the impact of such a policy on farmers' welfare. This is precisely the purpose of the empirical analysis we propose in the following sections.

### 3 Data

In order to test the predictions of the theoretical model and quantify the effects 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 questions designed to elicit time discounting and risk aversion preferences.

#### 3.1 Sampling

The survey design generated a representative sample of households in two administrative districts of Burkina Faso, the Tuy and Mouhoun provinces. Those provinces are located in the western region of the country, which is the main maize production area. Data were collected in cooperation with the Confédération Paysanne du Faso (CPF), a nation-wide organization of farmers. A total of 73 villages were randomly selected from the CPF list (Figure 2). In these villages, an average number of 20 households were selected through the use of a door-to-door strategy with the aim of gathering a random sample of households. With the help of the Burkinabe Agriculture Ministry, twenty investigators and two supervisors were recruited for the data collection. A total of 1,549 households were surveyed in February 2013. Surveys were conducted in the Dioula language. The investigators interviewed the household head, defined as the person responsible for farming decisions.<sup>22</sup> The participants com-

<sup>22</sup>We remain agnostic concerning the way in which the individual preferences and beliefs are aggregated within each family.

pleted a face-to-face interview and participated in a field experiment.

### 3.2 Survey Data

The declarative survey is a recall survey about what happened between January 2012 and February 2013. It is comprised of nine distinct sections: (i) the socio-economic characteristics of the household and of the household's head; (ii) the household's economic assets; (iii) the type and amount of crop production; (iv) crop sales; (v) fertilizer expenses; (vi) the type and amount of non agricultural activities undertaken by the household members; (vii) the household's social expenses; (viii) the type and the amount of the household's loans and (ix) the household's food expenses. Table 1 reports mean values for various farmer characteristics. On average, surveyed households have 13 members, 7 of whom work in farming activities. In almost all cases (98%), the household is headed by a man of an average age of 43 years, who has received a formal education in 40% of cases, lives a 40-minute walk from the closest market,<sup>23</sup> and is very often (in 85% of cases) a member of a producer organization, whether CPF or some other producer organization. In the Tuy and Mouhoun provinces, the main crops are cotton, maize, sorghum, millet, and sesame.

Maize is the most marketed grain. Most households of the sample (73%) harvested maize during October or November, while the rest harvested in December 2012. One third of the sample sold maize during 2012. During the harvest season, i.e. between October 2012 and January 2013, 25% of households made one maize sale, and 13% of households made two. The quantity sold by those who made a single sale over the harvest season is one ton on average. This represents about 25% of the total maize harvest. Since the data were collected in February 2013, we do not observe the quantity of maize sold during the lean season of the studied crop year but we do observe the quantity of maize sold during the lean season of the previous crop year. Table 2 summarizes information on maize sales at the harvest season, i.e. between October 2012 and January 2013 ( $q_h$ ), and the quantity of maize sold at the previous lean season, i.e. between February 2012 and September 2012 ( $q_l$ ). It appears that 67% of the households did not sell maize over the 2012-2013 harvest season. Moreover, 52% of households did not sell maize during the previous lean season either, which suggests that they usually prefer to consume maize rather than to sell it. Unfortunately, data are missing on maize purchases.<sup>24</sup>

### 3.3 Eliciting Risk and Time Preferences

In order to elicit households' time and risk preferences, we use an artefactual field experiment, to use the terminology of Harrison and List (2004). As with the survey, the experiments were conducted in the Dioula language.

#### 3.3.1 Risk Aversion Data

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

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<sup>23</sup>We calculated the distance between each village and its associated assembly market using the ArcGIS Software. We assumed the speed of vehicles traveling on paved roads to be equal to 40 km per hour and the speed on non-paved roads to be equal to 10 km per hour.

<sup>24</sup>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. In contrast, it is much easier to collect data on sales, which are generally few over the period.

two lotteries of risky and safe options, and this choice was repeated nine times with different pairs of lotteries, as illustrated in Table 3. Farmers were asked to choose either lottery A or lottery B. For example, the first row of Table 3 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.

Low payoffs 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, Harrison, Lau, and Rutstrom (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 ten times higher payoffs (10,000 CFA, or around 20 USD, corresponding to the average price of a 100-kg-bag of cereal at the harvest season).

In practice, lotteries A and B were materialized 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. The composition of the bags was revealed to the farmers, but they could not see inside the bag. As indicated in the last column of Table 3, 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. In order to make our results comparable to previous studies, we assume a constant relative risk aversion (CRRA) utility function, which enables to compute the intervals provided in the last column of Table 3.<sup>25</sup>

We then follow the same approach as Andersen, Harrison, Lau, and Rutstrom (2008) to infer the risk aversion coefficients and the discount rates implied by the raw responses. We allow risk aversion to be a linear function of the observed households' characteristics. We consider six characteristics that we assume to be unambiguously exogenous in driving risk preferences: gender, age, education, village, and province. Elicited individual  $r$  coefficients are predicted values in the model, which we estimate using an interval regression, a generalization of censored regression for data where each observation is measured using an interval scale.

Figure 3 and Figure 4 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 risk loving or risk neutral behaviour. Most farmers are risk averse, with an average of  $r = 0.69$  in the low-payoff experiment and  $r = 0.63$  in the high-payoff experiment (Table 4). These average values are comparable to those obtained by Harrison, Humphrey, and Verschoor (2010) who used similar experiments in India, Ethiopia, and Uganda.

<sup>25</sup>The CRRA utility function has 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  $p$  of winning  $a$  and probability  $1-p$  of winning  $b$ , and lottery B, with probability  $p$  of winning  $c$  and probability  $1-p$  of winning  $d$ , if and only if the two expected utility levels are equal:

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

or,

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

which can be solved numerically in terms of  $r$ .

### 3.3.2 Discount Rate Data

We built our time preference experiment on Harrison, Lau, and Williams (2002) and on Collier and Williams (1999), who collected experimental data in Denmark and in the U.S., respectively. However, we had to adapt the content in order to offer hypothetical pay-offs that made sense to the respondents. To do so, we ran pre-tests of the experiment with a subset of farmers. Finally, we conducted two experiments that differed in the time delays offered to respondents. 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 5 displays the experiment aiming to elicit the four-day-delay discount rate. 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 6 displays the experiment aiming to elicit the one-month-delay discount rate. 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.<sup>26</sup> 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  $\delta$  to be a linear function of exogenous covariates (gender, age, education, village, and province). The elicited individual  $\delta$  coefficients are predicted values of a linear model, which we estimate using an interval regression. Results are displayed in Table 4. They show that farmers are very impatient in the far future, with an average value of 24 percent per month. Interestingly, they are even more impatient in the near future, with an average value of 10 percent for every four days.

Recent work has addressed an important issue in much of the literature on discount rate elicitation, showing that a more appropriate specification of discount-rate models should include a curvature correction for non-linearity in the utility function in order to account for the influence of risk aversion on time preferences (Laury, McInnes, and Todd Swarthout, 2012). We thus follow the approach proposed by Andersen, Harrison, Lau, and Rutstrom (2008), who apply maximum likelihood estimation to jointly estimate risk and time preferences.<sup>27</sup> By this approach, individuals appear to discount the future even more than in previous estimates (Table 7). Our estimates of the time preference parameter fall well above previous estimates of discount rates that have been elicited for selected segments of populations in developed countries, which range between one and three percent per month

<sup>26</sup>The form of the utility function is:  $U(x) = x^{1-r}/(1-r)$ , 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:

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

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

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

from which we can explicitly solve for  $\delta$  as a function of risk aversion  $r$ :

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

<sup>27</sup>The less computationally expensive way of running the maximum likelihood estimations is to use an exponential discount factor, i.e.  $\exp(-\delta)$  instead of  $\frac{1}{1+\delta}$ .

(Harrison, Lau, and Williams, 2002). Our estimates also suggest that the farmers in our sample have higher discount rates than rural villagers who participated in the experiments conducted by Tanaka, Camerer, and Nguyen (2010) in Vietnam and Bauer, Chytilova, and Morduch (2012) in India. Altogether, these results suggest that Burkinabe farmers are more impatient on average than Vietnamese and Indian farmers, and that Vietnamese and Indian farmers are more impatient than a nationally representative sample of Danish people. This ranking makes sense since those with the least amount of wealth are expected to have the highest levels of impatience. Indeed, a very high discount rate characterizes life among farmers in Burkina Faso: life expectancy is relatively short, and the likelihood of losing one's savings due to diseases and agricultural shocks can be quite high.<sup>28</sup>

### 3.4 Evidence for Hyperbolic Time Preferences

In order to render them comparable, we converted the four-day discount rate to the equivalent discount rate for a one-month-delay. The results show that the four-day discount rate differs considerably from the one-month discount rate in a way that suggests hyperbolic preferences. We run a test of the equality of the distributions and a test of equality of the means, and the null hypothesis is indeed rejected in both cases. Impatience in the near future is in fact higher than impatience in the far future for almost 90% of respondents, as illustrated in Figure 5.

This result is in line with recent literature that shows the existence of hyperbolic discounting from experimental data (Noor, 2009; Rohde, 2010). We take this into account in our estimates by introducing a hyperbolic parameter  $\alpha$  in the utility function (Prelec, 2004).<sup>29</sup> Unfortunately, our data do not allow us to estimate an individual hyperbolic parameter  $\alpha_i$  for each household.<sup>30</sup> However, we are able to jointly estimate individual discount rates as well as a common value for the hyperbolic parameter that equals  $\alpha = 0.46$  ( $sd = 0.025$ ). This method yields estimates of the individual discount rates that do not differ much from those we previously obtained (see the last row in Table 7). We retain these estimates for robustness checks. Finally, we are able to calculate individual hyperbolic parameters from individual discount rates that are estimated separately.<sup>31</sup> This variable will be used to test whether hyperbolic preferences play a significant role in storage decisions.

<sup>28</sup>Our estimates of the discount rate differ considerably 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 households are extremely patient. This is a surprising result considering that poor farmers are usually expected to have high levels of impatience. However, it is worth mentioning that this result may be due to the fact that the authors study a reward that is delivered immediately (rather than delayed), which is not common practice for this type of experiment due to people's extreme preferences for immediate rewards.

<sup>29</sup>To do so, we introduce the  $\alpha$  parameter in the utility function when applying the maximum likelihood approach to jointly estimate risk and time preferences. We use the general hyperbolic specification proposed by Prelec (2004), wherein the discount factor is defined as  $\exp(-\delta_i t^\alpha)$ , and  $t$  is the time delay. The  $\alpha$  parameter characterizes the "decreasing impatience" of the decision maker, which is a smoother way to capture the notion of "passion for the present" in quasi-hyperbolic specifications (Andersen, Harrison, Lau, and Rutstrom, 2008). The  $\delta_i$  parameter characterizes time preference in the usual sense.

<sup>30</sup>Even when using data from the four experiments, the maximum likelihood procedure does not converge.

<sup>31</sup>To do so, we follow Prelec (2004), considering the following equality:

$$\exp \delta_i^{\text{near}} \left( \frac{4}{30} \right)^{\alpha_i} = \exp \delta_i^{\text{far}} (1)^{\alpha_i}$$

where  $\delta_i^{\text{near}}$  (resp.  $\delta_i^{\text{far}}$ ) refers to the value of the four-day delay discount rate (resp. one-month delay discount rate), which can be solved in term of  $\alpha_i$ .

## 4 Expected Sign of the Effect of Preferences on Sales

At this stage, we already have the necessary information that will allow us to determine the sign of the effects under study. This is possible thanks to Proposition 3 and Proposition 4. We use the sample means of  $r$  and  $\delta$  (Table 4) along with secondary data on  $\bar{p}$  and  $\underline{p}$ . We moreover estimate a  $\sigma$  parameter from our experimental data, assuming that households are homogeneous with respect to this parameter. To do so, we introduce the  $\sigma$  parameter in the utility function when applying the maximum likelihood approach to jointly estimate risk and time preferences.<sup>32</sup> From this procedure, we obtain a common parameter that equals 1.32 ( $sd = 0.318$ ), which is very close to the value that can be derived from the Burkina Faso Annual Agricultural Survey (EPA 2010/2011) run by the Ministry of Agriculture.<sup>33</sup>

In order to make predictions regarding the effect of impatience on the quantity of grain sold during the harvest season, we first check our assumption that  $r > \sigma/(1 + \sigma)$ . The average value for  $\frac{\sigma}{1+\sigma}$  is around 0.56, which is lower than the sample mean of  $r$ . Therefore, 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 regarding the effect of risk aversion on the quantity of grain sold during the harvest season, we must compare the threshold  $\left(\frac{\underline{p}}{\bar{p}}\right)^{\frac{1}{1+\sigma}}$  to the household discount factor  $\left(\frac{1}{1+\delta}\right)^{\Delta T}$  where  $\Delta T$  is the time interval between the harvest and the lean season (Proposition 4). To do so, we use data from the Burkina Faso Market Information System, the SONAGESS, which gathers and disseminates data on grain prices in several local markets throughout the country. Using data over the 2005-2012 period from the regions of Tuy and Mouhoun, we observe that maize prices increase by an average of 44% between the harvest season and the lean season. The average annual price ratio is then  $\underline{p}/\bar{p} = 100/144$ , where  $\underline{p}$  refers to the harvest period and  $\bar{p}$  refers to the lean period. Using the estimated value of  $\sigma$ , we thus have  $\left(\frac{\underline{p}}{\bar{p}}\right)^{\frac{1}{1+\sigma}} = \left(\frac{1}{1.44}\right)^{\frac{1}{1+1.32}} \simeq 0.85$ . Next, assuming a three-month interval between the 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.<sup>34</sup> In what follows, we provide two approaches that enable us to quantify these effects.

<sup>32</sup>More precisely, we consider  $U(x)$  to be an indirect utility function defined as follows. Assume that households use lottery gain  $x$  to buy and consume grain (at price  $p$ ) and the generic good, maximizing their utility function  $u(c^g, c^m) = \frac{1}{1-r} \left( (c^g)^\sigma (c^m) \right)^{1-r}$ . The indirect utility function is written:  $U(x) = A^{1-r} \frac{x^{(1-r)(1+\sigma)}}{(1-r)}$ , where  $A = \left(\frac{\sigma}{1+\sigma}\right)^\sigma \left(\frac{1}{1+\sigma}\right)$ . Note that we were unable to estimate individual values for  $\sigma$  because even when using the four experiments, the maximum likelihood procedure did not converge.

<sup>33</sup>In our model, self-consumption is given by  $(c_h^{g*} + c_h^{m*})/H = \frac{\sigma}{1+\sigma}$ , provided  $B$  is negligible. Using the average self-consumption level of 55% provided by Annual Agricultural Survey, one finds  $\sigma = 1.22$ .

<sup>34</sup>This is all the more true when storage costs are high. In contrast, this prediction would be reversed if, for instance, one assumed that the price of maize doubles between the harvest season and the lean season and household self-consumption falls below 40%. In this case, we would have  $\left(\frac{\underline{p}}{\bar{p}}\right)^{\frac{1}{1+\sigma}} \leq 0.52$ .

## 5 Effects of Preferences on Storage: A Sample Selection Model

### 5.1 Identification Strategy

In this section, we present the econometric model used to estimate the effects of preferences on the quantity of grain sold post-harvest (and on storage), and we address the selection issue that arises due to a missing data problem.

#### 5.1.1 Equation to be Estimated

From Proposition 2, we derive the equation to be estimated:

$$q_h^{g*} = \frac{\theta}{1+\theta} \frac{1}{1+\sigma} \left( H + \frac{B}{\underline{p}} \right) - \frac{B}{\underline{p}} \quad (16)$$

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

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

$$q_h^{g*} \simeq \beta_0 + \beta_1 r + \beta_2 \delta + \beta_3 H + \beta_4 \sigma + \beta_5 B \quad (17)$$

Our estimates will enable us to validate the comparative static results regarding the effects of  $r$  and of  $\delta$  on the quantity of maize sold at the harvest season. The objective of our analysis here is to recover consistent and unbiased estimates of the unknown coefficients  $\beta_1$  and  $\beta_2$  using our data. Our data consist of two measures of the variable  $r$  and two measures of the variable  $\delta$  (the elicited parameters that we infer from the experiments), a measure of  $q_h^{g*}$ , the quantity of maize sold post-harvest, as well as a measure of  $H$ , the harvested quantity of maize in 2012. We do not directly observe cash income  $B$ . However, several variables in our dataset may provide some measurement of the cash available to the farmer (e.g. the harvested quantities of sorghum, millet, rice, groundnut and cotton, the total number of cattle and poultry). All other potential sources of cash such as non-agricultural income, as well as the relative preference for grain  $\sigma$ , remain unobserved. We thus specify the regression model as follows:

$$q_{hi} = \mu_0 + \beta_1 r_i + \beta_2 \delta_i + \beta_3 H_i + X_i \beta_6 + \epsilon_i, \quad (18)$$

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

#### 5.1.2 Selection Problem

Applying ordinary least squares (OLS) to the regression equation (18) for the sample of available data would yield biased estimates of the  $\beta$ s. Indeed, a selection problem arises in the fact that the sample consists uniquely of households who sell maize (since we observe  $q_{hi}$  only when  $q_{hi} > 0$ ), and that these households may differ in important unmeasured ways from those that do not (Heckman, 1979). For example, some households may belong to the sample of sellers not because they are impatient but because they need cash (i.e. they have a small cash income  $B$ ), and this characteristic is unobservable to us. The problem is that, whether or not time preference is correlated with cash income in the overall

population, these two variables are correlated in the selected sample. By using the OLS estimation method, one would thus underestimate the effect of  $\delta$  on  $q$ . We therefore turn to a sample selection model to describe our estimation problem:

$$q_{hi} = \begin{cases} \gamma_0 + \gamma_1 r_i + \gamma_2 \delta_i + \gamma_3 H_i + \gamma_4 X_i + \eta_i & \text{if } \widetilde{V}_i > 0 \\ - & \text{if } \widetilde{V}_i \leq 0 \end{cases} \quad (19)$$

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 can be written as:

$$\widetilde{V}_i = \lambda_0 + \lambda_1 r_i + \lambda_2 \delta_i + \lambda_3 H_i + Z_i \lambda_4 + X_i \lambda_5 + \epsilon_i \quad (20)$$

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.  $\epsilon_i$  is assumed to be jointly normally distributed with  $\eta_i$ . We do not observe  $\widetilde{V}_i$ , but we do 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 used by Heckman (1979), and Maximum Likelihood Estimation (MLE). In this paper we use both. The Heckman estimator consists of estimating the selection equation through the use of the usual Probit model in order to generate an estimate of the inverse Mills ratio. This procedure requires several instruments, which are stored in  $Z_i$ .

We use two variables as instruments. The first, which we denote  $po$ , is a dummy variable that equals one if the household head is member of a producer organization (PO) and zero otherwise. We argue that participation in a PO is very likely to determine participation in the market as a seller. There are indeed large fixed costs required in order to reach distant markets, e.g. the purchase or rental of a truck, which would be very difficult for an individual producer to afford. For this reason, farmers often organize in groups in order to share the cost burden associated with these types of expenses. In our data, the odds of a PO member being a seller are 0.56, which is 3.5 times higher than the odds of non-members. On the contrary, it is reasonable to assume that PO membership does not determine the quantity of grain sold itself because variable costs (the price for an additional bag of maize) are low compared to fixed costs.

Our second instrument, which we denote  $q_{lean}$ , is a dummy variable that equals one if the household sold some maize during the previous lean season. Households who were able to sell some maize over the previous season are likely to be able to bear the fixed costs of reaching the market. Consequently, having sold maize during the previous season should be correlated with the probability of participating in the market as a seller in the current season.<sup>35</sup> In our data, the odds of a previous seller being a seller over the harvest season are indeed 3.2 times higher than the odds for a farmer who did not sell any maize over the previous lean season.

The empirical model also includes the following control variables stored in  $X$ : the harvested quantities of sorghum, millet, rice, groundnut, and cotton, the total number of cattle and poultry, the size of the family, and the distance from the village to the market in minutes (Table 8).<sup>36</sup>

<sup>35</sup>However, the quantity of grain sold over the previous lean season is very unlikely to be correlated with the quantity sold over the harvest season because the vast majority of households are not able to save maize from one harvest to another.

<sup>36</sup>Since we include village dummy variables in the model used to estimate the risk and time preference parameters, we

## 5.2 Results

Main results are presented in Table 9. Column (1) displays the results that we obtain when applying the Heckman two-step (H2S) consistent estimator to our data, while columns (2) to (5) display the results we obtain when applying the MLE. Comparing column (1) and column (2), we observe that both estimators provide very similar results. In the case of MLE, we report standard errors that are clustered at the village level. Since the predicted values for preferences are generated from a prior regression, we also use bootstrap techniques to obtain standard errors that explicitly take into account the presence of generated regressors (Pagan, 1984).<sup>37</sup> The likelihood-ratio test ( $\chi^2$ ) provided at the bottom of Table 9 justifies the use of the Heckman selection model with our data.<sup>38</sup> In accordance with these results, other tests reject the independence of the two equations (19) and (20), as well, so we reject the hypothesis that the inverse hyperbolic tangent of  $\rho$  equals zero<sup>39</sup> (this estimate is reported as  $\text{atanh}\rho$  in the bottom of the table), as well as the hypothesis that  $\lambda = 0$ , where  $\lambda = \pi\rho$  (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 harvest season at standard levels of significance, with the expected negative sign. This result holds whatever the measure used (high or low payoffs experiments). The results moreover indicate that a one-standard-deviation increase in relative risk aversion decreases the quantity of maize sold by about 140 kg (taking the smallest estimated impact), which corresponds to a 10% decrease from the mean maize harvest. This impact is even larger with respect to storage, as it is multiplied by  $-(1 + \sigma)$  (see Corollary 2 in Section 2.3). As a result, a 10% decrease in sales corresponds to a 24% increase in storage.

Estimates of the impact of time preference are even more precise (most times we can reject the null at the 1% significance level). Examining the impact of impatience in the far future, these results indicate that a one-standard-deviation increase in impatience increases the quantity of maize sold by about 260 kg (columns 1 to 3 in Table 9). This effect is similar in size with respect to impatience in the near future (columns 4 and 5 in Table 9). Note that this effect is not only precisely estimated but also large in magnitude, as it corresponds to a 20% increase in sales from the mean value, and a 44% decrease in storage. For instance, a jump from the 25th percentile to the 75th percentile in the discount rate is estimated to correspond to a 12% increase in post-harvest sales and a 28% decrease in storage.

Results are robust to various measures of time and risk preferences. Table 10 displays the results obtained when we use jointly estimated measures of time and risk parameters (columns 1 and 2) as well as those obtained from measures that include a hyperbolic preference parameter that is common to all farmers (column 3 and 4). Again, impatience appears to affect the quantity of maize sold during the harvest season at standard levels of significance, with the expected positive sign. The impact of risk aversion has the expected negative sign, but does not appear to be significant. We moreover test

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cannot include dummy variables for villages in the sample selection model because this would generate a multi-collinearity problem. In order to control for village specificities, we thus include in the empirical model a variable that measures the time to reach the market from the village.

<sup>37</sup>Results are displayed in Appendix C.

<sup>38</sup>The reported likelihood-ratio test is an equivalent test for  $\rho = 0$ , where  $\rho$  is the correlation between  $\eta_i$  and  $\epsilon_i$ , and is computationally the comparison of the joint likelihood of an independent probit model for the selection equation (20) and an OLS regression model on the observed  $q_{hi}$  data against the Heckman model likelihood.

<sup>39</sup>The reported test for  $\text{atanh}\rho = 0$  is equivalent to the test for  $\rho = 0$ .

the impact of the constructed variable  $\alpha_i$ , which measures some hyperbolic preference for present consumption, but we fail to detect any significant impact on sales (Table 11).

Turning to the selection equation, we observe that both instrumental variables play a significant role in participation as a seller. We moreover observe the selection effect discussed in Section 5.1.2: while one would expect sellers to be more impatient than non-sellers, results instead indicate that they are more patient on average. This may be due to the possibility that a large number of patient households were forced to sell over the harvest season because of an immediate need for cash. Other explanatory variables<sup>40</sup> indicate that maize sellers in the harvest season are also rice sellers, while farmers who do not participate in the market as maize sellers tend to be large producers of sorghum and millet. Interestingly, the variable that measures the time to reach the market (*time*) significantly determines the probability of participating in the market as a seller, although it does not determine the quantity of grain sold in the outcome equation. This suggests that the transactions costs incurred to reach the market in order to sell maize are fixed costs rather than variable costs.

In order to complete the discussion concerning the sample selection issue, we also provide the results we obtain when applying the ordinary least square estimator to the sample of maize sellers (Table 12). As expected, the effects from this analysis are smaller compared to those we obtain using the Heckman selection model. These results indicate that a one standard deviation increase in the discount rate translates into an increase in the quantity of maize sold at the harvest season of only 7 to 9%, while the same increase is two times greater when generated by the Heckman selection procedure. These results clearly show that taking into account the selection issue related to unobserved cash needs is of crucial importance for our estimates.

## 6 Structural Estimate of the Effects of Preferences

Because the validity of the exclusion restrictions in a selection model cannot be tested, we return to the theoretical model with the aim of structurally estimating the impact of risk and time preferences. While we must still deal with the missing data issue, it is possible to solve this problem without making any assumptions about the selection process that sorts farmers into the group of sellers. Specifically, we address this issue by estimating the value of the unobserved cash availability ( $B$ ) for the subset of sellers. To do so, we use Proposition 2, which describes the relationship between  $q_{hi}^g$  and  $B$  (and all other observable parameters). Because this relationship is linear in  $\frac{B}{\underline{p}}$ , we are able to obtain an estimator of  $\frac{B}{\underline{p}}$  directly by applying the OLS estimator to the following regression equation:

$$q_{hi}^g = x_{0i} + \frac{B}{\underline{p}} x_{1i} + v_i \quad (21)$$

where  $x_{0i} = \left(\frac{\theta_i}{1+\theta_i}\right) \left(\frac{1}{1+\sigma}\right) H$ ,  $x_{1i} = \left(\frac{\theta_i}{1+\theta_i}\right) \left(\frac{1}{1+\sigma}\right) - 1$  and where  $\theta_i = \left( (1 + \delta_i) \left(\frac{\bar{p}}{\underline{p}}\right)^{-(1-r_i)} \right)^{\frac{1}{(1+\sigma)r_i-\sigma}}$ .

We obtain an estimate of the (homogeneous) parameter  $B$  that falls close to 60,000 CFA if computed from measures of impatience in the far future, and around 30,000 CFA if computed from measures of impatience in the near future.

<sup>40</sup>For the sake of readability, the coefficients associated with controls are not shown in the tables. Results are available upon request.

Having estimated a value for  $B/\underline{p}$  (and the estimated common parameter  $\sigma$ ), we are able to compute the individual marginal impact of impatience ( $\delta_i$ ) on sales ( $q_{hi}^g$ ) using Equation (9), where we introduce subscript  $i$  to denote household specific variables (see Section 2.4):

$$\frac{\partial q_{hi}^{g*}}{\partial \delta_i} = \frac{\theta_i}{(1+\theta_i)^2} \frac{1}{1+\sigma} \frac{1}{1+\delta_i} \frac{H_i + B/\underline{p}}{(1+\sigma)r_i - \sigma}, \quad (22)$$

as well as the marginal impacts of risk aversion using Equation (10):

$$\frac{\partial q_{hi}^{g*}}{\partial r_i} = -\frac{1}{1+\sigma} \frac{\theta_i}{(1+\theta_i)^2} \frac{H_i + B/\underline{p}}{(r_i - \sigma + r\sigma)^2} \ln\left((1+\delta_i)^{1+\sigma} \underline{p}/\bar{p}\right), \quad (23)$$

where  $\theta_i$  is defined as in Equation (21).

Table 13 compares the results we obtain from this structural approach with those we obtain from the linear approximation approach (i.e. the sample selection model). The average marginal impacts are actually very close. Using the measure of impatience derived from the one-month-delay experiment, a one-standard-deviation increase in impatience results in an increase in the quantity of grain sold by about 350 kg in the structural estimation, and by about 260 kg in the linear approximation model. Results are comparable when considering the measure of impatience derived from the four-day-delay experiment: a one-standard-deviation increase in impatience results in an increase in the quantity of grain sold by about 280 kg in the structural model versus 220 kg in the linearized model. This corresponds to an increase in sales (from the mean value) that ranges from 19% to 21% when relying on estimates from the linearized model, and from 16% to 26% when relying on structural estimates. This translates to even larger impacts on storage: a one-standard-deviation increase in impatience results in a decrease that ranges from 44% to 47% when we use the linearized model, and from 37% to 60% when we use the structural model.

Similar comments can be made about the impact of risk aversion: both approaches yield average estimates that are similar in size, albeit much less precise (Table 14). A one-standard-deviation increase in risk aversion results in a decrease in sales (from the mean value) that ranges from 10% to 14% when we use the linearized model, and from 10% to 50% when we use the structural model. This translates to an increase in storage that ranges from 24% to 33% using the linearized model, and from 23% to 113% using the structural model. Overall, our results are robust to the two approaches. We are thus confident that the theoretical framework, parameterized to our data, can be used to simulate public policies.

## 7 Price Stabilisation Policy

In this section, we use the theoretical results from Section 2.5 to simulate a grain price stabilisation policy, and we quantify farmers' willingness to accept (WTA) not implementing this policy. The WTA can be understood as the individual cash transfer that should be provided by the government to make a farmer from the group of sellers indifferent between receiving this cash transfer and benefiting from the implementation of the price stabilisation policy.

## 7.1 A Counterfactual Simulation Experiment

In order to calculate the values of  $p^*$  and  $G^*$  that define the counterfactual price stabilisation policy, we begin by computing the total quantity of grain sold during both seasons. Again using secondary data on grain prices made available by SONAGESS (see Section 4), we replace  $\underline{p} = 100$  CFA francs per kg and  $\bar{p} = 144$  CFA francs per kg in Equation (16) that describes the relationship between  $q_h^{g*}$ ,  $\bar{p}$ ,  $\underline{p}$ , the previously estimated common parameters  $B$  and  $\sigma$ , and all other individual parameters observable in our data ( $H, \delta, r$ ). The same computations are performed for  $q_l^{g*}$ .

By aggregating the values of  $q_h^{g*}$  and  $q_l^{g*}$  for all farmers in the sample, we obtain 684 tons of maize for the harvest season and 604 tons of maize for the lean season. It is worth noting that these quantities, which are predicted by the model, are very close to the aggregated quantities of maize that were actually sold by the farmers in the sample. In our data, the aggregated quantity sold by farmers during the harvest season is 666 tons of maize.<sup>41</sup> Figure 6, which compares the actual and predicted quantities sold, suggests that our model performs quite well in reproducing the observed data.

Assuming that the demand function is linear,  $D(p) = ap + d$ , we are then able to recover the two parameters of the demand function: its slope  $a < 0$  and its maximum  $d > 0$ . We find  $a \simeq -1,829$  and  $d \simeq 866,989$ . Solving for the market clearing conditions (see conditions 13 and 14 in Section 2.5), we find that  $p^*$  falls around 120 CFA francs per kg. This corresponds to a price elasticity of grain demand around -0.35. The corresponding quantity  $G^*$  falls close to 107 tons of maize.<sup>42</sup> Replacing  $p^*$  by its value in the expression of the optimal grain sales at the harvest season  $q_h^{g*}$  (see Proposition 2), we are able to compute the grain sales for each farmer under the scenario where the price of grain is 120 CFA francs per kg throughout the year. Figure 7 compares the predicted quantities sold without policy with those that the model predicts under the price stabilisation policy scenario. The chart illustrates that a price grain policy would translate into higher sales by farmers post-harvest (about 70 tons more in all, i.e. a 10% increase).

## 7.2 Farmer Willingness to Accept

Replacing  $p^*$  by its value in the expression of WTA derived from equality (15), we then compute the WTA for each farmer. The distribution of individual WTAs is displayed on Figure 8. Half of farmers have a positive willingness to accept, which indicates that they would benefit from the maize price stabilisation policy. For these farmers, the WTA exceeds 1,200 CFA. For one quarter of the farmers, the WTA even exceeds 15,000 CFA, which corresponds to one 100kg bag of maize. The fact that a price stabilisation policy would be beneficial to half of the farmers in our sample is mainly driven by the price increase in the harvest season (+20%). Interestingly, this translates to higher consumption of the generic good (+20%) in the harvest season for the median farmer. Grain consumption does not increase much (+1.5%). In the lean season, both consumption levels are lower (a 30% decrease in grain consumption and a 42% decrease in generic good consumption).

Finally, we examine the cost-effectiveness of the price stabilisation policy under study. Assuming that the costs of storing grain incurred by the Government represent around 9% of the market value

<sup>41</sup>We do not observe sales that occur between February 2013 and September 2013. However, we observe sales that occur between February 2012 and September 2012, which refers to the previous lean season. The aggregated quantity sold over this period is 546 tons.

<sup>42</sup>Using conditions (13) and (14), we have  $G^* = \frac{1}{2}(S_h - S_l)$  and  $p^* = \frac{1}{a} \left( \frac{1}{2}(S_h + S_l) - d \right)$ .

of the quantity  $G^*$  that is stored until the lean season,<sup>43</sup> we estimate these costs to amount to about 2,300 CFA francs per farmer. Because the median WTA does not exceed 1,200 CFA francs, we conclude that the price stabilisation policy would not be cost-effective for the median seller in our sample.<sup>44</sup>

## 8 Conclusion

Onfarm grain storage is an important consumption smoothing asset in developing countries, and storage decisions can vary significantly across households from a given region. Most studies show that many farmers who are expected to store grain 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 harvest season are liquidity constrained, we have provided evidence that impatience and risk aversion also significantly affect the quantity of grain sold in the harvest period. We report large effects of risk and time preferences on storage behaviours. A one-standard-deviation increase in impatience results in a large decrease in storage of about 45%, and a one-standard-deviation increase in risk aversion results in a large increase in storage, about 25%. The estimated effects are statistically significant and robust to various measures of time and risk preferences.

We moreover showed that our theoretical model performs quite well in reproducing the observed data. We therefore utilized it to simulate a grain price stabilisation policy. We showed that half of farmers among sellers would benefit from such a policy and that this result is mainly driven by the increase in the price of grain during the harvest season. Finally, we showed that the amount of cash that would compensate the median farmer for not implementing the grain price stabilisation policy is about 1,200 CFA francs. This value does not exceed the per capita storage costs associated with the policy.

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<sup>43</sup>This figure is based on estimates provided by Ayel, Beaujeu, Blein, Coste, Gérard, Konaté, Leturque, Rayé, and Siam (2013).

<sup>44</sup>The price stabilisation policy would be cost-effective for 47% of farmers.

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## Tables and Figures

Table 1: 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	man=1	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
Distance to market	minutes	1544	40.1	25.5	0	122
<b>Cultivated areas</b>						
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
<b>Production levels</b>						
Cotton	ton	1543	4.45	10.87	0	272
Maize	ton	1544	3.63	7.10	0	97
Sorghum	ton	1546	1.34	1.95	0	26
Millet	ton	1547	0.54	1.00	0	14
Sesam	ton	1540	0.11	0.26	0	4
Groundnut	ton	1535	0.19	0.41	0	5
Rice	ton	1544	0.19	0.76	0	17
<b>Maize marketing</b>						
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

Note: This table shows summary statistics for a set of variables. yes=1 means that the variable is a dummy.

Table 2: Maize Sales over the Two Seasons

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

Note: Previous  $q_l$  refers to maize sales that occur between February 2012 and September 2012. Current  $q_h$  refers to maize sales that occur between October 2012 and January 2013.

Table 3: The 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 4: Elicited Risk Aversion and Discount Rate

Variable	Mean	1 <sup>st</sup> Quartile	Median	3 <sup>rd</sup> Quartile
$r$ (low payoffs)	0.69	0.34	0.63	1.06
$r$ (high payoffs)	0.63	0.25	0.59	0.93
$\delta^{\text{far}}$ (1 month)	0.24	0.12	0.23	0.38
$\delta^{\text{near}}$ (4 days)	0.09	0.05	0.10	0.14

Note: The first row ( $r$  (low payoffs)) and the second row ( $r$  (high payoffs)) display summary statistics for the risk aversion parameters that were elicited from the low-payoff experiment and the high-payoff experiment, respectively. The third row ( $\delta^{\text{far}}$ ) and the fourth row ( $\delta^{\text{near}}$ ) display summary statistics for the discount rates that were elicited from the 1-month-delay experiment and the 4-day-delay experiment, respectively. This was done given a constant relative risk aversion utility function where the risk aversion parameter was set to the sample mean (low payoffs),  $r = 0.69$ .

Table 5: “Would you prefer to get A in one day or B in five days?”

	A	B	range of $\delta$	
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  $\delta$ ” indicates the associated interval for monthly  $\delta$  for a respondent who switches from A to B.

Table 6: “Would you prefer to get A in one month or B in two months?”

	A	B	range of $\delta$	
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  $\delta$ ” indicates the associated interval for monthly  $\delta$  for a respondent who switches from A to B.

Table 7: Elicited Discount Factors

Discount factor	Obs.	Mean	1 <sup>st</sup> Quartile	Median	3 <sup>rd</sup> Quartile
Separate estimate	1293	0.78	0.71	0.78	0.86
Joint estimate	989	0.57	0.42	0.52	0.72
Joint estimate ( $\alpha$ )	979	0.60	0.48	0.58	0.71

Note: This table shows summary statistics for discount factors (not discount rates) in order to make the values directly comparable. The first row (*Separate estimate*) displays summary statistics for the discount factor that was elicited from the 1-month-delay experiment, in which risk aversion is set to the sample mean,  $r = 0.69$ . The second row (*Joint estimate*) displays summary statistics for the discount factor that was elicited jointly with the risk aversion parameter, from the four experiments. This discount factor is assumed to be of the exponential form, that is  $\exp(-\delta_i t)$ , where  $t$  is the time delay and  $\delta_i$  is a monthly value. The last row (*Joint estimate ( $\alpha$ )*) displays summary statistics for the discount factor that was elicited jointly with the risk aversion parameter and a common hyperbolic parameter  $\alpha$ . This discount factor is assumed to be of the form  $\exp(-\delta_i t^\alpha)$ , where  $t$  is the time delay and  $\alpha$  captures hyperbolic preferences. This table reports summary statistics for positive discount factors only.

Table 8: Description of Variables

Label	Unit	Description
risk aversion ( $r$ )	none	risk aversion coefficient
discount rate ( $\delta$ )	none	discount rate
hyperbolic parameter ( $\alpha$ )	none	constructed from $\exp \delta_i^{\text{near}} \left(\frac{4}{30}\right)^{\alpha_i} = \exp \delta_i^{\text{far}} (1)^{\alpha_i}$
maize harvest ( $H$ )	tons	maize harvest
cattle $\geq$ 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	number of chickens, turkeys, ducks, and geese
family	number	number of members in the household
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
time	minutes	time to reach the market
po	dummy	equals one if the farmer is member of a producer organization
$q_{\text{lean}}$	dummy	equals one if the farmer sold maize during previous lean season

Table 9: The Effect of Preferences on Sales

	(1)		(2)		(3)		(4)		(5)	
Dep. Var. is Sales ( $q_h$ )	H2S		MLE		MLE		MLE		MLE	
risk aversion	-255.24	*	-258.39	°	-196.04	°	-317.98	*	-231.61	*
	<i>143.10</i>		<i>157.35</i>		<i>129.63</i>		<i>168.00</i>		<i>137.61</i>	
discount rate	1163.60	***	1125.83	**	1153.40	**	2739.43	**	2655.81	**
	<i>399.16</i>		<i>490.22</i>		<i>519.90</i>		<i>1097.47</i>		<i>1161.93</i>	
H maize	92.46	***	110.90	***	110.00	***	110.39	***	108.67	***
	<i>15.80</i>		<i>31.62</i>		<i>31.65</i>		<i>31.32</i>		<i>31.40</i>	
<hr/>										
Dep. Var. is $V$										
risk aversion	0.30	***	0.29	***	0.25	***	0.35	***	0.28	***
	<i>0.06</i>		<i>0.10</i>		<i>0.09</i>		<i>0.11</i>		<i>0.10</i>	
discount rate	-0.86	***	-0.82	**	-0.86	**	-2.48	***	-2.44	***
	<i>0.16</i>		<i>0.39</i>		<i>0.39</i>		<i>0.75</i>		<i>0.80</i>	
H maize	0.04	***	0.06	**	0.06	**	0.06	**	0.06	**
	<i>0.01</i>		<i>0.02</i>		<i>0.02</i>		<i>0.02</i>		<i>0.02</i>	
po	0.55	***	0.46	***	0.46	***	0.45	**	0.45	**
	<i>0.13</i>		<i>0.17</i>		<i>0.17</i>		<i>0.18</i>		<i>0.18</i>	
$q_{lean}$	0.32	***	0.18	°	0.19	°	0.19	°	0.19	°
	<i>0.08</i>		<i>0.12</i>		<i>0.12</i>		<i>0.13</i>		<i>0.13</i>	
<hr/>										
$\lambda$	-1272.83	***	-1252.02	***	-1248.32	***	-1258.35	***	-1259.97	***
	<i>449.18</i>		<i>545.39</i>		<i>553.93</i>		<i>544.40</i>		<i>555.30</i>	
$\text{atanh}\rho$			-0.91	**	-0.90	**	-0.91	**	-0.91	**
			<i>0.38</i>		<i>0.38</i>		<i>0.38</i>		<i>0.39</i>	
$\chi_2$			5.75	**	5.53	**	5.81	**	5.58	**
Number of obs	1496		1496		1496		1496		1496	
Censored obs	1007		1007		1007		1007		1007	
Uncensored obs	489		489		489		489		489	
Payoffs	low		low		high		low		high	
Time delay	1 month		1 month		1 month		4 days		4 days	

Note: This table reports estimation results for the sample selection model. The top of the table reports the estimates of the outcome equation, where the dependent variable is the quantity of maize sold during harvest season. The bottom of the table reports the estimates of the selection equation. Both equations also include as controls the harvested quantities of sorghum, millet, rice, groundnut, and cotton, the total number of cattle and of poultry, the family size and time to travel to the market. Column (1) reports Heckman-Two-Step estimates, columns (2) to (5) report Maximum Likelihood estimates.  $\lambda$ ,  $\text{atanh}\rho$ , and  $\chi_2$  are statistics of three tests of the null hypothesis  $\rho = 0$ , where  $\rho$  is the correlation between the error terms of the two equations. Standard errors clustered at village level are in italics. Three asterisks \*\*\* (resp. \*\*, \*, °) denote rejection of the null hypothesis at the 1% (resp. 5%, 10%, 15%) significance level. The variables *risk aversion* and *discount rate* are individual parameters that were estimated separately from the experiments, as explained in Section 3.3.1 and in Section 3.3.2. The row *Payoffs* indicates whether the low-payoff experiment or the high-payoff experiment was used to elicit the risk aversion parameter included in the model. The row *Time delay* indicates whether the 4-day-delay experiment or the 1-month-delay experiment to elicit the discount rate included in the model.

Table 10: The Effect of Preferences on Sales - joint estimates of preferences

	(1)		(2)		(3)		(4)	
Dep. Var. is Sales ( $q_h$ )	H2S		MLE		H2S		MLE	
risk aversion	132.96		90.76		-158.72		-204.26	
	<i>469.36</i>		<i>401.37</i>		<i>535.21</i>		<i>432.27</i>	
discount rate	413.86	***	407.34	**	474.58	***	468.14	**
	<i>143.49</i>		<i>175.65</i>		<i>166.67</i>		<i>202.05</i>	
H maize	92.58	***	109.41	***	93.26	***	0.11	***
	<i>15.56</i>		<i>31.16</i>		<i>15.40</i>		<i>0.03</i>	
<hr/>								
Dep. Var. is $V$								
risk aversion	0.31		0.29		0.64		0.61	
	<i>0.24</i>		<i>0.42</i>		<i>0.26</i>		<i>0.42</i>	
discount rate	-0.35	***	-0.33	***	-0.43	***	-0.41	***
	<i>0.06</i>		<i>0.11</i>		<i>0.06</i>		<i>0.13</i>	
H maize	0.04	***	0.06	**	0.04	***	0.06	**
	<i>0.01</i>		<i>0.02</i>		<i>0.01</i>		<i>0.02</i>	
po	0.56	***	0.47	***	0.56	***	0.47	***
	<i>0.12</i>		<i>0.17</i>		<i>0.12</i>		<i>0.18</i>	
$q_{lean}$	0.32	***	0.19	°	0.32	***	0.19	°
	<i>0.08</i>		<i>0.13</i>		<i>0.08</i>		<i>0.13</i>	
<hr/>								
$\lambda$	-1217.52	***	-1231.92	***	-1221.76	***	-1230.68	***
	<i>439.77</i>		<i>547.47</i>		<i>439.04</i>		<i>550.32</i>	
$\text{atanh}\rho$			-0.89	**			-0.89	**
			<i>0.38</i>				<i>0.38</i>	
$\chi_2$			5.54	**			5.45	**
Number of obs	1496		1496		1496		1496	
Censored obs	1007		1007		1007		1007	
Uncensored obs	489		489		489		489	
Hyperbolic	no		no		yes		yes	

Note: This table reports estimation results for the sample selection model, where individual preferences are jointly elicited. The top of the table reports the estimates of the outcome equation, where the dependent variable is the quantity of maize sold during harvest season. The bottom of the table reports the estimates of the selection equation. Both equations also include as controls the harvested quantities of sorghum, millet, rice, groundnut, and cotton, the total number of cattle and of poultry, the family size and time to travel to the market. Columns (1) and (3) report Heckman-Two-Step estimates, columns (2) to (4) report Maximum Likelihood estimates.  $\lambda$ ,  $\text{atanh}\rho$ , and  $\chi_2$  are statistics of three tests of the null hypothesis  $\rho = 0$ , where  $\rho$  is the correlation between the error terms of the two equations. Standard errors clustered at village level are in italics. Three asterisks \*\*\* (resp. \*\*, \*, °) denote rejection of the null hypothesis at the 1% (resp. 5%, 10%, 15%) significance level. The variables *risk aversion* and *discount rate* are individual parameters that were jointly estimated from the experiments, as explained in Section 3.3.2. The elicited discount rates are a monthly values. The row *Hyperbolic* indicates whether the joint elicitation of risk and time preferences includes the common hyperbolic discounting parameter (à la (Prelec, 2004)).

Table 11: The Effect of Preferences on Sales - Specification including hyperbolic parameter  $\alpha$

Dep. Var. is Sales ( $q_h$ )	H2S		MLE		MLE		MLE		MLE	
risk aversion	-475,63	***	-412,36	**	-300,68	*	-384,73	**	-260,25	*
	<i>176,09</i>		<i>191,04</i>		<i>155,13</i>		<i>182,71</i>		<i>138,68</i>	
discount rate	1633,67	***	1425,37	***	1548,99	**	4248,00	***	4536,10	***
	<i>476,77</i>		<i>537,45</i>		<i>604,28</i>		<i>1552,30</i>		<i>1705,75</i>	
hyperbolic $\alpha$	214,93		182,66		181,93		357,81	*	368,34	*
	<i>201,92</i>		<i>153,19</i>		<i>156,27</i>		<i>198,41</i>		<i>201,30</i>	
H maize	94,72	***	116,37	***	115,27	***	116,48	***	114,99	***
	<i>19,75</i>		<i>29,38</i>		<i>29,57</i>		<i>29,51</i>		<i>29,76</i>	
<hr/>										
Dep. Var. is $V$										
risk aversion	0,38	***	0,38	***	0,33	***	0,36	***	0,30	***
	<i>0,07</i>		<i>0,12</i>		<i>0,10</i>		<i>0,12</i>		<i>0,10</i>	
discount rate	-1,07	***	-1,00	**	-1,14	**	-3,31	**	-3,57	***
	<i>0,19</i>		<i>0,46</i>		<i>0,47</i>		<i>1,29</i>		<i>1,29</i>	
hyperbolic $\alpha$	0,04		0,04		0,04		-0,12		-0,14	
	<i>0,11</i>		<i>0,12</i>		<i>0,12</i>		<i>0,14</i>		<i>0,14</i>	
H maize	0,05	***	0,08	***	0,08	***	0,08	***	0,08	***
	<i>0,01</i>		<i>0,03</i>		<i>0,03</i>		<i>0,03</i>		<i>0,03</i>	
op	0,45	***	0,34	*	0,34	*	0,33	*	0,32	*
	<i>0,13</i>		<i>0,18</i>		<i>0,18</i>		<i>0,18</i>		<i>0,18</i>	
$q_{lean}$	0,29	***	0,13		0,14		0,14		0,15	
	<i>0,09</i>		<i>0,14</i>		<i>0,24</i>		<i>0,14</i>		<i>0,14</i>	
<hr/>										
$\lambda$	-1576,86	***	-1330,93	***	-1341,33	***	-1340,54		-1355,37	***
	<i>493,24</i>		<i>597,75</i>		<i>618,55</i>		<i>604,85</i>		<i>626,81</i>	
$\text{atanh}\rho$			-1,01	**	-1,02	**	-1,02		-1,03	**
			<i>0,45</i>		<i>0,47</i>		<i>0,46</i>		<i>0,48</i>	
$\chi_2$			4,96	**	4,65	**	4,91	**	4,61	**
Number of obs	1344		1344		1344		1344		1344	
Censored obs	913		913		913		913		913	
Uncensored obs	431		431		431		431		431	
Payoffs	low		low		high		low		high	
Time delay	1 month		1 month		1 month		4 days		4 days	

Note: This table reports estimation results for the sample selection model, including the individual hyperbolic discounting parameter  $\alpha$ . The top of the table reports the estimates of the outcome equation, where the dependent variable is the quantity of maize sold during harvest season. The bottom of the table reports the estimates of the selection equation. Both equations also include as controls the harvested quantities of sorghum, millet, rice, groundnut, and cotton, the total number of cattle and of poultry, the family size and time to travel to the market. Column (1) reports Heckman-Two-Step estimates, columns (2) to (5) report Maximum Likelihood estimates.  $\lambda$ ,  $\text{atanh}\rho$ , and  $\chi_2$  are statistics of three tests of the null hypothesis  $\rho = 0$ , where  $\rho$  is the correlation between the error terms of the two equations. Standard errors clustered at village level are in italics. Three asterisks \*\*\* (resp. \*\*, \*, °) denote rejection of the null hypothesis at the 1% (resp. 5%, 10%, 15%) significance level. The variables *risk aversion* and *discount rate* are individual parameters that were estimated separately from the experiments, as explained in Section 3.3.1 and in Section 3.3.2. The row *Payoffs* indicates whether the low-payoff experiment or the high-payoff experiment was used to elicit the risk aversion parameter included in the model. The row *Time delay* indicates whether the 4-day-delay experiment or the 1-month-delay experiment to elicit the discount rate included in the model.

Table 12: OLS Estimates of the Effect of Preferences on Sales

	(1)	(2)	(3)	(4)
Dep. Var. is Sales ( $q_h$ )	OLS	OLS	OLS	OLS
risk aversion	-45.94 <i>113.73</i>	-10.34 <i>96.99</i>	-72.96 <i>118.80</i>	-22.39 <i>100.76</i>
discount rate	540.66 * <i>306.61</i>	530.26 * <i>309.18</i>	990.76 ° <i>686.11</i>	907.93 <i>688.08</i>
H maize	118.06 *** <i>11.44</i>	117.54 *** <i>11.38</i>	117.27 *** <i>11.43</i>	116.53 *** <i>11.37</i>
Number of obs	489	489	489	489
Payoffs	low	high	high	low
Time delay	1 month	1 month	4 days	4 days

Note: This table reports OLS estimation results for a regression of the grain sales on risk and time preferences. Controls include the harvested quantities of sorghum, millet, rice, groundnut, and cotton, the total number of cattle and of poultry, the family size and time to travel to the market. Standard errors clustered at village level are in italics. Three asterisks \*\*\* (resp. \*\*, \*, °) denote rejection of the null hypothesis at the 1% (resp. 5%, 10%, 15%) significance level. The variables *risk aversion* and *discount rate* are individual parameters that were estimated separately from the experiments, as explained in Section 3.3.1 and in Section 3.3.2. The row *Payoffs* indicates whether the low-payoff experiment or the high-payoff experiment was used to elicit the risk aversion parameter included in the model. The row *Time delay* indicates whether the 4-day-delay experiment or the 1-month-delay experiment was used to elicit the discount rate included in the model.

Table 13: Structural Estimates of the Effect of Impatience on Sales and on Storage

(1)	(2)	Marginal Effect on Sales			+1 SD on Sales (kg)		+1 SD on Sales (%)		Effect on Storage (%)	
		(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
risk aversion	discount rate	Linear	Structural	$B/p$	Linear	Structural	Linear	Structural	Linear	Structural
low payoffs	1 month	1126 **	1546 ***	687 ***	+258 kg	+354 kg	+19%	+26%	-44%	-60%
high payoffs	1 month	1153 **	1537 ***	591 ***	+264 kg	+352 kg	+19%	+26%	-45%	-60%
low payoffs	4 days	2739 **	2286 ***	299 ***	+285 kg	+238 kg	+21%	+17%	-48%	-40%
high payoffs	4 days	2656 **	2071 ***	364 ***	+276 kg	+215 kg	+20%	+16%	-47%	-37%

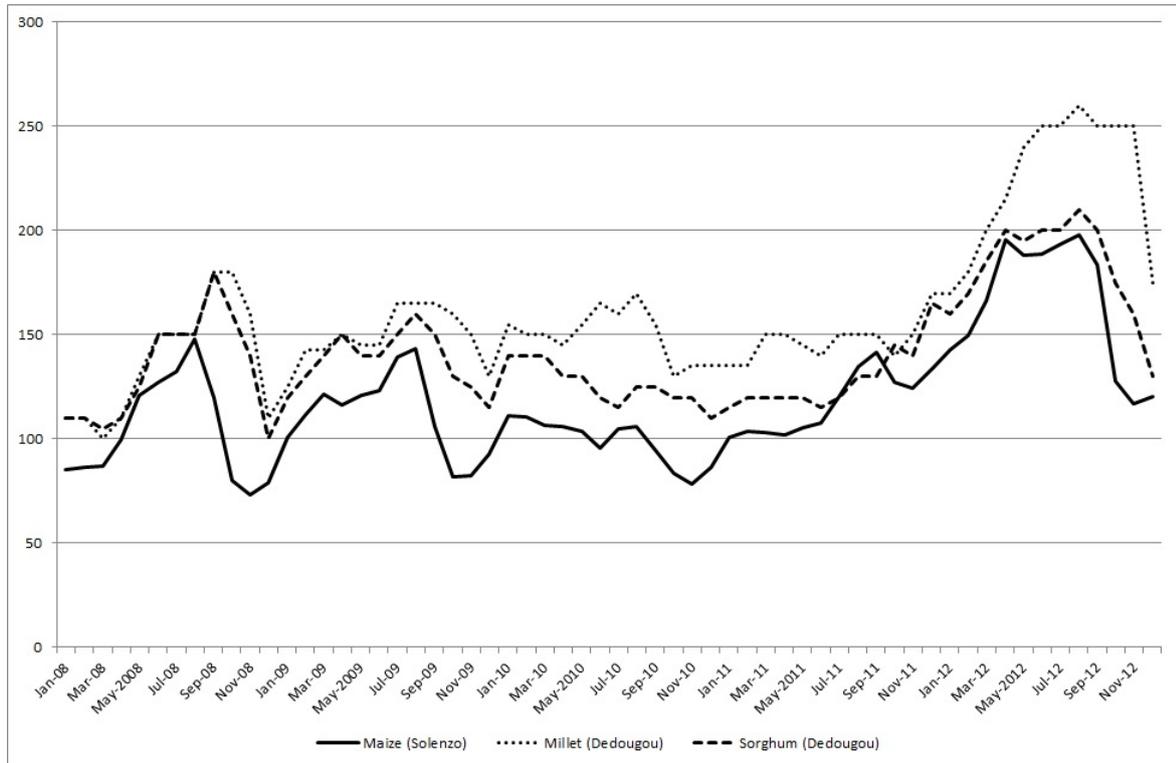
Note: This table compares estimation results for the sample selection model and the structural approach. Three asterisks \*\*\* (resp. \*\*, \*, °) denote rejection of the null hypothesis at the 1% (resp. 5%, 10%, 15%) significance level. For the structural estimates, standard errors are computed using a bootstrap procedure. Column (1) indicates whether the low-payoff experiment or the high-payoff experiment was used to elicit the risk aversion parameter. Column (2) indicates whether the four-day-delay experiment or the one-month-delay experiment was used to elicit the discount rate. Column (3) reports the average effect of an increase in the discount rate on sales when using the sample selection model. Column (4) reports the average effect of an increase in the discount rate on sales computed from equation (22). Column (5) reports the estimates of the cash amount  $B/p$  (in kg of maize). Columns (6) and (7) report additional sales of maize (in kg) induced by a one-standard-error increase in the discount rate when using the sample selection model and the structural model, respectively. Columns (8) and (9) report the same results expressed as a percentage of average sales. Columns (10) and (11) report additional stored quantities of maize (in percentage of average stored quantities) induced by a one-standard-error increase in the discount rate when using the sample selection model and the structural model, respectively.

Table 14: Structural Estimates of the Effect of Risk Aversion on Sales and on Storage

risk aversion	Marginal effect of risk aversion				+1 SD on Sales (kg)		+1 SD on Sales (%)		+1 SD on Storage (%)	
	discount rate	Linear	Structural	$B/p$	Linear	Structural	Linear	Structural	Linear	Structural
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
low payoffs	1 month	-258 °	-1085 ***	687 ***	-158 kg	-662 kg	-12%	-49%	+27%	+113%
high payoffs	1 month	-196 °	-589 ***	591 ***	-139 kg	-419 kg	-10%	-31%	+24%	+71%
low payoffs	4 days	-318 *	-445 °	299 ***	-194 kg	-271 kg	-14%	-20%	+33%	+46%
high payoffs	4 days	-232 *	-190 ns	364 ***	-165 kg	-135 kg	-12%	-10%	+28%	+23%

Note: This table compares estimation results for the sample selection model and the structural approach. Three asterisks \*\*\* (resp. \*\*, \*, °) denote rejection of the null hypothesis at the 1% (resp. 5%, 10%, 15%) significance level. For the structural estimates, standard errors are computed using a bootstrap procedure. Column (1) indicates whether the low-payoff experiment or the high-payoff experiment was used to elicit the risk aversion parameter. Column (2) indicates whether the four-day-delay experiment or the one-month-delay experiment was used to elicit the discount rate. Column (3) reports the average effect of an increase in the risk aversion parameter on sales when using the sample selection model. Column (4) reports the average effect of an increase in the risk aversion parameter on sales computed from equation (22). Column (5) reports the estimates of the cash amount  $B/p$  (in kg of maize). Columns (6) and (7) report additional sales of maize (in kg) induced by a one-standard-error increase in the risk aversion parameter when using the sample selection model and the structural model, respectively. Columns (8) and (9) report the same results expressed as a percentage of average sales. Columns (10) and (11) report additional stored quantities of maize (in percentage of average stored quantities) induced by a one-standard-error increase in the risk aversion parameter when using the sample selection model and the structural model, respectively.

Figure 1: Wholesale price of cereals in Mouhoun (nominal price in CFA/kg)



Source: SONAGESS.

Figure 2: Location of surveyed farmers

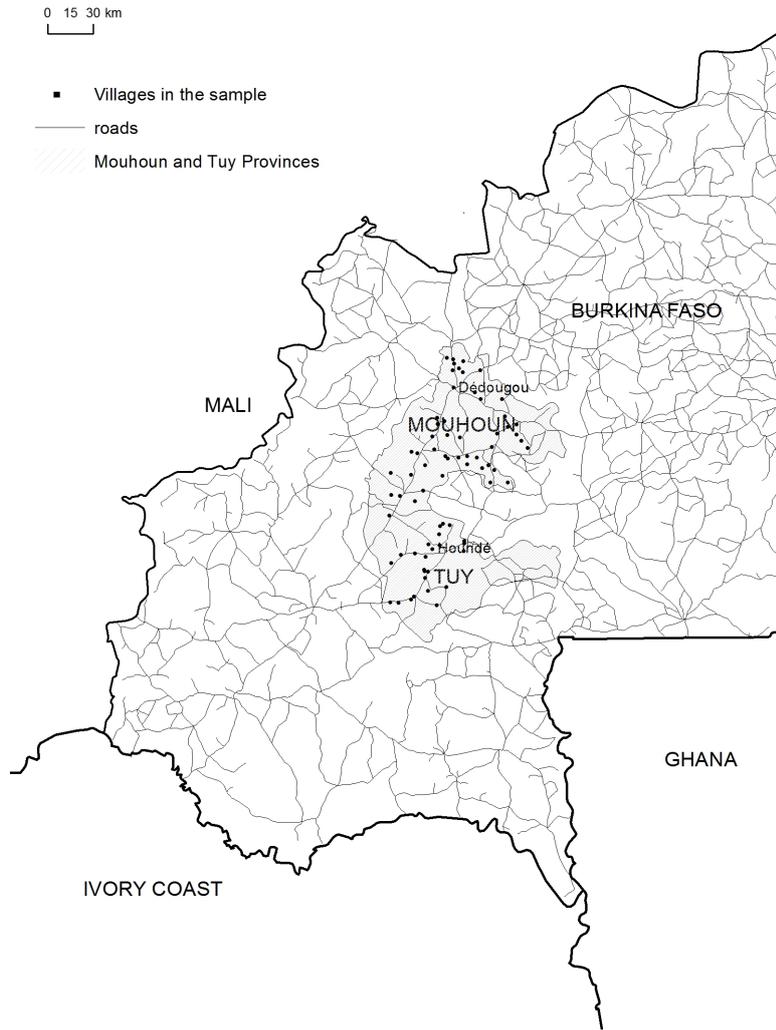


Figure 3: Elicited risk aversion coefficients (low payoffs)

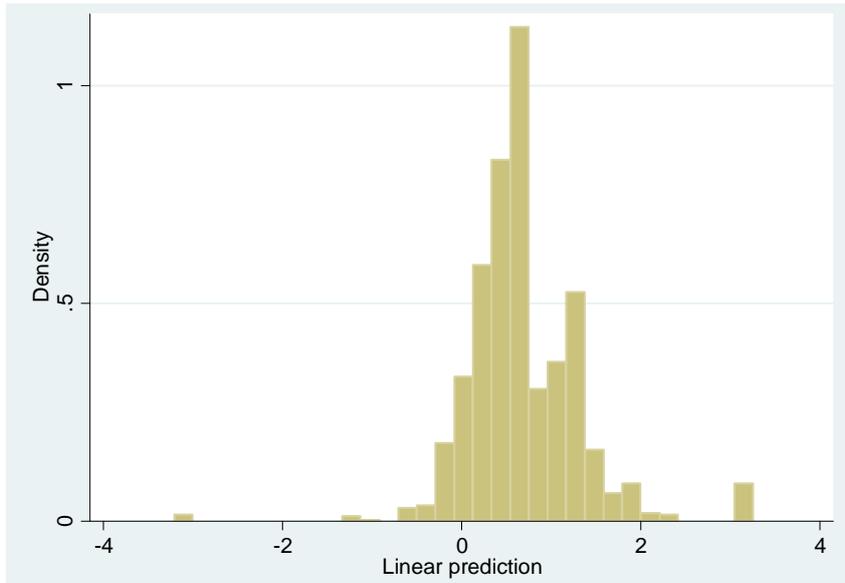


Figure 4: Elicited risk aversion coefficients (high payoffs)

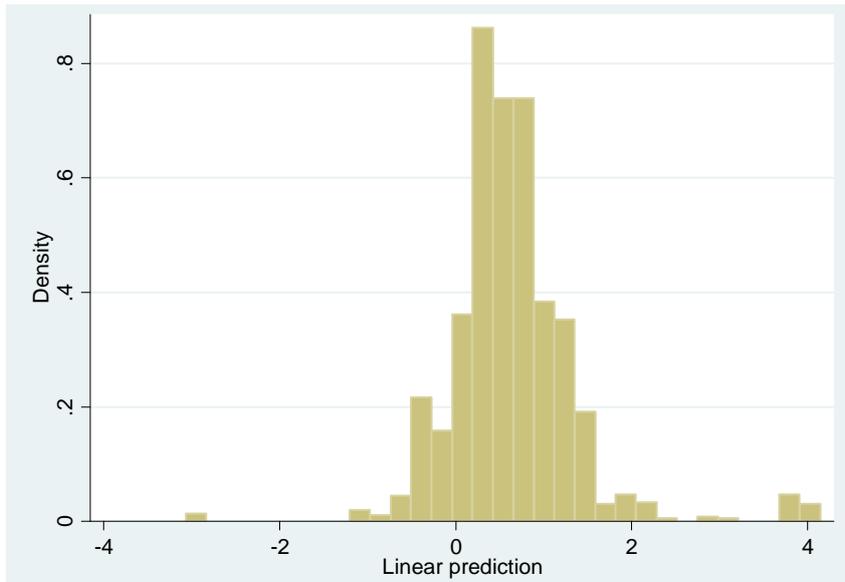


Figure 5: Comparison of elicited discount rates ( $\delta$ )

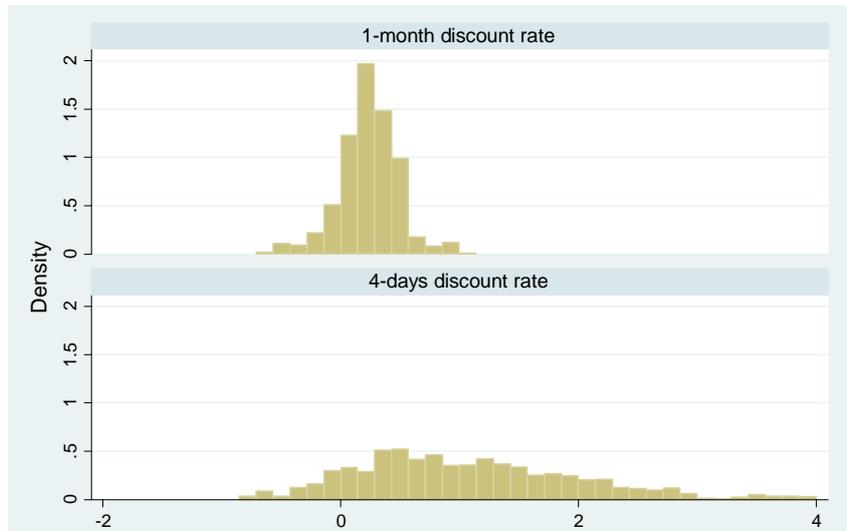


Figure 6: Distribution of grain sales (predicted versus actual values)

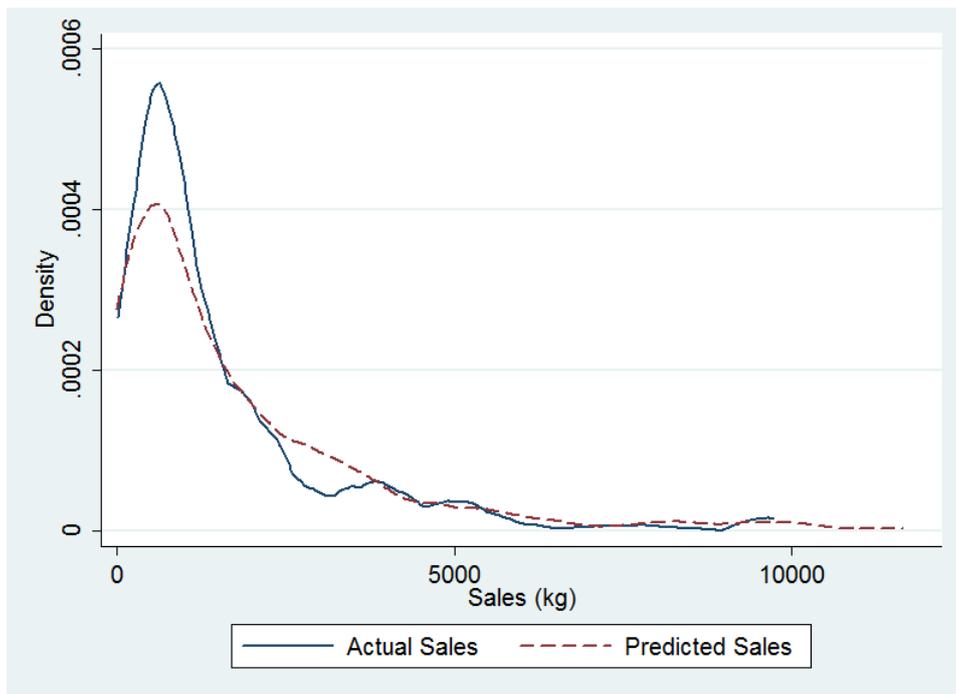


Figure 7: Distribution of predicted sales (in kg)

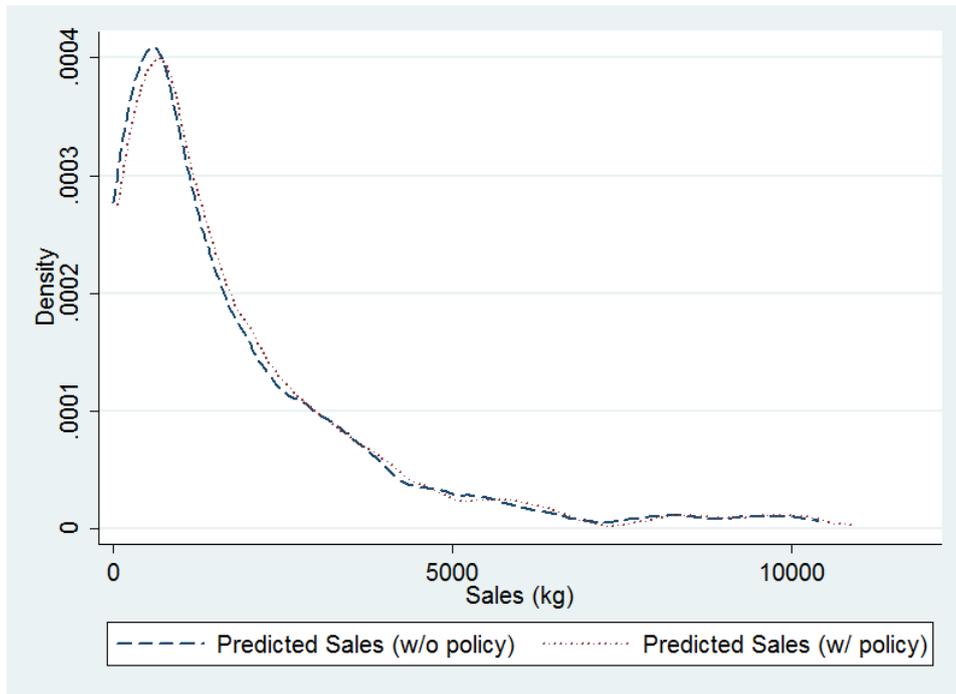
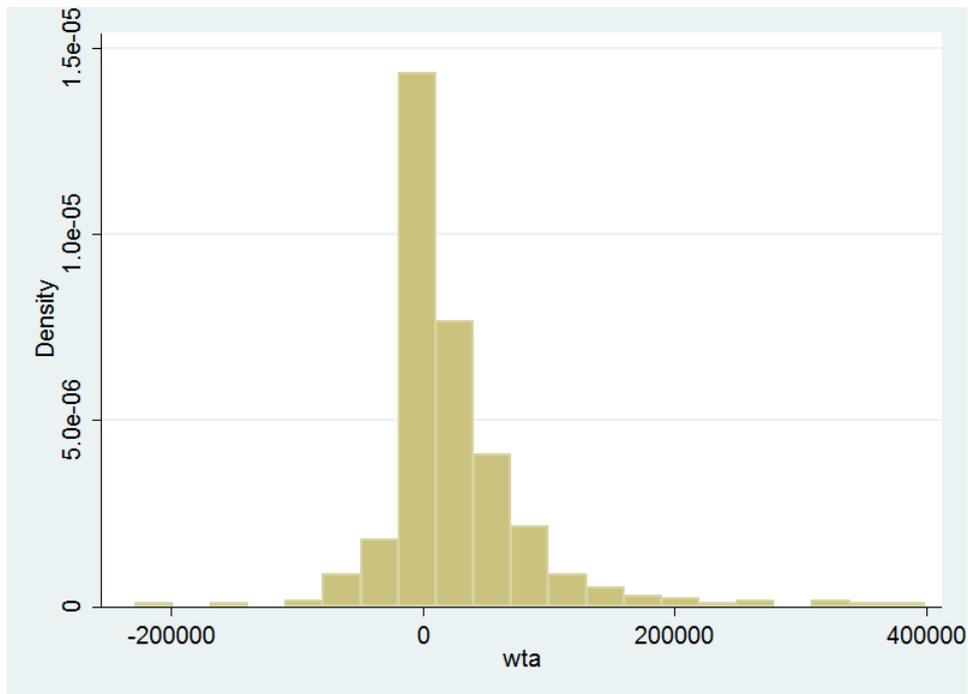


Figure 8: Distribution of Willingness To Accept (in CFA francs)



## 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 holds):

$$\text{Maximize}_{\{c_h^g, q_h^g, c_l^g, q_l^g\}} U = \frac{1}{1-r} \left( (c_h^g)^\sigma (\underline{p}q_h^g + b_h) \right)^{1-r} + \frac{1}{1+\delta} \frac{1}{1-r} \left( (c_l^g)^\sigma (\bar{p}q_l^g + B - b_h) \right)^{1-r}, \quad (24)$$

such that:

$$c_h^g + q_h^g + c_l^g + q_l^g = H, \quad (25)$$

and,

$$b_h \leq B. \quad (26)$$

Let the Lagrange multipliers associated with the constraints (25) and (26) be  $\lambda$  and  $\mu$ . The Lagrangian is given by

$$L = U + \lambda [H - c_h^g - q_h^g - c_l^g - q_l^g] + \mu (B - b_h), \quad (27)$$

such that  $\lambda \geq 0, \mu \geq 0, \lambda [H - c_h^g - q_h^g - c_l^g - q_l^g] \geq 0$  and  $\mu (B - b_h) \geq 0$ .

The first order conditions include:

$$\frac{\partial L}{\partial c_h^g} = \sigma (c_h^g)^{\sigma(1-r)-1} (\underline{p}q_h^g + b_h)^{1-r} - \lambda = 0, \quad (28)$$

$$\frac{\partial L}{\partial q_h^g} = \underline{p} (c_h^g)^{\sigma(1-r)} (\underline{p}q_h^g + b_h)^{-r} - \lambda = 0, \quad (29)$$

$$\frac{\partial L}{\partial c_l^g} = \frac{\sigma}{1+\delta} (c_l^g)^{\sigma(1-r)-1} (\bar{p}q_l^g + B - b_h)^{1-r} - \lambda = 0, \quad (30)$$

$$\frac{\partial L}{\partial q_l^g} = \frac{1}{1+\delta} \bar{p} (c_l^g)^{\sigma(1-r)} (\bar{p}q_l^g + B - b_h)^{-r} - \lambda = 0, \quad (31)$$

$$\frac{\partial L}{\partial b_h} = (c_h^g)^{\sigma(1-r)} (\underline{p}q_h^g + b_h)^{-r} - \frac{1}{1+\delta} (c_l^g)^{\sigma(1-r)} (\bar{p}q_l^g + B - b_h)^{-r} - \mu = 0 \quad (32)$$

and (25).

Let us first show that  $\mu > 0$ . Suppose the contrary, i.e  $\mu = 0$ . Then, (32) becomes

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

Combining (29) and (31), we obtain

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

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

Combining (28), (29), (30), and (31), we find,

$$\sigma \left( q_h^g + \frac{B}{\underline{p}} \right) = c_h^g \quad (33)$$

$$\sigma q_l^g = c_l^g \quad (34)$$

$$q_l^g = \frac{1}{\theta} \left( q_h^g + \frac{B}{\underline{p}} \right), \quad (35)$$

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

Using (25), we obtain

$$q_h^g = \frac{1}{1+\sigma} \frac{\theta}{1+\theta} \left( H + \frac{B}{\underline{p}} \right) - \frac{B}{\underline{p}}, \quad (36)$$

and then, we have

$$c_h^g = \frac{\sigma}{1+\sigma} \frac{\theta}{1+\theta} \left( H + \frac{B}{\underline{p}} \right), \quad (37)$$

$$c_l^g = \frac{\sigma}{1+\sigma} \frac{1}{1+\theta} \left( H + \frac{B}{\underline{p}} \right), \quad (38)$$

$$q_l^g = \frac{1}{1+\sigma} \frac{1}{1+\theta} \left( H + \frac{B}{\underline{p}} \right), \quad (39)$$

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

$$c_h^m = \underline{p} \frac{1}{1+\sigma} \frac{\theta}{1+\theta} \left( H + \frac{B}{\underline{p}} \right), \quad (40)$$

and,

$$c_l^m = \bar{p} \frac{1}{1+\sigma} \frac{1}{1+\theta} \left( H + \frac{B}{\underline{p}} \right). \quad (41)$$

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,

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

□

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

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

or,

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

□

**Proof of Proposition 3:** The derivative of  $q_h^{g*}$  with respect to  $\delta$  is given by:

$$\frac{\partial q_h^{g*}}{\partial \delta} = \frac{\theta}{(1 + \theta)^2} \frac{1}{1 + \sigma} \left( H + \frac{B}{\underline{p}} \right) \frac{1}{1 + \delta} \frac{1}{(1 + \sigma)r - \sigma} \quad (42)$$

It is positive as long as  $r > \frac{\sigma}{1 + \sigma}$ . □

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

$$\frac{\partial q_h^{g*}}{\partial r} = -\frac{1}{1 + \sigma} \frac{s^* \left( H + \frac{B}{\underline{p}} - s^* \right)}{\left( H + \frac{B}{\underline{p}} \right) (r - \sigma + r\sigma)^2} \ln \left( (1 + \delta)^{1 + \sigma} \frac{\underline{p}}{\bar{p}} \right), \quad (43)$$

which is negative only if

$$(1 + \delta)^{1 + \sigma} \left( \frac{\underline{p}}{\bar{p}} \right) \geq 1, \quad (44)$$

or,

$$\left( \bar{p} / \underline{p} \right)^{\frac{1}{1 + \sigma}} - 1 < \delta. \quad (45)$$

□

## Appendix B: Model with price risk

Assume that the situation is the same as the one described in Section 2 except that, at the harvest season, the household does not know the (future) price of grain at the lean season. Instead, we assume that, at the time of harvest, the anticipated price of grain at the lean season is  $\tilde{p}$ , and it is a random variable with mean  $\bar{p} > \underline{p}$ , where  $\underline{p}$  is the (known) price of grain at the harvest season. The uncertainty regarding the price of grain at the lean season is resolved before the household makes its selling and consumption decisions at the lean season. Thus, the timing is as follows: at the harvest season, 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. At this point in time, the household knows the price of grain at the harvest season,  $\underline{p}$ , but not the price of grain at the lean season,  $\tilde{p}$ . The household then makes its consumption and storage decisions. At the lean season, the household learns the realized price of grain and consequently allocates the quantity of stored grain  $s$  between consumption  $c_l^g$  and sales  $q_l^g$ . We use the following assumption regarding the lean season price uncertainty ( $E$  denotes the expectation operator):

**Assumption (R):**  $E((\tilde{p})^{1-r}) - \underline{p}E((\tilde{p})^{-r}) > 0$ .

In order to get some intuition as regards this assumption, assume that the price risk is additive, that is  $\tilde{p} = \bar{p} + \varepsilon$ ,

where  $\varepsilon$  is a random variable with mean 0 and variance  $\sigma_\varepsilon^2$ . The assumption becomes  $E((\bar{p} + \varepsilon)^{1-r}) - \bar{p}E((\bar{p} + \varepsilon)^{-r}) > 0$ . Using a second order Taylor approximation, this inequality can be rewritten as

follows:  $\frac{1}{2} \left( \frac{\sigma_\varepsilon}{\bar{p}} \right)^2 \left[ \frac{\bar{p}-\underline{p}}{\underline{p}} r^2 - \frac{\bar{p}+\underline{p}}{\underline{p}} r \right] + \frac{\bar{p}-\underline{p}}{\underline{p}} > 0$ . A sufficient condition for this inequality to hold is that  $\sigma_\varepsilon < \sqrt{8} \left( \frac{\bar{p}-\underline{p}}{\bar{p}+\underline{p}} \right) \bar{p}$ . In other words, if the variance of the price of grain at the lean season is sufficiently low (which encompasses the case developed in the body of the paper, that is  $\sigma_\varepsilon = 0$ ), Assumption (R) holds.

Notice that, at the harvest season, the household makes its consumption decisions,  $c_h^g$  and  $c_h^m$ , its selling decision,  $q_h^g$ , its cash spending decision,  $b_h$ , and its storage decision,  $s$ , anticipating that it will be able to make its consumption and sale decisions at the lean season knowing the true lean season price of grain. We then solve the problem backward: we first consider the lean season and characterize the optimal consumption and sale decisions,  $c_l^g$ ,  $c_l^m$  and  $q_l^g$ , taking the price of grain,  $\bar{p}$ , the stored quantity of grain,  $s$ , and the stored amount of non agricultural income,  $b_l$ , as given. We then consider the harvest season and characterize the consumption, sales, grain storage and non agricultural income spending levels,  $c_h^g$ ,  $c_h^m$ ,  $q_h^g$ , which maximize the household harvest season expected discounted utility.

Let us first analyze its optimal decision problem at the lean season.

*Lean season:* At the lean season, the programme of the household is the following:

$$\text{Max}_{\{c_l^g, c_l^m, q_l^g, b_l\}} U_l = \frac{1}{1-r} \left( (c_l^g)^\sigma c_l^m \right)^{1-r}, \quad (46)$$

such that

$$c_l^m = \bar{p} q_l^g + b_l, \quad (47)$$

$$c_l^g + q_l^g = s, \quad (48)$$

and,

$$b_l \leq B - b_h. \quad (49)$$

The solution of this maximization problem is  $b_l = B - b_h$ ,  $c_l^g = \frac{\sigma}{1+\sigma} \left( s + \frac{b_l}{\bar{p}} \right)$ ,  $c_l^m = \frac{1}{1+\sigma} (\bar{p}s + b_l)$  and  $q_l^g = \frac{1}{1+\sigma} \left( s - \frac{\sigma}{\bar{p}} b_l \right)$ . Let  $U_l^*$  be the optimal value of the utility of the household at the lean season, with  $U_l^*(s, b_h, \bar{p}) = \frac{1}{1-r} A \left( \frac{(\bar{p}s + B - b_h)^{1+\sigma}}{(\bar{p})^\sigma} \right)^{1-r}$  where  $A = (\sigma)^{\sigma(1-r)} \left( \frac{1}{1+\sigma} \right)^{(1+\sigma)(1-r)}$ .

We now analyze the decision at the harvest season.

*Harvest season:* At the harvest season, the programme of the household is the following:

$$\text{Max}_{\{c_h^g, c_h^m, q_h^g, b_h, s\}} EU = \frac{1}{1-r} \left( (c_h^g)^\sigma c_h^m \right)^{1-r} + \frac{1}{1+\delta} EU_l^*(s, b_h, \bar{p}), \quad (50)$$

such that

$$b_h \leq B, \quad (51)$$

and,

$$c_h^m = \underline{p} q_h^g + b_h, \quad (52)$$

and,

$$c_h^g + q_h^g + s = H. \quad (53)$$

Let us substitute  $c_h^m$  with  $\underline{p}q_h^g + b_h$  and denote  $\lambda_1$  and  $\lambda_2$  the Lagrange multipliers associated with the constraints (51) and (53), respectively. The Lagrangian of the optimization problem can be written as follows:

$$L = \frac{1}{1-r} \left( (c_h^g)^\sigma (\underline{p}q_h^g + b_h) \right)^{1-r} + \frac{1}{1+\delta} \frac{1}{1-r} A.E \left[ \left( \frac{(\tilde{p}s + B - b_h)^{1+\sigma}}{(\tilde{p})^\sigma} \right)^{1-r} \right] + \lambda_1 (B - b_h) + \lambda_2 (H - c_h^g - q_h^g - s) \quad (54)$$

The first order conditions include:

$$\frac{\partial L}{\partial c_h^g} = \sigma (c_h^g)^{\sigma(1-r)-1} (\underline{p}q_h^g + b_h)^{1-r} - \lambda_2 = 0, \quad (55)$$

$$\frac{\partial L}{\partial q_h^g} = \underline{p} (c_h^g)^{\sigma(1-r)} (\underline{p}q_h^g + b_h)^{-r} - \lambda_2 = 0, \quad (56)$$

$$\frac{\partial L}{\partial b_h} = (c_h^g)^{\sigma(1-r)} (\underline{p}q_h^g + b_h)^{-r} - \frac{1+\sigma}{1+\delta} A.E \left[ \frac{(\tilde{p}s + B - b_h)^{(1+\sigma)(1-r)-1}}{(\tilde{p})^{\sigma(1-r)}} \right] - \lambda_1 = 0, \quad (57)$$

$$\frac{\partial L}{\partial s} = \frac{1+\sigma}{1+\delta} A.E \left[ \tilde{p} \frac{(\tilde{p}s + B - b_h)^{(1+\sigma)(1-r)-1}}{(\tilde{p})^{\sigma(1-r)}} \right] - \lambda_2 = 0, \quad (58)$$

$$\lambda_1 (B - b_h) = 0; \lambda_2 (H - c_h^g - q_h^g - s); \lambda_1 \geq 0, \lambda_2 \geq 0, B - b_h \geq 0; H - c_h^g - q_h^g - s = 0. \quad (59)$$

Combining (56), (57) and (58), we have

$$\begin{aligned} \underline{p}\lambda_1 &= \frac{1+\sigma}{1+\delta} A.E \left[ \tilde{p} \frac{(\tilde{p}s + B - b_h)^{(1+\sigma)(1-r)-1}}{(\tilde{p})^{\sigma(1-r)}} \right] \\ &\quad - \underline{p} \frac{1+\sigma}{1+\delta} A.E \left[ \frac{(\tilde{p}s + B - b_h)^{(1+\sigma)(1-r)-1}}{(\tilde{p})^{\sigma(1-r)}} \right]. \end{aligned} \quad (60)$$

Assume that  $\lambda_1 > 0$ , then  $b_h = B$  and condition (60) becomes:

$$\underline{p}\lambda_1 = \frac{1+\sigma}{1+\delta} A(s)^{(1+\sigma)(1-r)-1} \left( E \left[ (\tilde{p})^{1-r} \right] - \underline{p} E \left[ (\tilde{p})^{-r} \right] \right), \quad (61)$$

which is strictly positive, according to Assumption (R).

Thus, conditions (55), (56) and (58) become:

$$\sigma (c_h^g)^{\sigma(1-r)-1} (\underline{p}q_h^g + B)^{1-r} = \lambda_2, \quad (62)$$

and,

$$\underline{p} (c_h^g)^{\sigma(1-r)} (\underline{p}q_h^g + B)^{-r} = \lambda_2, \quad (63)$$

and,

$$\frac{1+\sigma}{1+\delta} A(s)^{(1+\sigma)(1-r)-1} E \left[ (\tilde{p})^{1-r} \right] = \lambda_2. \quad (64)$$

Using (59), after some computations, we obtain:

$$q_h^g = \frac{\hat{\theta}}{1+\hat{\theta}} \frac{1}{1+\sigma} \left( H + \frac{B}{\underline{p}} \right) - \frac{B}{\underline{p}}, \quad (65)$$

where  $\hat{\theta} = \left( (1 + \delta) \frac{E\left[(\tilde{p})^{1-r}\right]^{-1}}{\underline{p}^{-(1-r)}} \right)^{\frac{1}{(1+\sigma)r-\sigma}}$ .

Notice that the expression of  $q_h^g$  is the same as in the case without price risk except the term  $\left(E\left[(\tilde{p})^{1-r}\right]\right)^{-1}$  which replaces  $(\bar{p})^{-(1-r)}$  in the case without risk.

The optimal storage level is:

$$s = \frac{1}{1 + \hat{\theta}} \left( H + \frac{B}{\underline{p}} \right), \quad (66)$$

and the optimal consumption levels are:

$$c_h^g = \frac{\hat{\theta}}{1 + \hat{\theta}} \frac{\sigma}{1 + \sigma} \left( H + \frac{B}{\underline{p}} \right), \quad (67)$$

$$c_h^m = \underline{p} \frac{\hat{\theta}}{1 + \hat{\theta}} \frac{1}{1 + \sigma} \left( H + \frac{B}{\underline{p}} \right), \quad (68)$$

$$c_l^g = \frac{1}{1 + \hat{\theta}} \frac{\sigma}{1 + \sigma} \left( H + \frac{B}{\underline{p}} \right), \quad (69)$$

$$c_l^m = \tilde{p} \frac{1}{1 + \hat{\theta}} \frac{1}{1 + \sigma} \left( H + \frac{B}{\underline{p}} \right). \quad (70)$$

The optimal levels of storage and consumption differ from the levels we obtained when there is no price risk in two ways. First,  $\theta$  is replaced by  $\hat{\theta}$ , which affect all the optimal levels. Second, the consumption of the generic good at the lean season depends on the realized price of grain (notice that the consumption of grain is not affected by the realization of the price).

We can then show the following result:

**Proposition 5:** *The following claims hold if and only if  $\frac{\sigma}{1+\sigma} \leq r \leq 1$ . Price risk affects consumption, sales and storage as follows : (i) it increases the consumption of grain and of the generic good at the harvest season; (ii) it decreases the consumption of grain and the expected consumption of the generic good at the lean season; (iii) it decreases grain storage and sales at the lean season; (iv) it increases grain sales at the harvest season.*

**Proof of Proposition 5:** The expected consumption of generic good at the lean season is  $E(c_l^m) = \bar{p} \frac{1}{1 + \hat{\theta}} \frac{1}{1 + \sigma} \left( H + \frac{B}{\underline{p}} \right)$ . To prove the results of the proposition, it is sufficient to notice that  $E\left[(\tilde{p})^{1-r}\right] \leq \left(E[\tilde{p}]\right)^{1-r} = (\bar{p})^{1-r}$  if and only if  $0 \leq \frac{\sigma}{1+\sigma} \leq r \leq 1$ , because  $x \mapsto (x)^{1-r}$  is concave when  $\frac{\sigma}{1+\sigma} \leq r \leq 1$  and convex otherwise. Hence,  $\hat{\theta} \geq \theta$  if and only if  $\frac{\sigma}{1+\sigma} \leq r \leq 1$ .  $\square$

Now, let us discuss how the price risk affects the comparative static results provided in the body of the paper. *Corollary 1 is qualitatively unaffected:* sales at the harvest are still decreasing with the cash income,  $\frac{\partial q_h^g}{\partial B} = -\left(1 - \frac{1}{1+\sigma} \frac{\hat{\theta}}{1+\hat{\theta}}\right) < 0$ , and households having a small cash income  $B$  are still those who will sell rather than buy grain at the harvest season:  $q_h^g \geq 0 \iff \underline{p} \frac{\hat{\theta}}{1+\sigma(1+\hat{\theta})} H \geq B$ . However, the threshold is larger when there is a price risk.

*Corollary 2 and Proposition 3 remain unchanged.* Proposition 4 becomes:

**Proposition 4':** *Sales at the harvest season decrease with risk aversion if and only if the household is*

sufficiently impatient:

$$\frac{\partial q_h^g}{\partial r} < 0 \Leftrightarrow \frac{E[(\tilde{p})^{1-r}]}{\left(\underline{p}\right)^{\frac{1}{1+\sigma}}} \exp\left(\left(r - \frac{\sigma}{1+\sigma}\right) \frac{E[(\tilde{p})^{(1-r)} \ln(\tilde{p})]}{E[(\tilde{p})^{(1-r)}]}\right) - 1 < \delta.$$

**Proof of Proposition 4':** It is sufficient to study the sign of  $\frac{\partial \hat{\theta}}{\partial r}$ , which is such that

$$\frac{\partial \hat{\theta}}{\partial r} = \frac{(1+\sigma)\hat{\theta}}{((1+\sigma)r - \sigma)^2} \left( \begin{array}{c} -\ln(1+\delta) - \frac{1}{1+\sigma} \ln(\underline{p}) + \ln E[(\tilde{p})^{(1-r)}] \\ + \left(r - \frac{\sigma}{1+\sigma}\right) \frac{E[(\tilde{p})^{(1-r)} \ln(\tilde{p})]}{E[(\tilde{p})^{(1-r)}]} \end{array} \right), \quad (71)$$

which is negative only if  $\frac{E[(\tilde{p})^{1-r}]}{\left(\underline{p}\right)^{\frac{1}{1+\sigma}}} \exp\left(\left(r - \frac{\sigma}{1+\sigma}\right) \frac{E[(\tilde{p})^{(1-r)} \ln(\tilde{p})]}{E[(\tilde{p})^{(1-r)}]}\right) - 1 < \delta$ .  $\square$

Hence, the main insight of Proposition 4' is not affected by the introduction of the price risk. However, the threshold above which impatience is sufficiently large now depends on the risk aversion parameter.

## Appendix C: The Effect of Preferences on Sales - Bootstrapped Standard Errors

	(1)		(2)		(3)		(4)		(5)	
Dep. Var. is Sales ( $q_h$ )	H2S		MLE		MLE		MLE		MLE	
risk aversion	-255,24		-258,39		-196,04		-317,98	**	-231,61	
	<i>202,55</i>		<i>172,13</i>		<i>141,06</i>		<i>173,10</i>		<i>143,10</i>	
discount rate	1163,60	**	1125,83	**	1153,40	**	2739,43	**	2655,81	**
	<i>594,75</i>		<i>482,97</i>		<i>502,60</i>		<i>1094,60</i>		<i>1163,76</i>	
H maize	92,46	**	110,90	***	110,00	***	110,39	***	108,67	***
	<i>38,71</i>		<i>32,13</i>		<i>32,03</i>		<i>31,51</i>		<i>31,58</i>	
Dep. Var. is V										
risk aversion	0,30	**	0,29	**	0,25	**	0,35	***	0,28	**
	<i>0,13</i>		<i>0,13</i>		<i>0,12</i>		<i>0,13</i>		<i>0,13</i>	
discount rate	-0,86	**	-0,82	*	-0,86	**	-2,48	***	-2,44	***
	<i>0,43</i>		<i>0,43</i>		<i>0,43</i>		<i>0,90</i>		<i>0,92</i>	
H maize	0,04	**	0,06	**	0,06	**	0,06	**	0,06	**
	<i>0,02</i>		<i>0,02</i>		<i>0,03</i>		<i>0,02</i>		<i>0,02</i>	
op	0,55	***	0,46	***	0,46	***	0,45	**	0,45	**
	<i>0,17</i>		<i>0,17</i>		<i>0,17</i>		<i>0,18</i>		<i>0,18</i>	
$q_{lean}$	0,32	**	0,18		0,19		0,19		0,19	
	<i>0,13</i>		<i>0,13</i>		<i>0,12</i>		<i>0,13</i>		<i>0,13</i>	
$\lambda$	-1272,83	*	-1252,02	***	-1248,32	***	-1258,35	**	-1259,97	***
	<i>728,19</i>		<i>485,02</i>		<i>486,08</i>		<i>483,30</i>		<i>485,42</i>	
$\operatorname{atanh}\rho$			-0,91	***	-0,90	**	-0,91	***	-0,91	***
			<i>0,35</i>		<i>0,36</i>		<i>0,35</i>		<i>0,36</i>	
$\chi_2$			24,82	***	24,12	***	25,48	***	24,80	***
Number of obs	1496		1496		1496		1496		1496	
Censored obs	1007		1007		1007		1007		1007	
Uncensored obs	489		489		489		489		489	
Payoffs	low		low		high		low		high	
Time delay	1 month		1 month		1 month		4 days		4 days	

Note: This table reports estimation results for the sample selection model. The top of the table reports the estimates of the outcome equation, where the dependent variable is the quantity of maize sold during harvest season. The bottom of the table reports the estimates of the selection equation. Both equations also include as controls the harvested quantities of sorghum, millet, rice, groundnut, and cotton, the total number of cattle and of poultry, the family size and time to travel to the market. Column (1) reports Heckman-Two-Step estimates, columns (2) to (5) report Maximum Likelihood estimates.  $\lambda$ ,  $\operatorname{atanh}\rho$ , and  $\chi_2$  are statistics of three tests of the null hypothesis  $\rho = 0$ , where  $\rho$  is the correlation between the error terms of the two equations. Standard errors clustered at village level are in italics. Three asterisks \*\*\* (resp. \*\*, \*, °) denote rejection of the null hypothesis at the 1% (resp. 5%, 10%, 15%) significance level. The variables *risk aversion* and *discount rate* are individual parameters that were estimated separately from the experiments, as explained in Section 3.3.1 and in Section 3.3.2. The row *Payoffs* indicates whether the low-payoff experiment or the high-payoff experiment was used to elicit the risk aversion parameter included in the model. The row *Time delay* indicates whether the 4-day-delay experiment or the 1-month-delay experiment to elicit the discount rate included in the model.

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