# Price risk and small farmer maize storage in Sub-Saharan Africa: New insights into a long-standing puzzle

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**Abstract**

We provide new insight into a persistent puzzle: small farmers in low-income countries tend to sell their maize at harvest, when prices are low, rather than storing and waiting until prices increase later in the year. We use 20 years of data from 1038 retail markets in 30 African countries to demonstrate that the lean season price (the "high price" season) fails to rise above the harvest season price (the "low price" season) 16.3% of the time on average, leading to negative returns to intra-annual arbitrage in those years. On the basis of that stylized fact, we propose that aversion to these negative returns may contribute to farmers' decisions to opt out of storage. We show that even moderately risk averse farmers would opt out of storage in 15.3% of market-years.

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# 1 Introduction

Maize grain prices exhibit recurring patterns of seasonal price fluctuations in rural markets in low income countries (Kaminski et al., 2016, 2014). These markets are characterized by large and largely predictable swings in prices within a year: on average maize prices are lowest at harvest and rise throughout the year, peaking in the lean season just before the next harvest. This intra-annual price pattern is a documented contributor to seasonal hunger, malnutrition, and food insecurity among small farm households (Sahn, 1989; Christian and Dillon, 2018).

Even so, small farm households have generally proved unable or unwilling to exploit inter-temporal arbitrage opportunities for their maize. Farm households tend to liquidate some portion of their harvest for cash at harvest to meet non-maize consumption needs and to pay debts that have accrued during the growing season, storing the rest of their crop for their own household consumption. If a household fails to store enough to meet its consumption needs through the lean season it may return to the market to re-purchase maize later in the year when the prices are high (Barrett, 2007).

But if price rises after harvest are certain, net-seller households could increase crop revenues by selling surpluses late in the season when prices rise. And net-buyer households could purchase maize in the market at harvest when the price was low, adding it to their own stores to last the year. This is not what we tend to see in markets. Two recent examples from the literature: Burke et al. (2019) show that the median farmer in their Kenyan study switched from selling maize to purchasing maize five months after harvest and Stephens and Barrett (2011) note that 62% of the Western Kenyan households who had sold the majority of their production at harvest were purchasing maize a few months later.

Explanations for farmers' failing to exploit apparent inter-temporal arbitrage opportunities have centered on liquidity constraints and transaction costs (Stephens and Barrett, 2011; Burke et al., 2019; Aggarwal et al., 2018) - selling later is only viable if you can access credit or alternative sources of funds to meet consumption needs and pay debts at harvest. Other factors that likely contribute include consumption price-hedging (Saha, 1994; Park, 2006), inadequate storage technologies (Walker et al., 2018; Channa et al.,

2019) problems of post-harvest pest damage in storage (Kadjo et al., 2016), preferences to consume one's own maize rather than maize in the market (Hoffmann and Gatobu, 2014), and time-inconsistent preferences (Le Cotty et al., 2019).

We contribute a new insight relevant to the documented reluctance among small farmers to store across seasons for later sale: a risk of realizing negative returns[1] on stored maize in years in which prices fail to rise after harvest. While on average across years prices do rise after harvest, and those increases are on average economically significant, we document that prices do not always rise, and we demonstrate the importance of this possibility for poor farmers who cannot borrow across years. Even our most conservative calculations, which abstract away from costs of storage and capital, show that risk averse farmers would rationally forego storage in some markets. We are not arguing that the price risk we document is sufficient to explain observed patterns of farmer behavior. Our point is that output price rises after harvest are not guaranteed and the risk of flat or declining prices after harvest should be considered in concert with other important constraints that farmers face.

Our analysis has three parts. First, we review 20 years of data from 1183 retail markets in 32 African countries to establish the distribution of price differences across seasons. We demonstrate that market prices in lean ("high price") seasons do not always exceed the prevailing price during the harvest ("low price") season; we calculate returns for each season as the percent change from the harvest season price to the following lean season price. We document a high frequency of *negative* returns to storage: returns are negative 16.3% of the time across markets and years in retail markets in countries with a single maize season, ranging from a low of 10.9% in Mozambique to a high of 50.0% in Mauritania. (Table 2) We show that the phenomenon of harvest season prices failing to rise occurs in every year since 2000 and across all countries in our data.

In fact, a lean season price can not only fail to rise relative to the harvest season price; it can also prove considerably lower. For example, in years when the lean season price fails to exceed the price at harvest,

[1] We use the term "negative returns to storage" throughout the paper in reference to circumstances in which the price after harvest stays flat or declines. This calculation abstracts away from three other factors that would push returns to storage lower: interest rates, loss rates in storage, discount rates in excess of interest rates. Our calculations are therefore an upper bound on negative returns; additional costs push returns lower. We discuss this point and add interest rates in Section 4.3.

the average difference has recently ranged between 4.2% lower in Cabo Verde to 27.5% lower in South Sudan (Table 2). Our estimates are conservative; we abstract away from the costs of storage equipment and space, post-harvest losses in storage, foregone interest on sales revenue, and any added costs farmers might incur associated with selling in the lean season. Moreover, our calculation of the returns to storage is also conservative: we use the minimum price during the harvest months and the highest realized price during the lean season.

Second, because price dynamics varying from year to year are not sufficient to imply that farmers face a risk, we show that farmers cannot reliably predict intertemporal returns from the realized harvest price. Years with high and low harvest season prices (relative to average) exhibit negative returns, and regressions of the returns to storage on the harvest price z-score fail to explain the observed variation. We demonstrate that farmers cannot predict with certainty the years in which prices fail to rise after harvest and returns to storage are negative. [2]

Third, based on insights from analysis of the price data, we calculate the degree of risk aversion required to rationalize farmers selling at harvest. Focusing on households storing for later sales, we show that in countries with a single maize season, moderately risk averse farmers would opt out of storage in 15.3% of market-years.

Economists have long focused on the effects of price volatility and stabilization on consumers and producers (Waugh, 1944; Oi, 1961; Stiglitz, 1969; Sandmo, 1971; Deaton and Laroque, 1992; Sarris et al., 2011; Bellemare et al., 2013). Barrett and Dorosh (1996) show that price uncertainty reduces the incentive to store among poor farmers in Madagascar. Saha and Stroud (1994) use risk aversion to explain what they characterize as an excess of precautionary storage among small farmers in India. We address a related problem, and one that has perplexed researchers for many years working in Sub-Sharan Africa: why farmers sell their crop at harvest rather than storing and waiting until prices rise.[3]

[2]This result is consistent with qualitative work conducted by the team with small traders and farmers in Zambia. Small traders mention what they term “flat price risk”, the risk that the price will go down or stay flat after harvest; small farmers report that storing maize usually does not guarantee them that that the price in the lean season will be higher and cited examples from recent years in which storage failed to yield profits.

[3]Park (2006) considers both price and yield risk and finds that farmers in China store grain as a consumption price hedge, not as a substitute for credit, and that the non-negativity of grain storage can explain why many subsistence farmers are net buyers across seasons. The commodity storage literature has modeled endogenous storage decisions under different expectation

Our insight that prices can stay flat or decline after harvest is unlikely to come as a surprise to researchers contributing to the rich literature documenting and exploring the causes of staple grain price volatility in African markets including Gilbert et al. (2017) Jayne et al. (2006) Tschirley and Jayne (2010), and Porteous (2017). For example, Chapoto and Jayne (2009) analyze and document the operations of government maize marketing boards and their effects on maize price volatility, Ellis and Manda (2012) describe a series of recent food crises in Malawi and their causes and consequences, and Jayne et al. (2006) describe structural changes in maize markets in eastern and southern Africa and analyze the design of possible policies to stabilize prices. Our modest contribution to this important literature is to quantify the magnitude and scope of a particular aspect of crop output price volatility - intra-annual variation between harvest and lean season - and to work through potential implications for the classic puzzle of limited small farmer storage for sale across seasons. The breadth of data we bring to the analysis and our focus on characterizing variable price trends between harvest and lean season that could have consequence for small, credit-constrained farmers provides new insight. We demonstrate how price variations can affect storage choice. Our work builds on Gilbert et al. (2017), who use data from 193 markets in 7 countries to document food price seasonality in Sub-Saharan Africa and demonstrate that short samples (between 5-15 years) can produce upwardly biased estimates of the extent of seasonality in food markets. However, Gilbert et al. (2017) deals with averages, quantifying seasonal changes in expected returns, but not risk.

Our insight is important to development economists working in agriculture and puzzling over farmers' persistent failure to store and wait to sell until prices rise. This literature has focused on randomized controlled trials (RCTs) to address the storage puzzle in recent years. This literature is not well-integrated with the staple grain price volatility literature. Our work begins to try and rectify that problem, to bring those two literatures together. The starting premise of much of this recent RCT-focused research is that by failing to store farmers are leaving money on the table. Our analysis shows that while on average this is true, prices do not always rise after harvest, and holding maize with the intent to sell means bearing some risk.[4] Numerous recent interventions by Non-Governmental Organizations and researchers have provided

models: Maître d'Hôtel and Le Cotty (2018); Mitra and Boussard (2012); Boussard (1996) find that grain storage often fails to mitigate price shocks, and that imperfect storage behavior may increase price volatility.

[4]Holding maize with the intent to consume later also means tying up capital in years when the price declines after harvest.

credit and storage options to farmers, and RCTs implemented in recent years evaluate such efforts. Burke et al. (2019) provide credit to farmers in Kenya; Basu and Wong (2015) distribute storage equipment to farmers in Indonesia; Aggarwal et al. (2018) encourage communal maize storage in Kenya; Channa et al. (2018) combine storage and credit in Tanzania, Le Cotty et al. (2019) and Delavallade and Godlonton (2020) offer an inventory credit system in Burkina Faso in two separate studies. Yet these studies generally dismiss the possibility of risky returns to storage if they mention it at all. For example, Aggarwal et al. (2018) write, "An older literature has looked at price risk as a potential explanation Saha and Stroud (1994); however, the current consensus among academics as well as policy-makers is that this is largely implausible."

These existing studies documenting price fluctuations and proposing interventions related to storage and credit have two important limitations: first, these analyses are commonly based on only one or two years of data; second, they normally analyze the differences between mean harvest season prices and lean season prices by averaging either across years or across markets or both.[5] Our breadth of data allow us to characterize the distribution of returns across years and space and to more comprehensively quantify intra-annual price changes.

Recent studies implementing and analyzing randomized controlled trials to promote maize storage have noted incidents of the phenomena that we discuss here - prices failing to rise after harvest - mostly when an intervention to encourage storage has achieved attenuated results because it was conducted in a year in which prices failed to rise significantly after harvest (Le Cotty et al., 2019; Channa et al., 2018). For example, Le Cotty et al. (2019) mention in their analysis of inventory credit in Burkina Faso, "In 2013, the rise in grain prices was exceptionally low (only three percent on average). As a result the capital gain was not enough to offset the cost of warrantage" (p.15). Channa et al. (2018) conduct their storage and credit RCT in a year in which the price failed to rise in Malawi and write, "Maize prices did not rise in the lean season...because the government of Tanzania imposed an export ban".

Our results indicate that risky returns may contribute to the decision to forego storage by risk averse small

[5]Indeed, by pulling individual years of data or by averaging across years and markets, we can replicate the results and graphs suggesting the presence of inter-temporal arbitrage opportunities that drive the existing literature and associated interventions to promote farmer storage across seasons. See Table 2 , which shows (Column 7) that average total returns across market-years are positive for all countries.

farmers and small traders. Our work opens up new research questions and approaches. The assumption has been that households should always store. Maize-surplus households (those whose production exceeds their annual total consumption) should store for later sale. Maize-deficit households should store as much as possible so that they can avoid the high costs of maize later in the year. But it turns out that the problem that households face is much more interesting than that and much harder. Maize-surplus households need to time their sale. In some years it may be optimal for maize-surplus households to sell most of their production at harvest. Maize-deficit households need to optimally time their purchasing. In some years it may be optimal for them to purchase in the lean season. How do farmers make these decisions? What do they believe about price trends and how do they decide when to sell and when to hold? What strategies do they use to mitigate their exposure to output price risk?

Our observation that negative returns to storage are widespread and economically significant contributes an important insight relevant to the persistent puzzle of low storage uptake in much of sub-Saharan Africa.

# 2 Empirical Analysis

## 2.1 Data

The World Food Programme (WFP) food price monitoring system reports monthly food prices using data collected by WFP and national agricultural ministries (Caccavale and Flämig, 2017).[6] Data are available at a sub-national level for food staples, fruits, vegetables, and animal products. We select all countries in Sub-Saharan Africa (SSA) with monthly prices available for maize. Maize is an economically critical crop, the basis of the diet of many poor rural households in the region and a primary crop grown by those same households. We adjust prices to 2015 local currency values using Consumer Price Index (CPI) data from Food and Agricultural Organization (FAO) Statistics, based on data from the International Monetary Fund (IMF). We do this in order to control for inflation without introducing additional variability from exchange

[6] Caccavale and Flämig (2017) describe the collection process and recommend that weekly prices are collected and averaged to generate a monthly price, however stable commodities and resource constraints might result in a once a month collection.

rate fluctuations. [7]

The analysis requires that we identify the harvest and lean season for each market. Agricultural season data are collected by the FAO for the Global Information and Early Warning System (GIEWS) GIEWS reports national and sometimes sub-national harvest and planting season dates for various crops, with data provided by national ministries.

We merge the agricultural season designations with the price data to identify the prices for the harvest and planting season months. If GIEWS reports multiple agricultural regions within a country, we use the maize season data located closest to the market coordinates, within the same country. GIEWS designates planting and harvest start and end dates for the primary maize season in each country, as well as a secondary maize season if it exists.

We are careful to allow for differences in the price patterns we document between countries in Sub-Saharan Africa with a single cropping season versus those that have two seasons. GIEWS reports multiple maize seasons for a subset of countries with two growing seasons per year. In countries with more than one growing season, maize may enter the market at multiple times during the year, creating potential variations in seasonal price patterns driven by the relative timing and magnitude of the second harvest and in farmer expectations about the returns to storage. The price patterns in these two-harvest countries could be inherently more unpredictable and more likely to exhibit negative returns to storage.[8] Table 1 shows the distribution of data across countries and market types. We calculate separate returns for the primary and secondary season for countries with two maize growing seasons. Our descriptive analysis covers retail markets in both single and double season countries and finds similar results across the two sets of countries. We describe trends in wholesale maize markets in the Appendix.

Our designation of the harvest and lean season prices is obviously critical. Our calculation of inter-seasonal price differences (and associated returns) is conservative and data-driven. We designate the seasons from the perspective of a farmer considering grain storage to take advantage of any arbitrage opportunities: we create

[7] We replicate the descriptive analysis and simulations using nominal maize prices and the conclusions of the paper hold. See Appendix tables A13-A20.

[8] Interestingly, several recent studies promoting randomized interventions to increase farmer storage are sited in Kenya (Burke et al., 2019; Aggarwal et al., 2018) and Tanzania (Channa et al., 2018), countries with multiple cropping seasons.

a "harvest season price" as the minimum price in the months designated by GIEWS as harvest months for a given market. The "lean season price" is the maximum price in the three months prior to the subsequent harvest, when grain stocks tend to be at their lowest point. This combination of prices provides a lower bound on the probability and the magnitude of negative returns. We calculate returns for each season as the percent change in the "lean season price" over the previous "harvest season price". As a robustness check, we consider arbitrage opportunities over shorter time frames for single season countries, using the last month designated as a harvest month, and calculating returns for holding grain for 1-11 months post-harvest.

For the risk aversion analysis, we focus on retail markets in single season countries. We retain all markets for which we have price data for at least five market-years where a market-year contains prices for both the harvest season and the following lean season: for example, if the harvest occurs in September-October of 2018, the return for the 2018 market-year is the percent change from the September or October 2018 "harvest" price to the June, July, or August 2019 "lean" price, depending on whichever month had the lower price, and highest price, respectively. If either price was unavailable for that market-year pair, we do not include the observation in our data. We retain in the data all countries with at least nine markets, resulting in a smaller dataset of 10 countries and 425 markets.

Our descriptive dataset (Table 1) includes 5432 market-year observations for the primary maize season across 637 retail markets in 17 single season countries in sub-Saharan Africa between the years 2000-2021. In double season countries, the dataset includes 1765 observations in 401 retail markets for the primary season and 1729 observations in 371 markets for the secondary season.[9] A concern about missing data in our analysis is that prices may be more likely to be missing in lean season markets that are thin, with little maize present, and high prices. Leaving such market-years out of the analysis will depress the returns to storage in our calculations, biasing our results. In Appendix Tables A11 and A12, we show the distribution of missing observations across seasons and countries. Across all single season countries, harvest season prices were missing 13.7% on average, while lean season prices were missing 10.7% on average. Across double season countries, missing data occurred 6.7% on average in the primary maize season and 8.0% on average

[9]An analysis of the selection process and missing data is included in the Appendix. Wholesale market statistics are also available in the Appendix. All data and code are available on the author's website.

in the secondary maize season.

Another concern is that the missing data could be correlated with prices and hence returns. This could be the case if data are more likely to be missing, for example, in thin lean season markets when prices would be high if they were observed, biasing downwards our calculations of average returns and upwards our calculations of the incidence of negative returns. Overall, missing data are more likely in the harvest season months than the lean season months, with the exception of Malawi, Zambia, and South Sudan, where a price is slightly more likely to be missing in the lean season. (Appendix Table A11). Results in Appendix Tables A11 and A12 are also presented in Appendix Figures A4 and A5, showing the distribution of data availability and the average returns. We see no relationship between the distribution of data across seasons for a given country and the calculated average return.

The WFP market price data are mostly collected from primary and secondary markets. We observe market prices rather than farmgate prices. A critical assumption therefore is that the intra-annual variation we observe in the market data reflects variation that farmers experience. Smaller, rural markets tend to be less well spatially integrated than urban markets due to the fact that they are supplied by smaller market basins and the fact that they tend to be characterized by higher costs of transport and information (Badiane and Shively, 1998; Fafchamps, 1992). Dillon's analysis of the welfare effects of crop storage in Malawi includes a comparison of farmgate and market prices (using the same Malawi market series that we employ); Dillon shows that his constructed time series of farmer-reported maize sale prices exhibits intra-annual trends that are similar to the market price data.

## 2.2 Results: Price differentials across seasons

We find evidence of both positive and negative price differentials between harvest and lean seasons. Returns to storage are positive on average (across years) but negative price differentials are frequent. Moreover, the phenomenon of negative price differentials across harvest and lean season is widespread, not confined to any country or set of years. This finding is contrary to prior research that has assumed that higher lean season prices ensure positive returns to storing grain at harvest.

In Table 2, we present a summary of the data and findings for retail markets for single season countries. For each country, we present the years for which data was available in Column (3), the number of markets in Column (4) and the total number of market-years in Column (5) (ie: the Burkina Faso data consists of 455 total market-year observations across 54 markets and 19 years.) Column (6) presents the frequency of negative returns: the proportion of market-years in each country in which the price decreased from harvest to the following lean season. Column (7) presents the average returns by country across all market-years. Column (8) presents the average returns in each country for market-years in which the price increased from harvest to the subsequent lean season. Column (9) presents the average negative returns for market-years in which the price decreased, i.e. the alternative and less-discussed case: years in which the harvest season price exceeded the lean season price. As noted, these calculations are conservative and likely underestimate the frequency and magnitude of negative returns; due to storage costs and losses, storing grain profitably would require prices to rise to cover those costs just to break even.

The results presented in Table 2 demonstrate the presence of positive returns to storage on average: across all market-years in all countries, the average returns are positive: 41.7% (Column (7)). And yet, farmers in countries across Sub-Saharan Africa also experience years characterized by important negative price trends between harvest and lean season (Columns (6) and (9)); years in which the price stays flat or even declines in the lean season relative to its level at harvest. The phenomenon of negative returns to storage occurs in all countries. Mauritania has the highest incidence, with 50.0% of its market years exhibiting price declines after harvest; in all countries negative returns occur at least 10.9% of the time. Reliance on averages across years masks important variation across years and markets.

We present statistics for double season countries in Table 3. On average across all market-years in all countries, negative returns occur in 24.9% of primary maize seasons and 15.9% of secondary maize seasons, despite positive returns on average in both seasons: 35.2% returns on average in the primary season and 39.2% in the secondary season.[10]

[10]Market skewness data in Appendix Tables A3 and A4 further reinforce this finding: while on average, markets are positively skewed, with most averages falling between 0-1, the share of retail markets that are negatively skewed is high in a few countries such as Burkina Faso, Kenya, Sierra Leone, and Senegal. In these countries, frequent or severe price drops might deter risk averse farmers from storing to capture future arbitrage opportunities, even if returns are positive on average.

While Tables 2 and 3 focus on returns to storage in retail markets, the frequency of negative returns is similar in wholesale markets in single season countries (18.9%, Appendix Table A1) and 27.0% and 21.0% for the primary and secondary maize seasons respectively, in countries with two maize seasons, Appendix Table A2).

## 2.3 Negative returns to storage across years

We present the distribution of returns for each market-year across time in single and double season countries in the panels of Figure 1. These figures demonstrate that the phenomenon of negative returns to storage is not restricted to particular years across countries. Each dot in each graph presents returns to storage for a given market in a given year. In all years, we see markets where lean season prices were lower than harvest prices.

One explanation for low returns in a given year could be local supply shocks - high quantities of maize in oversupplied and poorly integrated markets. We use annual national maize yield and production data from FAO to assess associations between maize quantity and intra-annual price trends in a given year. The color of each dot in Figure 1a represents the national maize yield for each market-year. We see no clear relationship between these national-level yields and returns to storage, with both high and low yields associated with years of negative returns to storage. Our use of national-level yields likely masks significant within-country variation in maize yields in a given year. We also repeat the analysis using national production and find similar results (1b). Moreover, political and economic circumstances likely contribute idiosyncratically and unpredictably to intertemporal movements in commodity prices, especially in low harvest years. Food aid inflows or government release of grain stocks for example in response to poor regional harvests could contribute to the patterns we document: in years when high prices might generate a return to storing maize, such policies could decrease the price significantly in the lean season. Other government interventions or market policies such as export bans could be factors. An analysis of five countries in East and Southern Africa found that export bans did not have a statistically significant effect on cross-border price gaps, and moreover were associated with increases in domestic prices and inter-annual price volatility (Porteous, 2017). Export bans might successfully reduce intra-annual price volatility even as they increase inter-annual volatility, as (Ott, 2014) finds for global markets in staple cereals. The distinction between the effects of a policy on inter and intra-annual volatility is also relevant for stockholding. Zhou and Baylis (2020) show that government stockholding activities (maize purchase and sales) in Zambia stabilize maize retail prices intra-annually but have no discernable effect on inter-annual volatility.

Another explanation for negative returns in countries with two maize production seasons per year might be a preponderance of negative returns in either the primary or secondary season. The color of each dot in Figure 1c represents the season during which the return occurred. Although across countries, the frequency of negative returns was lower during the secondary season than the primary season (15.9% compared to 24.9%, Table 3), negative returns are present in all years.

## 2.4 Negative returns to storage across markets

Figure 2 shows that even in markets where expected returns are high on average, the risk of loss is nontrivial. These figures demonstrates the frequency and intensity of the negative returns phenomenon across markets in single and double season countries separately. Each dot represents one market. We present the percent of seasons in which the harvest season price exceeded the lean season in that market on the x-axis and the average returns to storage for that market on the y-axis. The size of the dot represents the number of yearly observations available for that market. Consistent with Table 2 and Figure 1, returns are generally positive on average for a given market across years; most of the dots sit above the y-axis value of zero. Mechanically, the graph is characterized by a downward-sloping trend, with markets characterized by higher average returns across years exhibiting a lower number of seasons with negative returns to storage. However, Figure 2 shows the considerable variation in average returns by frequency of negative returns; for example, numerous markets have average returns across years of more than 50% (on the y-axis) but the incidence of negative returns across those markets ranges between zero and 45%.[11]

[11] Note that in single season countries, returns are always positive in our data for 210 markets, covering 15 countries distributed across different regions of Africa, and across 20 years. The 25 markets that are always negative generally have only one or two market-years available. These observations are not included in the risk aversion analysis.

# 3 Are flat and/or declining price years predictable?

We have shown evidence of the substantial frequency of negative returns to storage in every country in our data, However, inter-annual variation in whether returns to storage are positive is not sufficient to imply the existence of risk. A key question is whether the farmer can predict when the returns will be negative or positive. The farmer has to make this prediction at harvest, when he decides to store or sell grain.

If the harvest price can predict whether returns to storage are negative, then the farmer knows which state of the world he is in (a year with negative returns or with positive returns to storage) and can make his decision accordingly. If the harvest price signal is a strong predictor of whether returns storage will be positive or negative, we would expect to see farmers opting out of storage when harvest prices are high relative to normal.

However, if the farmer cannot predict returns based on the observed harvest price, then the farmer will bear some risk associated with storing to sell. In this case, farmers seen to opt out of storage might be doing so because of a non-trivial risk of loss associated with storage and not because they can tell that the returns to storage will be negative.

We investigate whether farmers can tell when returns will be negative in two ways. First, we graph in Figure 3 the return to storage for each market-year over z-scores of harvest prices for each country, in single and double season countries respectively. The plus signs represent years with positive returns and the circles represent years in which returns proved less than or equal to zero. The blue lines are smoothed predictions with standard errors. In Figure 3b, the color of the symbol also represents the primary or secondary season. If harvest price was a consistent indicator of returns, we would expect a clear negative relationship between the magnitude of the returns to storage and the price at harvest, with positive returns (+) occurring when harvest prices were low, and negative returns (o) confined to regions characterized by higher than average harvest prices. While we see some evidence of this relationship, as characterized by the smoothed prediction lines in both figures, we find that negative returns occur across the distribution of harvest prices, indicating that farmers are unlikely to be able to perfectly predict the returns to storage given information at harvest.

Second, in Table 4 we evaluate country-specific regressions on returns to storage (Columns (1) and (2)) and the prediction as a classification problem - the likelihood of negative returns in a given year (Columns (3) and (4)). The former show results from separate OLS regressions by country where the dependent variable is returns to storage for the primary maize season, and the latter show results from probit regressions by country where the dependent variable is binary, equal to one if returns are less than or equal to zero. For both regressions, the explanatory variable is harvest price z-score and we include crop year and market fixed effects, as well as clustered standard errors. The dataset is limited to markets in single season countries with at least five market-years, and countries with at least nine markets meeting that criteria. This dataset includes 425 markets in 10 countries. Columns (1) and (3) show the coefficients on z-score and columns (3) and (4) show the "within" $R^2$ and pseudo-$R^2$, respectively. As expected, higher harvest prices are associated with lower returns to storage (Columns (1) and (3)) but considerable unexplained variation remains. Farmers cannot tell with certainty when they face a year characterized by negative returns to storage. The bottom two rows of Table 4 present the average $R^2$ across the regressions for all 10 countries and the $R^2$ from a regression pooling all observations across countries and including country dummies, and crop year and market fixed effects. The country dummies account for country-specific factors including whether the country has a marketing board and the functioning of private trade in the country and the crop year fixed effect captures broad trends across countries related to regional weather patterns, trade flows, and international and regional price trends. [12]

Our analysis in this and the subsequent section relies on a strong assumption that the returns to storage are stationary, so that the time series we use represents farmers' current beliefs about any given season's conditional seasonal price distribution. We test for the stationarity of returns by market. For only 14 out of 425 markets do we reject that the distribution of returns is stationary. Of course, we lack additional information that the farmer may have at his disposal about for example local transport or marketing disruptions, though to some degree the year fixed effect can proxy for these annual changes across markets in a given country.

[12]The same regression analysis without any fixed effects shows a weaker relationship between harvest prices and returns. (Appendix Table A5) Country dummies were included in the pooled regressions.

# 4 Risk aversion and opting-out of storage

The decision to store grain in each market-year is a gamble. At harvest, the farmer observes the harvest price and decides whether to sell or store, without knowing the lean season price. We established in the previous section that farmers cannot tell with certainty when the price will decline after harvest but we know that they will use that observed harvest price to make a decision about storage in a given year, given what they know about the distribution of returns.

What degree of risk aversion, given measured possible gains and losses, would be required to explain the strategy of not engaging in storage? We use the distribution of returns to calculate what degree of risk aversion would be required to make storage unappealing ex ante in each market.

## 4.1 Model

We consider a simple model where the household decides at the end of harvest whether to sell grain immediately or store the grain for future sale. Households that sell and consume grain encounter both income and price risk, and the decision to store relies on the share of the household budget allocated to grain and household preferences, as shown in Barrett (1996); Finkelshtain and Chalfant (1991) and others. In order to avoid placing theoretical constraints on income and household preferences between grain and other goods, we focus on grain stored for sale at a later date.

We assume the household is a price taker in both input and output markets and complete markets exist for both. Storage is restricted to being non-negative and farmers do not have access to credit or contingent claims markets. Later, we relax this assumption. At harvest time, the price $P_H$ of the maize grain is known, but the lean season price $P_L$ is not known, however the farmer is aware of the distribution and likelihood of returns if he stores grain to sell in the lean season. As in Section 3, we assume that while prices might exhibit trends, returns to storage ($r = \frac{P_L - P_H}{P_H}$) are likely stationary. We focus on markets in single season countries with at least 5 market-years and countries with at least nine markets. We test for stationarity of returns in markets using the Kwiatkowski–Phillips–Schmidt–Shin (KPSS) test and reject the null of stationarity in only 14 of the 425 markets. Results hold if we exclude those markets. We do not include storage costs or losses, or other transaction costs. We also conduct our analysis using the distribution of lean season prices rather than of returns, and calculate the share of market-years farmers opt out of storage in each market. The results hold and are presented in Appendix Table A6. We do not consider the impact of output risk, as the yield is known at harvest, nor can we separately identify the intertemporal discount factor in this framework.

The household should store grain if returns are positive: $r > 0$, however the stochastic nature of the lean season price prevents the household from evaluating this tradeoff and the additional price risk faced by the household may not be welfare-improving. We assume the households have von Neumann-Morgenstern utility functions. We calculate the farmer's certainty equivalent over a range of risk aversion levels for all markets. The intuition is the following: Pratt (1964) showed that an individual's certainty equivalent (CE) for a gamble is the lowest amount of money-for-certain that a decision-maker would be willing to accept instead of the gamble. For risk averse individuals, the CE will be less than the expected value of the gamble.

We calculate:

$$E[U(w(1+\tilde{r})] = U(w(1+C)) \tag{1}$$

where $w$ is household wealth, $\tilde{r}$ are the risky returns and $C$ is the certain return the household would be willing to accept to avoid storage. Newbery and Stiglitz (1979) showed that taking a Taylor-series approximation of the left and right hand sides of Equation (1) around the mean outcome $w(1+E[r]) = w(1+\bar{r})$ where $\bar{r}$ is the average return yields an approximation of the risk premium for small risks in terms of the Arrow-Pratt measures of risk aversion.

We define those measures of absolute risk aversion $A = -\frac{U''}{U'}(w)$ and relative risk aversion $R = -\frac{wU''}{U'}(w)$, and variance of the risky return equal to $\sigma^2$. The certainty equivalent can be approximated as

$$C \approx \bar{r} - \frac{1}{2}R\sigma^2 \tag{2}$$

In our case, the certainty equivalent is the lowest return the farmer would accept to not face the risk of storing; he would trade the gamble of storing (and the risk of prices falling in the lean season) for this return. The certainty equivalent is decreasing in risk aversion and in the variance of the return. If $C > 0$, then the farmer will prefer to store the grain for future sales, and if the certain return is less than or equal to zero, the farmer would be better off selling at harvest (i.e. when $r = 0$)

We calculate $C$ for each market in the data using the WFP price series, deflated to 2015 local currency units. We simulate the coefficient of relative risk aversion over the set [0,5) in increments of 0.1, drawing on findings in the experimental literature on small farmers in low income countries. (Fafchamps and Pender, 1997; Binswanger, 1982; Barrett, 1996) The set of 425 retail markets with primary season data includes markets with five or more years available, and countries with at least ten markets. We calculate the first and second moments of the risky return at the market level to determine the certain return and evaluate the storage decision for each market-year based on the harvest season price. Selling at harvest is a welfare-improving decision in a given market if the certainty equivalent of the risky return is less than or equal to zero, under the assumption of no additional storage costs or losses. We assume price shocks are exogenous, reasonable for modelling the decision of a smallholder farmer. Other models incorporate endogenous price shocks (Boussard, 1996) or restrict storage markets to be competitive and markets to be positively skewed (Deaton and Laroque, 1992).[13]

Note that we model the farmer's decision to sell or store some determined amount of the household's harvested crop production rather than the farmer's decision regarding the share of total production to store or sell at harvest, an interesting and related question. Farmers tend to sell a share of their production at harvest and store the rest for home consumption or sale later in the year. The price risk we focus on in this analysis may also help explain farmers' partial sale decision at harvest: they may sell some share in case the price does not rise, but store the rest for consumption and possible arbitrage in the case of a price increase.

[13]Mitra and Boussard (2012) use a Nerlovian adaptive expectation process where storage firms use information from the prior period to form expectations of future prices while Maître d'Hôtel and Le Cotty (2018) incorporate heterogeneity in farmer awareness of storage availability.

## 4.2 Results

We use the calculated certain return $C$ to determine the share of market-years in each country for which selling grain at harvest is the preferred choice, for each risk aversion coefficient between 0 and 5, with 0 representing risk neutral farmers. Table 5 presents these results aggregated into three categories: risk neutral and low risk aversion, moderate risk aversion, and high risk aversion, to show the share of market-years in which farmers would rationally forgo storage. We present these results by country. Results suggest that even for risk neutral and low risk aversion farmers, selling at harvest can be the optimal choice, either because of high harvest prices, low expected lean season prices, or high variance in returns. On average across the ten single season countries, farmers with a moderate level of risk aversion would opt out of storage in 15.3% of market-years. These results are conservative, as any storage costs or losses would increase the costs of storage, reducing the likelihood that a farmer should store for future sales.

Our results suggest that not all farmers would rationally store grain for later sale. In market-years in which they opt out, the risk of negative returns is too great relative to what they could earn with certainty at harvest.

## 4.3 Credit constraints and additional costs

The analysis in the preceding section includes no credit costs, no loss rates in storage, no discount rates in excess of interest, and no investment opportunities for farmers. In this section, we allow a cost for interest, relevant to the farmers' circumstance and decision in two ways: first, farmers who sold at harvest could invest any profits at a rate of return $i$, and second, farmers with harvest season debts could take out a loan at some cost while storing grain to sell in the lean season.

For simplicity, assume the interest rate ($i$) is equivalent in either scenario, and known to the farmer at harvest, and as before, there is no intertemporal discounting. Then the farmer should sell at harvest if 0 is greater than the certain return $C$ as defined in Equation (2) minus the interest cost, and he should store if $C - i > 0$. Even a conservative interest rate of 5% serves to increase the share of market-years in which a moderately risk averse farmer opts out of storage to 25.2%. (Table 6) An interest rate of 10% increases the opt-out rate for these farmers to 40% of market years. (Table 7)

The additional costs associated with taking on credit (or foregoing investments by tying up capital in maize) further reduce intertemporal arbitrage opportunities by reducing the payoff from storage, effectively shifting the distribution of returns toward zero. Storage fees, crop losses in storage, transaction and other carrying costs, and discount rates beyond the interest rate would have similar effects, and the reduction in payoffs would convince more farmers to sell at harvest. Our results in Tables 6 and 7, which do not consider costs beyond the interest rate, remain conservative.

# 5 Robustness Checks

## 5.1 Predicted lean season price

Table 4 showed that the harvest price is a predictor of lean season price, and therefore seasonal returns, but not a perfect predictor. As a robustness check, we use the predicted return from an OLS regression of returns on harvest season price for each market. Using the expectation and variance of predicted returns and a conservative interest rate of 5%, we construct the *predicted* certainty equivalent, and compare it to the known return of 0 at harvest to determine if a farmer would choose storage. We find that the share of market-years in which a farmer avoids storage decreases; on average across countries, moderately risk averse farmers would prefer to sell at harvest for 5.9% of market-years on average (Table 8).

# 6 Intra-annual returns

We have so far defined returns to storage as the increase or decrease in lean season price over the harvest season price. However, a farmer could store for a shorter period of time (selling after the harvest but before the lean season), to take advantage of any returns within-year across seasons. In the Appendix, we show the distributions of returns to storage by the number of months post-harvest for each country using the full dataset and separated by single and double season countries. We present evidence that in some countries such as Zambia, waiting five to nine months after harvest will yield positive results on average, however for all countries, there is a non-zero probability of negative returns for every month the farmer waits to sell (Appendix Figures A1 and A2).

Farmers face a series of decisions related to storage and sales. The optimal time to sell may be informed by changes over time, reducing the risks of holding stocks to sell. We define a harvest and lean season for each country in our analysis, with returns to storage calculated as the difference between the harvest season minimum and the lean season maximum. This works well if prices rise monotonically after harvest and peak during planting time. But it may be that in some years the price peaks in the months between harvest and lean season. In such circumstances we might falsely conclude that the returns to storage were negative when they could have been positive if farmers sold after harvest but before the decline in prices began.

# 7 Discussion

A focus on average patterns of seasonal prices in the literature has led many researchers to overlook an important maize storage risk relevant to small farmer and small trader decision-making: years in which the lean season price fails to rise above the price at the time of harvest and no inter-temporal arbitrage opportunity occurs. We demonstrate that negative returns to storage occur in all countries and all years. We also find that negative returns are associated with a range of harvest season prices, likely preventing households from predicting returns at harvest and adjusting storage choice to maximize returns. We show that storing is not a welfare-improving strategy in all markets in all countries, and that risk aversion can plausible contribute to the farmer's decision to store. Inclusion of loss aversion or present bias as well as calculations countenancing the costs of storage, transaction, and search costs only strengthen our result.

We propose that the risk of flat or declining prices after harvest and in particular the possibility of negative returns to storage may contribute to farmers' observed reluctance to hold a significant share of their harvest across seasons for later sale. This risk likely interacts with and may exacerbate other critical constraints that researchers have focused on related to small farmer maize marketing including inadequate storage technology, time inconsistent preferences and liquidity constraints.

The price risk we describe and quantify has particular salience in the context of a credit market failure that prevents farmers from borrowing across years. Our analysis therefore draws an important distinction regarding the sort of credit farmers need to access to take advantage of inter-temporal arbitrage opportunities between harvest and lean season. Average returns across years are high and positive; with credit access permitting borrowing across years farmers could pursue a buy-low sell-high strategy backed by the ability to borrow in bad years and pay back their loans in good years. Yet the focus in the literature has long been on credit permitting farmers to borrow within the same year between harvest and lean season to exploit intra-annual arbitrage opportunities.

Our calculations leave out the costs of storage, post-harvest losses in product quantity or quality, foregone interest on sales revenue and off-season trader search. Even our most conservative specifications using predicted lean season prices to adjust for the fact that harvest prices are observable find that moderately and high risk averse farmers would still optimally fail to store a non-zero share of market-years (5.9 and 13.6%, respectively).

We find evidence of considerable spatial heterogeneity in the probability of negative returns. Important drivers of the likelihood of negative returns to storage should be investigated in future analyses including: the degree to which markets exhibiting more incidence of negative returns are those that are poorly spatially integrated, more or less maize dependent, or located in regions with more or less population density. In particular, disentangling the relationship between negative returns to storage and external shocks from international markets versus government policy responses to anticipated shortfalls would be valuable.

Our results also suggest the potential importance of focusing on experimenting with and evaluating policies that address flat price risk to farmers and traders, given that farmer failure to store may not be attributable exclusively to credit market imperfections. Relevant policies that might increase farmer storage take-up and improve arbitrage include price-contingent loan repayment, forward contracts, and price insurance to large intermediaries who handle storage. Ultimately, the success of such policies would attenuate inter-temporal arbitrage opportunities, equilibrating markets over time. Given the general equilibrium effects of farmer storage on prices in proximate markets (Burke et al., 2019), inducing more risk tolerant farmers to store with these sorts of policies, perhaps in combination with credit, may have powerful effects

Finally, while we have focused on the circumstance and storage decision of net seller farm households in this analysis, risk aversion and price uncertainty among net buyer households would be expected to lead to more precautionary storage. Future work might also take our insights to data on household storage behavior, testing for heterogeneity in the relationship between price uncertainty and storage behaviors depending on whether the household is a net buyer or net seller for example.

We demonstrate that using a conservative definition of negative returns, the assumption of positive returns to storage does not always hold, and in fact, the possibility of negative returns provides new and important insight relevant to solving the widely-observed and persistent puzzle of low storage uptake among small farmers in Sub-Saharan Africa.

Table 1: Count of Countries and Markets by Number of Seasons and Type of Market

| | | | *Primary Season* | | *Secondary Season* | |
|---|---|---|---|---|---|---|
| Market Type | Seasons | Countries | Unique Markets | Market-year Observations | Unique Markets | Market-year Observations |
| Retail | single | 17 | 637 | 5432 | 0 | 0 |
| Retail | double | 13 | 401 | 1765 | 371 | 1729 |
| Total Retail | | 30 | 1038 | 7197 | 371 | 1729 |
| Wholesale | single | 6 | 32 | 297 | 0 | 0 |
| Wholesale | double | 9 | 113 | 1030 | 100 | 934 |
| Total Wholesale | | 15 | 145 | 1327 | 100 | 934 |
| Total | | 32 | 1183 | 8524 | 471 | 2663 |

[1] Monthly maize price data for retail markets from the WFP Global Food Prices Database for 2000-2021. Prices were adjusted to 2015 local currency value using FAO/IMF data on historical monthly CPI. National and subnational agricultural season data was reported from FAO-GIEWS via the University of Wisconsin.

[2] A market was included if there was price data for at least one market-year as defined as having a harvest price and lean season price available for that market year. A country was included if there was at least one market in the country.

[3] The totals in this table are smaller than the totals in Tables 2, 3, A1, A2 as a unique market may sell more than one type of maize, e.g. in Cameroon there is overlap between the markets that sell white and yellow maize .

Table 2: Frequency and Magnitude of Negative Returns to Storage for Retail Markets
(Countries with one maize season)

| Country (1) | Commodity (2) | Years (3) | Number of Markets (4) | Number of Market-Years (5) | Frequency of Negative Returns (6) | Average Total Returns (7) | Average Positive Returns (8) | Average Negative Returns (9) |
|---|---|---|---|---|---|---|---|---|
| Burkina Faso | Maize (white) | 2002-2020 | 54 | 455 | 11.0% | 24.9% | 28.6% | -5.1% |
| Cabo Verde | Maize (local) | 2007-2019 | 2 | 22 | 36.4% | 10.9% | 19.9% | -4.9% |
| Cabo Verde | Maize (yellow) | 2007-2019 | 2 | 22 | 31.8% | 5.8% | 10.4% | -4.2% |
| Chad | Maize | 2003-2019 | 3 | 48 | 16.7% | 27.5% | 35.7% | -13.6% |
| Chad | Maize (white) | 2003-2020 | 43 | 146 | 17.8% | 38.5% | 49.5% | -12.5% |
| Ethiopia | Maize (white) | 2005-2019 | 28 | 199 | 28.6% | 34.8% | 54.4% | -14.2% |
| Gambia | Maize | 2005-2020 | 28 | 164 | 34.8% | 14.4% | 32.2% | -19.0% |
| Guinea | Maize | 2012-2020 | 12 | 43 | 23.3% | 24.8% | 38.1% | -19.2% |
| Guinea-Bissau | Maize | 2006-2020 | 10 | 27 | 44.4% | 11.2% | 32.9% | -15.9% |
| Malawi | Maize | 2002-2021 | 120 | 986 | 11.4% | 80.1% | 92.2% | -14.3% |
| Mali | Maize | 2002-2020 | 69 | 705 | 15.7% | 29.7% | 37.2% | -10.8% |
| Mauritania | Maize (local) | 2018-2020 | 5 | 10 | 50.0% | 2.4% | 14.5% | -9.8% |
| Mozambique | Maize (white) | 1999-2021 | 39 | 330 | 10.9% | 71.7% | 82.0% | -12.9% |
| Niger | Maize | 1999-2020 | 66 | 779 | 23.2% | 15.6% | 22.9% | -8.2% |
| Senegal | Maize (local) | 2006-2020 | 53 | 459 | 16.3% | 19.7% | 24.8% | -6.1% |
| South Sudan | Maize (white) | 2007-2021 | 10 | 53 | 24.5% | 48.2% | 72.8% | -27.5% |
| Zambia | Maize (white) | 2002-2021 | 70 | 884 | 12.0% | 53.0% | 61.9% | -12.1% |
| Zimbabwe | Maize | 2009-2021 | 28 | 100 | 12.0% | 30.7% | 38.2% | -24.3% |
| Total | | | 642 | 5432 | 16.3% | 41.7% | 52.1% | -11.5% |

[1] Monthly maize price data for retail markets from the WFP Global Food Prices Database for 2000-2021. Prices were adjusted to 2015 local currency value using FAO/IMF data on historical monthly CPI. National and subnational agricultural season data was reported from FAO-GIEWS via the University of Wisconsin.

[2] Columns (6)-(9): Returns are calculated for each ”market-year” or ”crop-year” for the lean season price over the previous harvest season price. The lean season price is defined as the maximum price of the three months prior to the subsequent harvest, and the harvest season price is the minimum price of the months defined as harvest season. The ”Total” for these columns is an average across all market-year observations.

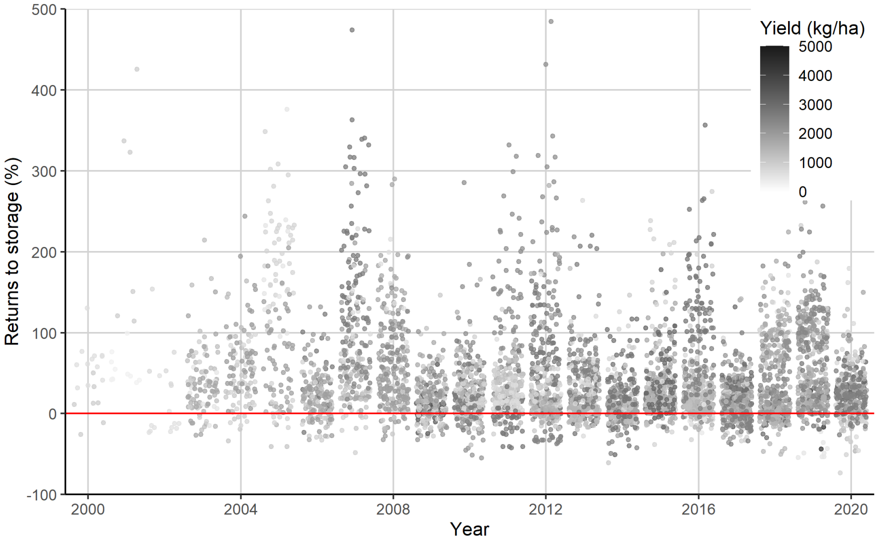
Table 3: Frequency and Magnitude of Negative Returns to Storage for Retail Markets
(Countries with two maize seasons)

| | | | **Primary Season** | | | | | | **Second Season** | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Country<br>(1) | Commodity<br>(2) | Years<br>(3) | Number of Markets<br>(4) | Number of Market-Years<br>(5) | Frequency of Negative Returns<br>(6) | Average Total Returns<br>(7) | Average Positive Returns<br>(8) | Average Negative Returns<br>(9) | Number of Markets<br>(10) | Number of Market-Years<br>(11) | Frequency of Negative Returns<br>(12) | Average Total Returns<br>(13) | Average Positive Returns<br>(14) | Averag Negati Return<br>(15) |
| Benin | Maize | 2012-2019 | 4 | 11 | 27.3% | 21.7% | 34.1% | -11.1% | 4 | 12 | 8.3% | 20.4% | 23.0% | -8.8% |
| Benin | Maize (white) | 2006-2020 | 51 | 142 | 9.9% | 44.1% | 49.9% | -9.3% | 51 | 147 | 9.5% | 36.2% | 40.8% | -7.9% |
| Burundi | Maize (white) | 2007-2021 | 64 | 272 | 18.0% | 40.9% | 52.2% | -10.6% | 68 | 295 | 6.4% | 56.3% | 60.6% | -6.3% |
| Cameroon | Maize | 2004-2020 | 25 | 80 | 21.2% | 25.1% | 34.3% | -9.2% | 5 | 70 | 10.0% | 17.9% | 20.2% | -3.3% |
| Cameroon | Maize (white) | 2014-2020 | 10 | 21 | 23.8% | 30.5% | 42.4% | -7.3% | 10 | 22 | 22.7% | 21.0% | 27.7% | -1.7% |
| Cameroon | Maize (yellow) | 2014-2020 | 10 | 20 | 15.0% | 33.3% | 41.4% | -12.2% | 10 | 22 | 27.3% | 18.6% | 25.9% | -0.8% |
| Central African Republic | Maize | 2003-2020 | 28 | 96 | 40.6% | 32.1% | 63.7% | -14.0% | 28 | 111 | 7.2% | 71.9% | 78.7% | -16.1% |
| Cote d'Ivoire | Maize | 2004-2020 | 13 | 62 | 25.8% | 29.6% | 43.3% | -10.0% | 13 | 76 | 23.7% | 48.9% | 66.5% | -8.0% |
| DR Congo | Maize | 2007-2021 | 37 | 137 | 31.4% | 44.2% | 72.8% | -18.4% | 38 | 115 | 33.9% | 40.0% | 74.6% | -27.6% |
| Ghana | Maize | 2019-2020 | 19 | 36 | 25.0% | 62.1% | 84.7% | -5.5% | 18 | 34 | 8.8% | 45.7% | 50.6% | -5.1% |
| Ghana | Maize (yellow) | 2019-2020 | 17 | 31 | 22.6% | 61.9% | 81.2% | -4.3% | 16 | 30 | 13.3% | 41.3% | 48.5% | -5.2% |
| Kenya | Maize (white) | 2005-2020 | 9 | 80 | 38.8% | 12.1% | 28.5% | -13.9% | 9 | 81 | 34.6% | 15.1% | 32.5% | -17.7% |
| Nigeria | Maize (white) | 2013-2020 | 15 | 17 | 0.0% | 79.8% | 79.8% | 0.0% | 15 | 24 | 16.7% | 51.2% | 62.5% | -5.3% |
| Nigeria | Maize (yellow) | 2013-2020 | 14 | 17 | 5.9% | 71.4% | 77.7% | -28.4% | 14 | 24 | 16.7% | 45.6% | 55.3% | -3.0% |
| Rwanda | Maize | 2008-2021 | 87 | 417 | 20.6% | 32.8% | 44.7% | -12.9% | 91 | 431 | 12.8% | 33.9% | 40.2% | -8.6% |
| Tanzania | Maize (white) | 2015-2021 | 25 | 125 | 47.2% | 16.5% | 51.7% | -22.9% | 15 | 75 | 52.0% | 6.0% | 45.0% | -30.0% |
| Togo | Maize (white) | 2000-2020 | 6 | 120 | 25.8% | 39.5% | 58.3% | -14.5% | 6 | 126 | 13.5% | 37.5% | 44.1% | -4.8% |
| Uganda | Maize | 2009-2018 | 2 | 12 | 16.7% | 52.8% | 69.1% | -28.4% | 1 | 7 | 14.3% | 38.1% | 44.8% | -1.9% |
| Uganda | Maize (white) | 2010-2021 | 14 | 69 | 36.2% | 20.8% | 41.5% | -15.6% | 5 | 27 | 11.1% | 29.3% | 33.8% | -7.1% |
| Total | | | 450 | 1765 | 24.9% | 35.2% | 51.7% | -14.3% | 417 | 1729 | 15.9% | 39.2% | 49.3% | -14.3% |

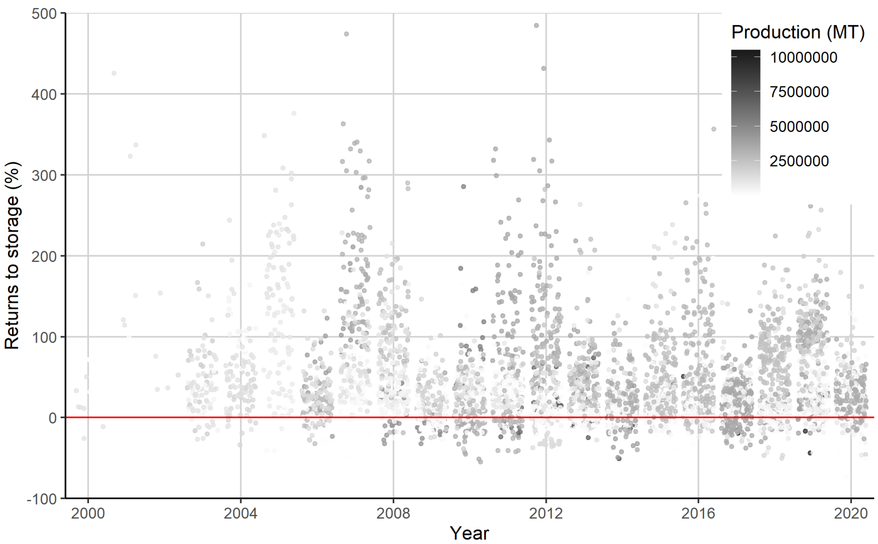
[1] Monthly maize price data for retail markets from the WFP Global Food Prices Database for 2000-2021. Prices were adjusted to 2015 local currency value using FAO/IMF data on historical monthly CF National and subnational agricultural season data was reported from FAO-GIEWS via the University of Wisconsin.

[2] Columns (6)-(9) and (12)-(15): Returns are calculated for each "market-year" or "crop-year" for the lean season price over the previous harvest season price. The lean season price is defined as the maximu price of the three months prior to the subsequent harvest, and the harvest season price is the minimum price of the months defined as harvest season. The "Total" for these columns is an average across market-year observations.

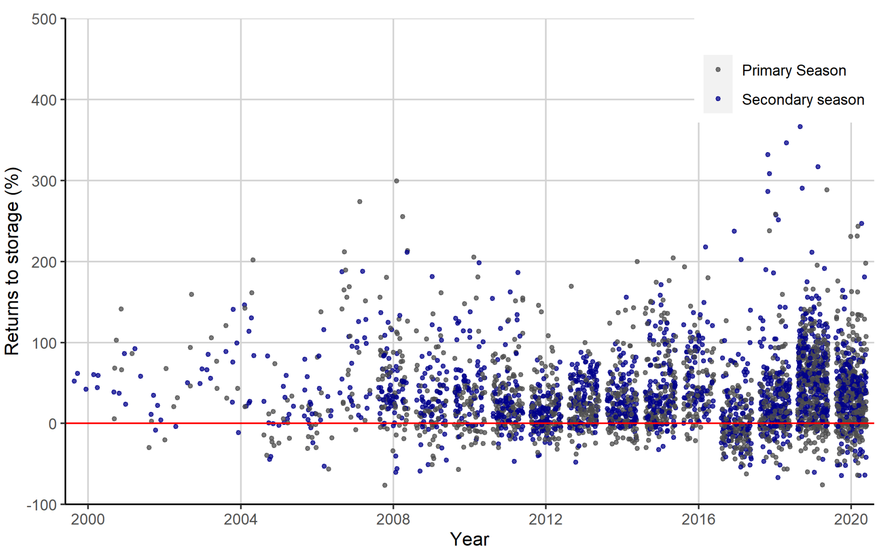
Figure 1: Returns to maize storage over time




(a) Retail markets in single season countries and national yield (market-year observations)

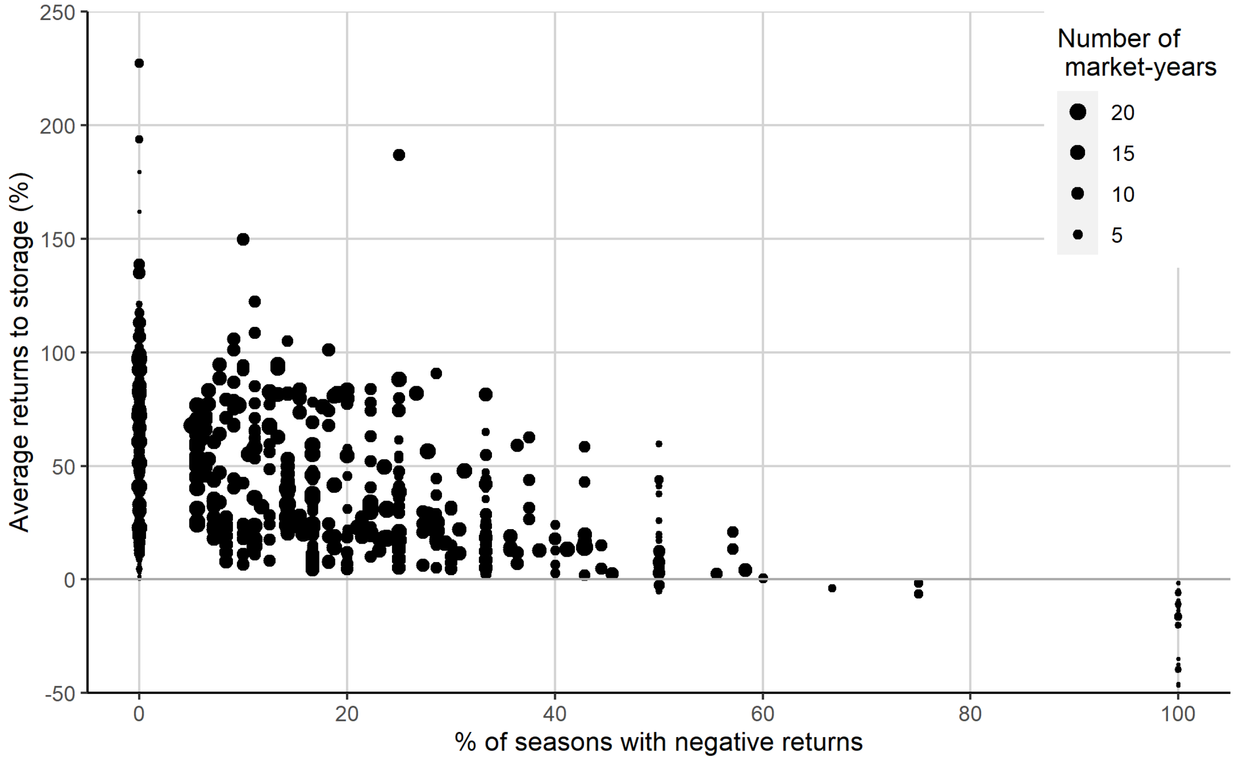



(b) Retail markets in single season countries and national production (market-year observations)

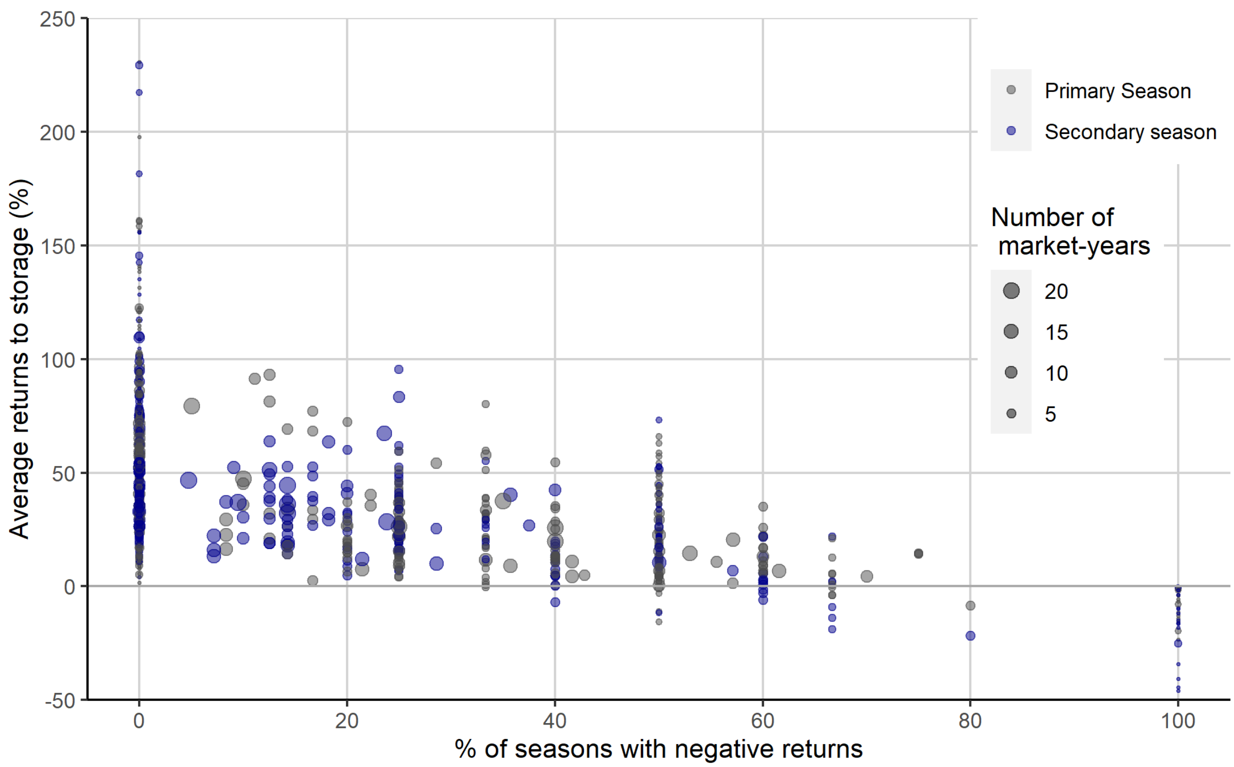



(c) Retail markets in double season countries (market-year observations)

Figure 2: Intensity and frequency of negative returns to storage

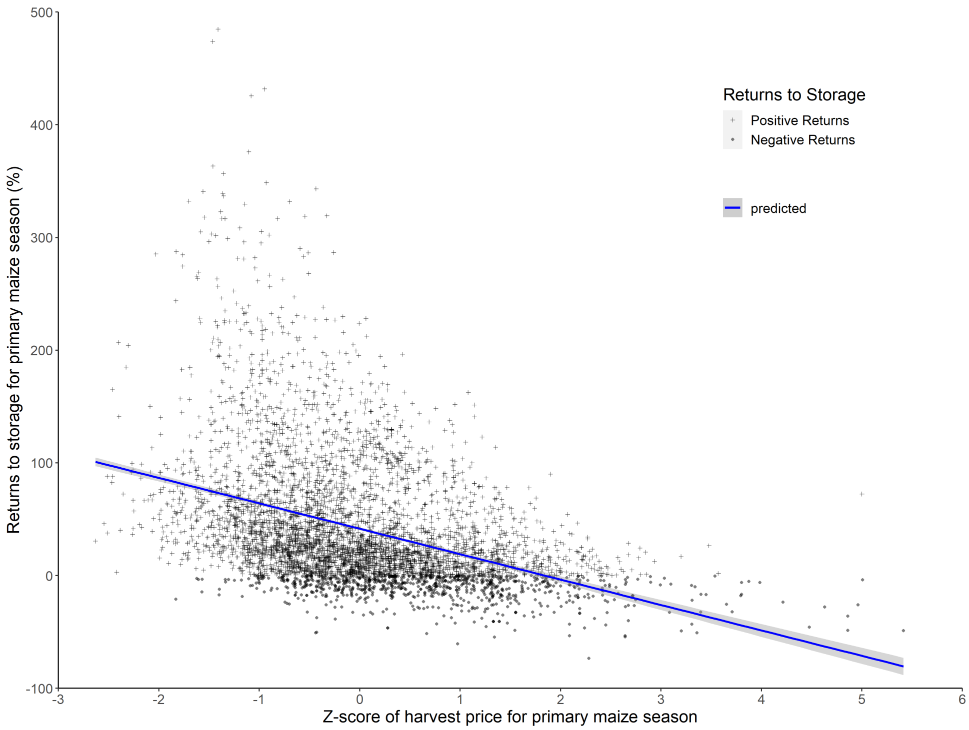



(a) Retail markets in single season countries
(market observations)

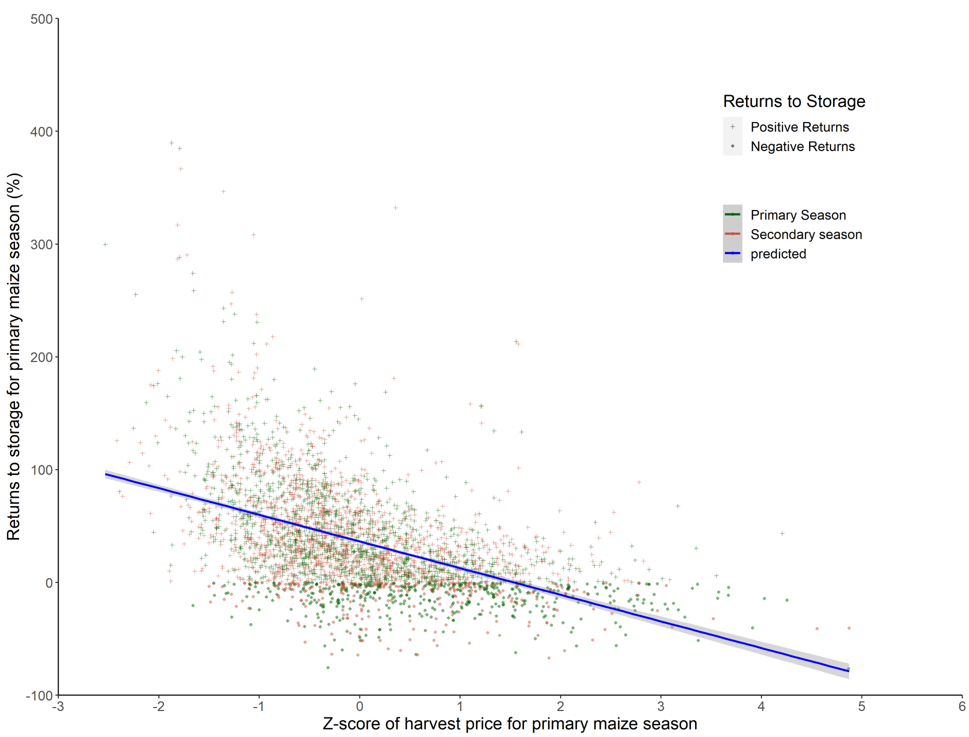



(b) Retail markets in double season countries
(market observations)

Figure 3: Predictability of returns to storage by harvest price




(a) Retail markets in single season countries
(market-year observations)




(b) Retail markets in double season countries
(market-year observations)

Table 4: Regressions of harvest prices on returns to storage and the probability of negative returns for retail markets in single season countries

| *Dep. variable* | | | Returns to Storage (%) | | Negative Returns (=1 if Returns$\leq$ 0) | |
|---|---|---|---|---|---|---|
| | | | Harvest price | | Harvest price | |
| | | Number of | z-score | $R^2$ | z-score | Pseudo-$R^2$ |
| Country | Commodity | Markets | (1) | (2) | (3) | (4) |
| Burkina Faso | Maize (white) | 54 | -22.217*** | 0.33 | 0.433*** | 0.22 |
| Chad | Maize (white) | 12 | -33.550*** | 0.37 | 0.758*** | 0.17 |
| Ethiopia | Maize (white) | 22 | -27.171*** | 0.32 | 0.432*** | 0.40 |
| Gambia | Maize | 16 | -26.893*** | 0.30 | 0.624*** | 0.26 |
| Malawi | Maize | 69 | -58.156*** | 0.30 | 0.426*** | 0.37 |
| Mali | Maize | 55 | -20.112*** | 0.20 | 0.197*** | 0.25 |
| Mozambique | Maize (white) | 23 | -40.213*** | 0.18 | 0.424*** | 0.11 |
| Niger | Maize | 62 | -16.255*** | 0.40 | 0.293*** | 0.28 |
| Senegal | Maize (local) | 46 | -22.126*** | 0.47 | 0.335*** | 0.15 |
| Zambia | Maize (white) | 66 | -30.921*** | 0.38 | 0.196*** | 0.33 |
| CC Average | | 425 | | 0.33 | | 0.25 |
| Pooled | | 425 | | 0.21 | | 0.12 |

[1] Columns (1) and (2) show results from OLS regressions by country of returns to storage (%) on harvest price z-score with cropyear and market fixed effects. Column (1) is the coefficient on harvest price z-score and column (2) is the "within" adjusted $R^2$for that regression. Columns (3) and (4) show results from regressions by country for negative returns (binary variable =1 if returns were zero or negative) on harvest price z-score with cropyear and market fixed effects. Column (3) is the average marginal effect (AME) of harvest price z-score from a probit model with cropyear and market fixed effects and column (4) is McFadden's pseudo-$R^2$ for that country-specific regression.

[2] The cross country average $R^2$ is the unweighted average of $R^2$ for all above countries. The pooled regression $R^2$ is calculated by regressing returns to storage and negative returns, respectively, on harvest price z-score, with cropyear and market fixed effects and country dummies. Country dummies were used for the pooled regressions to account for country characteristics without demeaning.

[3] Returns are calculated for each "market-year" for the lean season price over the previous harvest season price. The lean season price is defined as the maximum price of the three months prior to the subsequent harvest, and the harvest season price is the minimum price of the months defined as harvest season. Markets were included if data were available for at least five market-years. Countries were included if data were available for at least nine markets. Harvest Price z-score was calculated at the country level.

[4] ***Significant at the 1 percent level. **Significant at the 5 percent level.*Significant at the 10 percent level.

Table 5: Share of retail market-years for which farmers should optimally forgo storage by farmer risk tolerance (based on variation in returns) in single season countries

| Country | Commodity | Number of Markets | Risk Neutral and Low Risk Aversion R∈ $[0, 1)$ | Moderate Risk Aversion R∈ $[1, 3)$ | High Risk Aversion R∈ $[3, 5)$ |
|---|---|---|---|---|---|
| Burkina Faso | Maize (white) | 54 | 0.0% | 0.3% | 8.4% |
| Chad | Maize (white) | 12 | 0.0% | 3.0% | 36.3% |
| Ethiopia | Maize (white) | 22 | 0.0% | 29.9% | 88.2% |
| Gambia | Maize | 16 | 7.3% | 60.2% | 95.2% |
| Malawi | Maize | 69 | 0.3% | 28.9% | 87.6% |
| Mali | Maize | 55 | 0.0% | 11.6% | 68.8% |
| Mozambique | Maize (white) | 23 | 0.0% | 13.4% | 56.1% |
| Niger | Maize | 62 | 0.5% | 1.7% | 19.3% |
| Senegal | Maize (local) | 46 | 0.0% | 1.0% | 2.0% |
| Zambia | Maize (white) | 66 | 0.0% | 3.7% | 24.7% |
| Total | | 425 | 0.8% | 15.3% | 48.7% |

[1] Risk tolerance is calculated using the first and second moments of the returns to storage for the primary maize season for each retail market in single season countries with five or more crop years available, and countries with nine or more markets available.

Table 6: Share of retail market-years for which farmers should optimally forgo storage by farmer risk tolerance with an interest rate of 5% (based on variation in returns) in single season countries

| Country | Commodity | Number of Markets | Risk Neutral and Low Risk Aversion R∈ $[0, 1)$ | Moderate Risk Aversion R∈ $[1, 3)$ | High Risk Aversion R∈ $[3, 5)$ |
|---|---|---|---|---|---|
| Burkina Faso | Maize (white) | 54 | 4.0% | 7.9% | 16.5% |
| Chad | Maize (white) | 12 | 1.6% | 9.6% | 59.4% |
| Ethiopia | Maize (white) | 22 | 4.1% | 46.2% | 97.6% |
| Gambia | Maize | 16 | 17.1% | 84.0% | 95.5% |
| Malawi | Maize | 69 | 0.4% | 33.3% | 90.8% |
| Mali | Maize | 55 | 1.5% | 24.7% | 87.2% |
| Mozambique | Maize (white) | 23 | 0.0% | 16.4% | 64.2% |
| Niger | Maize | 62 | 7.4% | 16.4% | 42.7% |
| Senegal | Maize (local) | 46 | 5.6% | 7.7% | 17.2% |
| Zambia | Maize (white) | 66 | 0.0% | 5.8% | 32.7% |
| Total | | 425 | 4.2% | 25.2% | 60.4% |

[1] Risk tolerance is calculated using the first and second moments of the returns to storage for the primary maize season for each retail market in single season countries with five or more crop years available, and countries with nine or more markets available.

Table 7: Share of retail market-years for which farmers should optimally forgo storage by farmer risk tolerance with an interest rate of 10% (based on variation in returns) in single season countries

| Country | Commodity | Number of Markets | Risk Neutral and Low Risk Aversion R$\in [0, 1)$ | Moderate Risk Aversion R$\in [1, 3)$ | High Risk Aversion R$\in [3, 5)$ |
|---|---|---|---|---|---|
| Burkina Faso | Maize (white) | 54 | 8.4% | 16.8% | 41.0% |
| Chad | Maize (white) | 12 | 5.3% | 30.2% | 79.2% |
| Ethiopia | Maize (white) | 22 | 6.0% | 63.2% | 99.8% |
| Gambia | Maize | 16 | 41.8% | 94.4% | 98.3% |
| Malawi | Maize | 69 | 0.6% | 39.2% | 93.0% |
| Mali | Maize | 55 | 4.5% | 48.6% | 98.5% |
| Mozambique | Maize (white) | 23 | 0.0% | 20.9% | 72.6% |
| Niger | Maize | 62 | 31.4% | 52.6% | 77.4% |
| Senegal | Maize (local) | 46 | 19.7% | 24.8% | 43.2% |
| Zambia | Maize (white) | 66 | 0.0% | 9.0% | 43.2% |
| Total | | 425 | 11.8% | 40.0% | 74.6% |

[1] Risk tolerance is calculated using the first and second moments of the returns to storage for the primary maize season for each retail market in single season countries with five or more crop years available, and countries with nine or more markets available.

Table 8: Share of retail market-years for which farmers should optimally forgo storage by farmer risk tolerance with an interest rate of 5% (based on variation in predicted returns) in single season countries

| Country | Commodity | Number of Markets | Risk Neutral and Low Risk Aversion R$\in [0, 1)$ | Moderate Risk Aversion R$\in [1, 3)$ | High Risk Aversion R$\in [3, 5)$ |
|---|---|---|---|---|---|
| Burkina Faso | Maize (white) | 54 | 4.0% | 4.0% | 4.4% |
| Chad | Maize (white) | 12 | 0.0% | 4.7% | 7.7% |
| Ethiopia | Maize (white) | 22 | 3.3% | 11.2% | 40.7% |
| Gambia | Maize | 16 | 16.5% | 20.7% | 48.7% |
| Malawi | Maize | 69 | 0.2% | 1.1% | 9.0% |
| Mali | Maize | 55 | 1.5% | 2.1% | 3.4% |
| Mozambique | Maize (white) | 23 | 0.0% | 0.0% | 0.0% |
| Niger | Maize | 62 | 6.1% | 8.9% | 12.7% |
| Senegal | Maize (local) | 46 | 4.9% | 6.1% | 7.7% |
| Zambia | Maize (white) | 66 | 0.0% | 0.4% | 2.1% |
| Total | | 425 | 3.6% | 5.9% | 13.6% |

[1] Risk tolerance is calculated using the first and second moments of the returns to storage for the primary maize season for each retail market in single season countries with five or more crop years available, and countries with nine or more markets available. The predicted return is based on market level OLS regressions of returns on harvest price and crop year.

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# A Appendix

Table A1: Frequency and Magnitude of Negative Returns to Storage for Wholesale Markets (Countries with one maize season)

| Country (1) | Commodity (2) | Years (3) | Number of Markets (4) | Number of Market-Years (5) | Frequency of Negative Returns (6) | Average Total Returns (7) | Average Positive Returns (8) | Average Negative Returns (9) |
|---|---|---|---|---|---|---|---|---|
| Burkina Faso | Maize | 2002-2011 | 2 | 4 | 0.0% | 38.9% | 38.9% | 0.0% |
| Eswatini | Maize (white) | 2003-2019 | 1 | 12 | 75.0% | 4.5% | 46.1% | -9.4% |
| Ethiopia | Maize (white) | 1999-2020 | 17 | 180 | 18.9% | 31.0% | 40.9% | -11.6% |
| Mozambique | Maize (white) | 1999-2020 | 3 | 47 | 6.4% | 67.0% | 72.5% | -13.1% |
| South Africa | Maize (white) | 1999-2021 | 1 | 21 | 19.0% | 38.2% | 51.2% | -16.9% |
| South Africa | Maize (yellow) | 1999-2021 | 1 | 21 | 19.0% | 32.9% | 42.8% | -9.4% |
| South Sudan | Maize (white) | 2012-2021 | 8 | 12 | 16.7% | 44.2% | 58.4% | -26.6% |
| Total | | | 33 | 297 | 18.9% | 36.9% | 48.3% | -12.1% |

[1] Monthly maize price data for wholesale markets from the WFP Global Food Prices Database for 2000-2021. Prices were adjusted to 2015 local currency value using FAO/IMF data on historical monthly CPI. National and subnational agricultural season data was reported from FAO-GIEWS via the University of Wisconsin.

[2] Columns (6)-(9): Returns are calculated for each "market-year" for the lean season price over the previous harvest season price. The lean season price is defined as the maximum price of the three months prior to the subsequent harvest, and the harvest season price is the minimum price of the months defined as harvest season. The "Total" for these columns is an average across all market-year observations.

Table A2: Frequency and Magnitude of Negative Returns to Storage for Wholesale Markets (Countries with two maize seasons)

| | | | Primary Season | | | | | | Second Season | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Country (1) | Commodity (2) | Years (3) | Number of Markets (4) | Number of Market-Years (5) | Frequency of Negative Returns (6) | Average Total Returns (7) | Average Positive Returns (8) | Average Negative Returns (9) | Number of Markets (10) | Number of Market-Years (11) | Frequency of Negative Returns (12) | Average Total Returns (13) | Average Positive Returns (14) | Average Negative Returns (15) |
| Benin | Maize | 2001-2011 | 1 | 4 | 0.0% | 27.2% | 27.2% | 0.0% | 1 | 6 | 16.7% | 42.0% | 53.6% | -15.8% |
| Burundi | Maize | 2011-2020 | 3 | 19 | 21.1% | 29.4% | 41.1% | -14.5% | 3 | 20 | 10.0% | 55.0% | 61.8% | -6.1% |
| Cameroon | Maize | 2010-2020 | 33 | 96 | 19.8% | 22.7% | 29.9% | -6.3% | 31 | 92 | 10.9% | 25.5% | 30.3% | -13.7% |
| Cameroon | Maize (white) | 2014-2020 | 6 | 35 | 17.1% | 25.8% | 33.9% | -13.4% | 6 | 42 | 14.3% | 22.0% | 26.1% | -3.0% |
| Ghana | Maize | 2005-2020 | 19 | 180 | 15.0% | 43.2% | 53.2% | -13.5% | 18 | 205 | 16.6% | 34.9% | 43.7% | -9.2% |
| Ghana | Maize (yellow) | 2019-2020 | 13 | 23 | 0.0% | 70.0% | 70.0% | 0.0% | 12 | 22 | 9.1% | 44.7% | 49.6% | -3.7% |
| Kenya | Maize | 2005-2021 | 5 | 60 | 33.3% | 29.1% | 52.9% | -18.5% | 5 | 62 | 30.6% | 19.4% | 41.4% | -30.3% |
| Kenya | Maize (white) | 2005-2020 | 5 | 56 | 30.4% | 28.8% | 48.6% | -16.6% | 5 | 56 | 35.7% | 16.6% | 39.7% | -25.0% |
| Nigeria | Maize | 2001-2016 | 5 | 43 | 51.2% | 0.7% | 16.8% | -14.7% | 5 | 49 | 20.4% | 13.0% | 18.3% | -7.7% |
| Nigeria | Maize (white) | 2003-2020 | 15 | 102 | 43.1% | 24.7% | 59.3% | -20.9% | 15 | 106 | 17.0% | 32.2% | 40.4% | -7.9% |
| Nigeria | Maize (yellow) | 2013-2020 | 15 | 73 | 35.6% | 30.3% | 57.2% | -18.4% | 15 | 74 | 8.1% | 38.9% | 42.5% | -1.9% |
| Rwanda | Maize | 2000-2021 | 2 | 18 | 16.7% | 15.7% | 22.3% | -17.1% | 2 | 17 | 23.5% | 15.7% | 23.1% | -8.5% |
| Tanzania | Maize | 2005-2021 | 25 | 281 | 28.1% | 35.2% | 55.4% | -16.7% | 12 | 163 | 36.8% | 16.1% | 42.2% | -28.6% |
| Uganda | Maize | 2005-2021 | 5 | 40 | 27.5% | 35.6% | 55.5% | -16.6% | 3 | 20 | 20.0% | 27.3% | 35.6% | -6.3% |
| Total | | | 152 | 1030 | 27.0% | 31.9% | 49.7% | -16.4% | 133 | 934 | 21.0% | 27.0% | 39.1% | -18.3% |

[1] Monthly maize price data for wholesale markets from the WFP Global Food Prices Database for 2000-2021. Prices were adjusted to 2015 local currency value using FAO/IMF data on historical monthly CPI. National and subnational agricultural season data was reported from FAO-GIEWS via the University of Wisconsin.

[2] Columns (6)-(9) and (12)-(15): Returns are calculated for each "market-year" for the lean season price over the previous harvest season price. The lean season price is defined as the maximum price of the three months prior to the subsequent harvest, and the harvest season price is the minimum price of the months defined as harvest season. The "Total" for these columns is an average across all market-year observations.

Table A3: Market skewness analysis for retail markets in all countries

| Country | Commodity | Number of Markets (1) | Coefficient of Variation (2) | Market Skewness (3) | Percent Markets Negative Skew (4) |
|---|---|---|---|---|---|
| Benin | Maize | 4 | 0.16 | 0.26 | 25.0% |
| Benin | Maize (white) | 51 | 0.23 | 0.52 | 15.7% |
| Burkina Faso | Maize (white) | 56 | 0.15 | 0.27 | 33.9% |
| Burundi | Maize (white) | 68 | 0.28 | 0.58 | 5.9% |
| Cabo Verde | Maize (local) | 2 | 0.26 | 0.47 | 0.0% |
| Cabo Verde | Maize (yellow) | 2 | 0.11 | -0.71 | 100.0% |
| Cameroon | Maize | 35 | 0.30 | 0.32 | 28.6% |
| Cameroon | Maize (white) | 16 | 0.13 | 0.15 | 31.2% |
| Cameroon | Maize (yellow) | 16 | 0.12 | 0.12 | 31.2% |
| Central African Republic | Maize | 33 | 0.35 | 0.80 | 18.2% |
| Chad | Maize | 12 | 0.19 | 0.49 | 0.0% |
| Chad | Maize (white) | 47 | 0.19 | 0.52 | 29.8% |
| Cote d'Ivoire | Maize | 14 | 0.22 | 0.25 | 28.6% |
| DR Congo | Maize | 68 | 0.31 | 0.78 | 17.6% |
| Ethiopia | Maize (white) | 43 | 0.18 | 0.62 | 20.9% |
| Gambia | Maize | 28 | 0.25 | 1.54 | 17.9% |
| Ghana | Maize | 19 | 0.28 | 1.32 | 5.3% |
| Ghana | Maize (yellow) | 18 | 0.28 | 1.22 | 11.1% |
| Guinea | Maize | 15 | 0.21 | 0.95 | 13.3% |
| Guinea-Bissau | Maize | 29 | 0.19 | 0.21 | 27.6% |
| Kenya | Maize | 31 | 0.08 | 0.19 | 35.5% |
| Kenya | Maize (white) | 9 | 0.19 | 0.98 | 0.0% |
| Malawi | Maize | 123 | 0.40 | 0.66 | 0.8% |
| Mali | Maize | 108 | 0.20 | 1.85 | 14.8% |
| Mauritania | Maize (local) | 13 | 0.08 | -0.29 | 53.8% |
| Mozambique | Maize (white) | 49 | 0.31 | 0.97 | 16.3% |
| Niger | Maize | 77 | 0.13 | 0.46 | 22.1% |
| Nigeria | Maize (white) | 16 | 0.25 | 0.38 | 6.2% |
| Nigeria | Maize (yellow) | 16 | 0.25 | 0.39 | 12.5% |
| Rwanda | Maize | 102 | 0.23 | 0.49 | 20.6% |
| Senegal | Maize (local) | 63 | 0.12 | 0.34 | 30.2% |
| Sierra Leone | Maize | 13 | 0.03 | -0.53 | 100.0% |
| South Sudan | Maize (white) | 16 | 0.37 | 0.86 | 18.8% |
| Tanzania | Maize (white) | 26 | 0.28 | 0.64 | 7.7% |
| Togo | Maize (white) | 6 | 0.27 | 1.26 | 0.0% |
| Uganda | Maize | 2 | 0.28 | 0.24 | 0.0% |
| Uganda | Maize (white) | 16 | 0.25 | 0.39 | 12.5% |
| Zambia | Maize (white) | 71 | 0.30 | 1.10 | 2.8% |
| Zimbabwe | Maize | 105 | 0.23 | 0.25 | 32.4% |
| Total | | 1438 | 0.24 | 0.67 | 19.2% |

[1] Monthly maize price data for retail markets from the WFP Global Food Prices Database for 2000-2021. Prices were adjusted to 2015 local currency value using IFS data on historical monthly CPI.

[2] Column (1) is the average market skewness in each country, where market skewness was calculated over all monthly prices for each market in the dataset. Column (2) is the share of markets that are negatively skewed. Kurtosis was positive in all markets in all countries.

Table A4: Skewness in maize prices for wholesale markets in all countries

| Country | Commodity | Number of Markets (1) | Coefficient of Variation (2) | Market Skewness (3) | Percent Markets Negative Skew (4) |
|---|---|---|---|---|---|
| Benin | Maize | 1 | 0.28 | 1.78 | 0.0% |
| Burkina Faso | Maize | 2 | 0.17 | 0.32 | 0.0% |
| Burundi | Maize | 3 | 0.28 | 0.49 | 0.0% |
| Cameroon | Maize | 38 | 0.18 | 0.45 | 23.7% |
| Cameroon | Maize (white) | 6 | 0.20 | 0.43 | 0.0% |
| Eswatini | Maize (white) | 1 | 0.28 | 0.30 | 0.0% |
| Ethiopia | Maize (white) | 27 | 0.19 | 1.06 | 7.4% |
| Ghana | Maize | 44 | 0.27 | 0.80 | 2.3% |
| Ghana | Maize (yellow) | 13 | 0.26 | 1.27 | 7.7% |
| Kenya | Maize | 5 | 0.25 | 0.48 | 0.0% |
| Kenya | Maize (white) | 5 | 0.23 | 0.33 | 20.0% |
| Mozambique | Maize (white) | 3 | 0.41 | 1.46 | 0.0% |
| Nigeria | Maize | 5 | 0.40 | 1.02 | 20.0% |
| Nigeria | Maize (white) | 16 | 0.31 | 0.64 | 6.2% |
| Nigeria | Maize (yellow) | 16 | 0.32 | 0.63 | 6.2% |
| Rwanda | Maize | 2 | 0.22 | 0.76 | 0.0% |
| South Africa | Maize (white) | 1 | 0.32 | 0.77 | 0.0% |
| South Africa | Maize (yellow) | 1 | 0.26 | 0.15 | 0.0% |
| South Sudan | Maize (white) | 15 | 0.23 | 0.13 | 33.3% |
| Tanzania | Maize | 28 | 0.24 | 0.43 | 21.4% |
| Uganda | Maize | 5 | 0.28 | 0.54 | 0.0% |
| Total | | 237 | 0.24 | 0.65 | 11.8% |

[1] Monthly maize price data for wholesale markets from the WFP Global Food Prices Database for 2000-2021. Prices were adjusted to 2015 local currency value using IFS data on historical monthly CPI.

[2] Column (1) is the total number of markets in each country, Column (2) is the coefficient of variation averaged over markets in each country. Column (3) the average market skewness in each country, where market skewness was calculated over all monthly prices for each market in the dataset. Column (4) is the share of markets that are negatively skewed in each country. Kurtosis was positive in all markets in all countries.

Table A5: Regressions of harvest prices on returns to storage and the probability of negative returns for retail markets in single season countries (without year FE)

| *Dep. variable* | | | Returns to Storage (%) | | Negative Returns (=1 if Returns$\leq$ 0) | |
|---|---|---|---|---|---|---|
| | | | Harvest price | | Harvest price | |
| | | Number of | z-score | $R^2$ | z-score | Pseudo-$R^2$ |
| Country | Commodity | Markets | (1) | (2) | (3) | (4) |
| Burkina Faso | Maize (white) | 54 | -14.137*** | 0.28 | 0.086*** | 0.11 |
| Chad | Maize (white) | 12 | -26.448*** | 0.37 | 0.147*** | 0.13 |
| Ethiopia | Maize (white) | 22 | -35.030*** | 0.39 | 0.245*** | 0.32 |
| Gambia | Maize | 16 | -17.837*** | 0.21 | 0.316*** | 0.25 |
| Malawi | Maize | 69 | -40.361*** | 0.22 | 0.076*** | 0.09 |
| Mali | Maize | 55 | -18.094*** | 0.15 | 0.131*** | 0.16 |
| Mozambique | Maize (white) | 23 | -29.642*** | 0.17 | 0.062*** | 0.07 |
| Niger | Maize | 62 | -12.025*** | 0.27 | 0.141*** | 0.12 |
| Senegal | Maize (local) | 46 | -14.785*** | 0.44 | 0.128*** | 0.15 |
| Zambia | Maize (white) | 66 | -23.060*** | 0.23 | 0.069*** | 0.07 |
| CC Average | | 425 | | 0.27 | | 0.15 |
| Pooled | | 425 | | 0.33 | | 0.14 |

[1] Columns (1) and (2) show results from OLS regressions by country of returns to storage (%) on harvest price z-score. Column (1) is the coefficient on harvest price z-score and column (2) is the $R^2$for that regression. Columns (3) and (4) show results from regressions by country for negative returns (binary variable =1 if returns were zero or negative) on harvest price z-score. Column (3) is the average marginal effect (AME) of harvest price z-score from a probit model and column (4) is McFadden's pseudo-$R^2$ for that country-specific regression.

[2] The cross country average $R^2$ is the unweighted average of $R^2$ for all above countries with country dummies. The pooled regression $R^2$ is calculated by regressing returns to storage and negative returns, respectively, on harvest price z-score with country dummies. Country dummies were used for the pooled regressions to account for country characteristics without demeaning.

[3] Returns are calculated for each "market-year" for the lean season price over the previous harvest season price. The lean season price is defined as the maximum price of the three months prior to the subsequent harvest, and the harvest season price is the minimum price of the months defined as harvest season. Markets were included if data were available for at least five market-years. Countries were included if data were available for at least nine markets. Harvest Price z-score was calculated at the country level.

[4] ***Significant at the 1 percent level. **Significant at the 5 percent level.*Significant at the 10 percent level.

Table A6: Share of retail market-years for which farmers should optimally forgo storage by farmer risk tolerance (based on variation in lean season prices) in single season countries

| Country | Commodity | Number of Markets | Risk Neutral and Low Risk Aversion R$\in[0,1)$ | Moderate Risk Aversion R$\in[1,3)$ | High Risk Aversion R$\in[3,5)$ |
|---|---|---|---|---|---|
| Burkina Faso | Maize (white) | 54 | 6.2% | 9.3% | 15.1% |
| Chad | Maize (white) | 12 | 13.7% | 16.1% | 25.2% |
| Ethiopia | Maize (white) | 22 | 16.1% | 21.0% | 35.1% |
| Gambia | Maize | 16 | 28.1% | 34.5% | 52.0% |
| Malawi | Maize | 69 | 10.4% | 17.6% | 32.2% |
| Mali | Maize | 55 | 7.8% | 16.0% | 42.2% |
| Mozambique | Maize (white) | 23 | 6.9% | 10.0% | 26.7% |
| Niger | Maize | 62 | 15.8% | 18.9% | 25.0% |
| Senegal | Maize (local) | 46 | 12.9% | 14.7% | 17.5% |
| Zambia | Maize (white) | 66 | 3.5% | 7.1% | 18.6% |
| Total | | 425 | 12.1% | 16.5% | 29.0% |

[1] Risk tolerance is calculated using the first and second moments of the lean season price for the primary maize season for each retail market with five or more crop years available, and countries with nine or more markets available. The certainty equivalent return of the risk of storage is compared to the harvest price each market-year.

Figure A1: Intra-annual returns to storage for single season countries

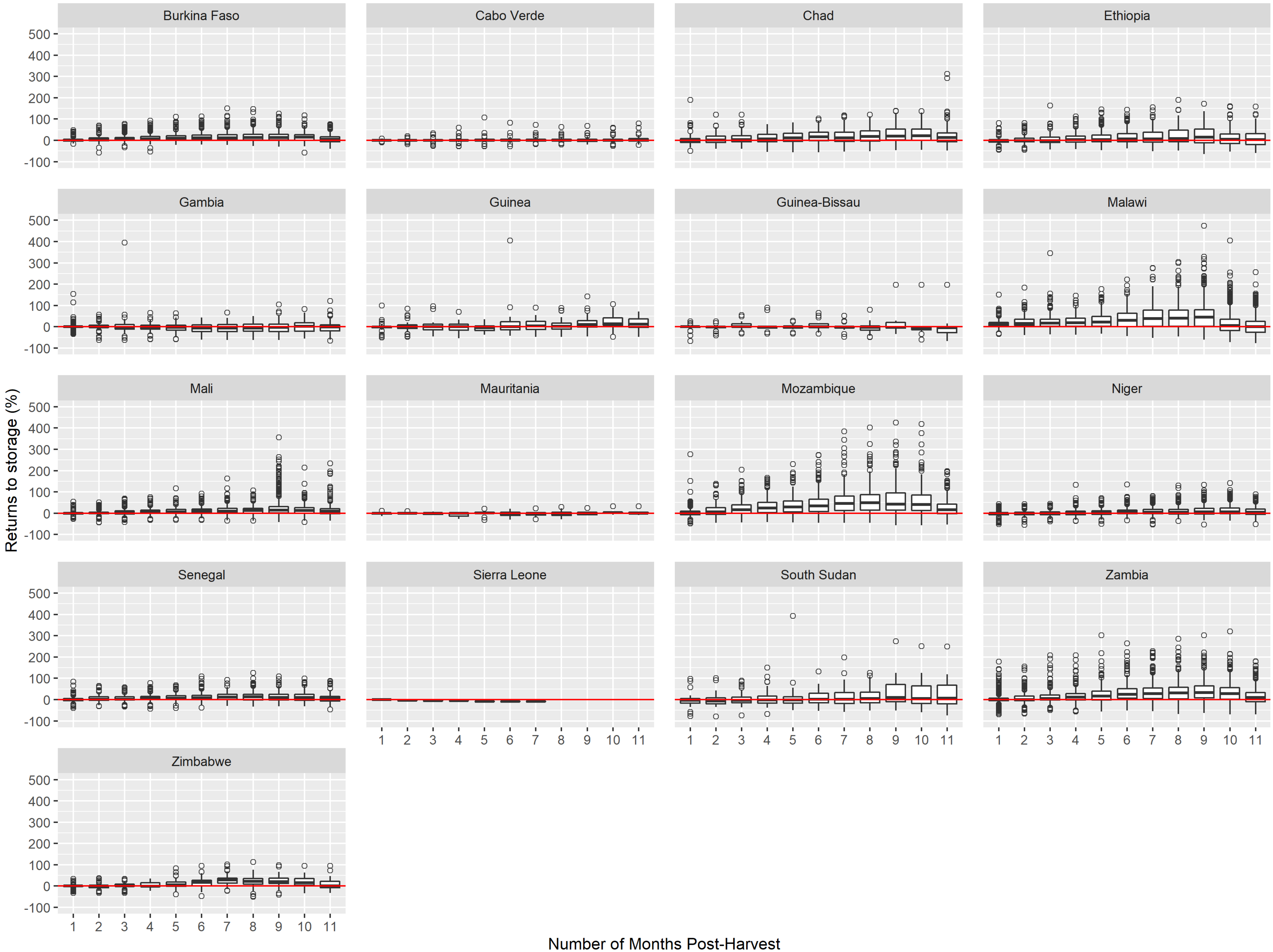
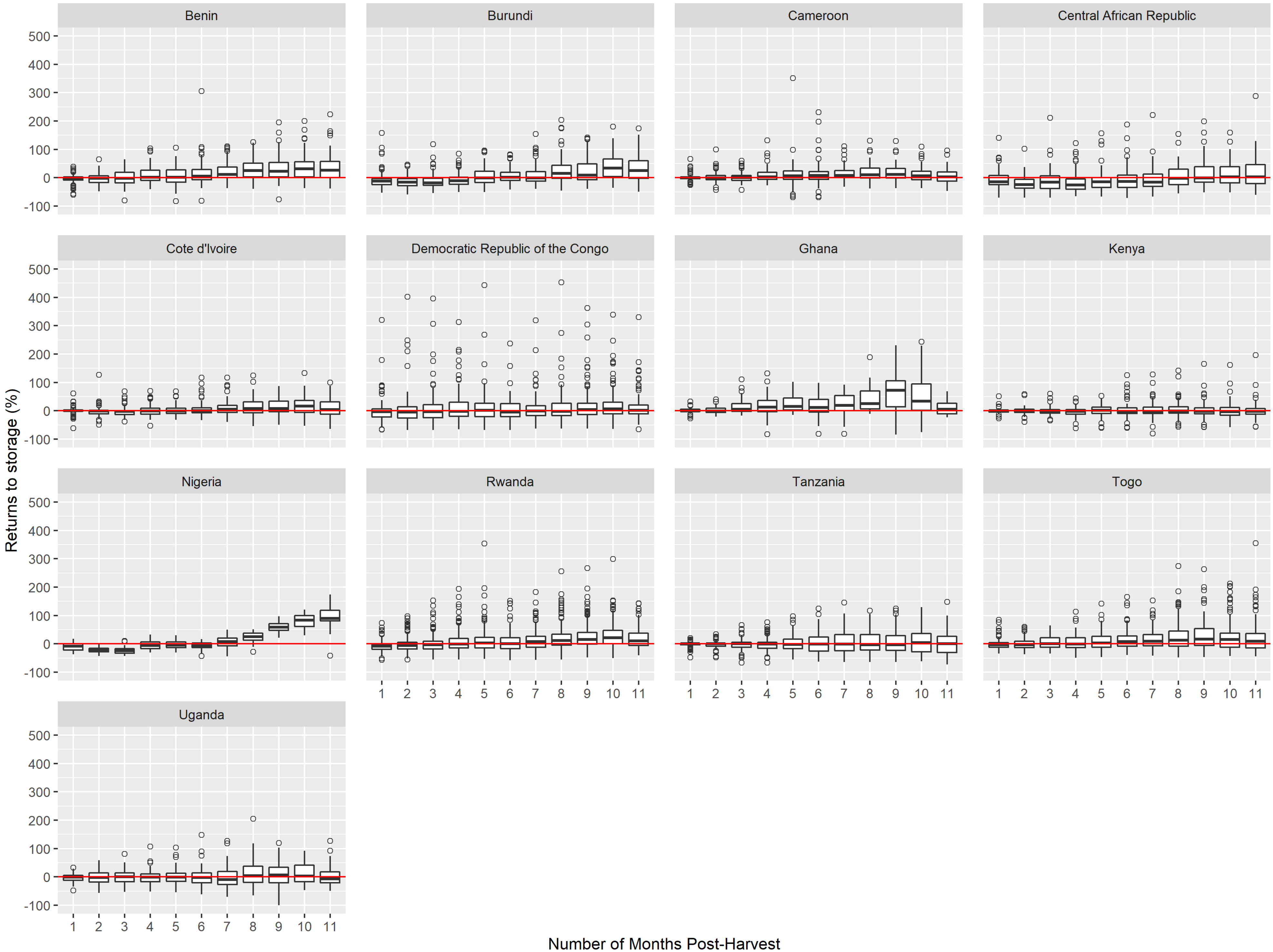


Figure A2: Intra-annual returns to storage for double season countries



**Missing price data**

The full set of monthly price data available in the WFP Global Food Price database for 2000-2021 is shown by country in Appendix Tables A7, A9,A8,and A10. We indicate the total number of markets with any data avaialble, markets with at least one year (for the descriptive analysis) and markets with at least five years available (for the risk aversion analysis.) The original set of observations can be viewed on the map in Appendix Figure A3, with markets delineated between retail and wholesale. In Appendix Tables A11 and A12, we show the distribution of monthly retail price data available in the WFP Global Food Price database, and the reason for exclusion from the descriptive dataset: for single season countries, we distinguish between market-years that are missing harvest price, lean season price, or both prices exist, and for double season countries, we show whether both the primary and secondary seasons are complete, or which maize season was incomplete. This data is replicated in Appendix Figures A4 and A5, sorted in order of data frequency, and the mean return is overlaid. There is no distinguishable pattern between returns and source of missingness.

Figure A3: Map of markets with WFP monthly maize price data

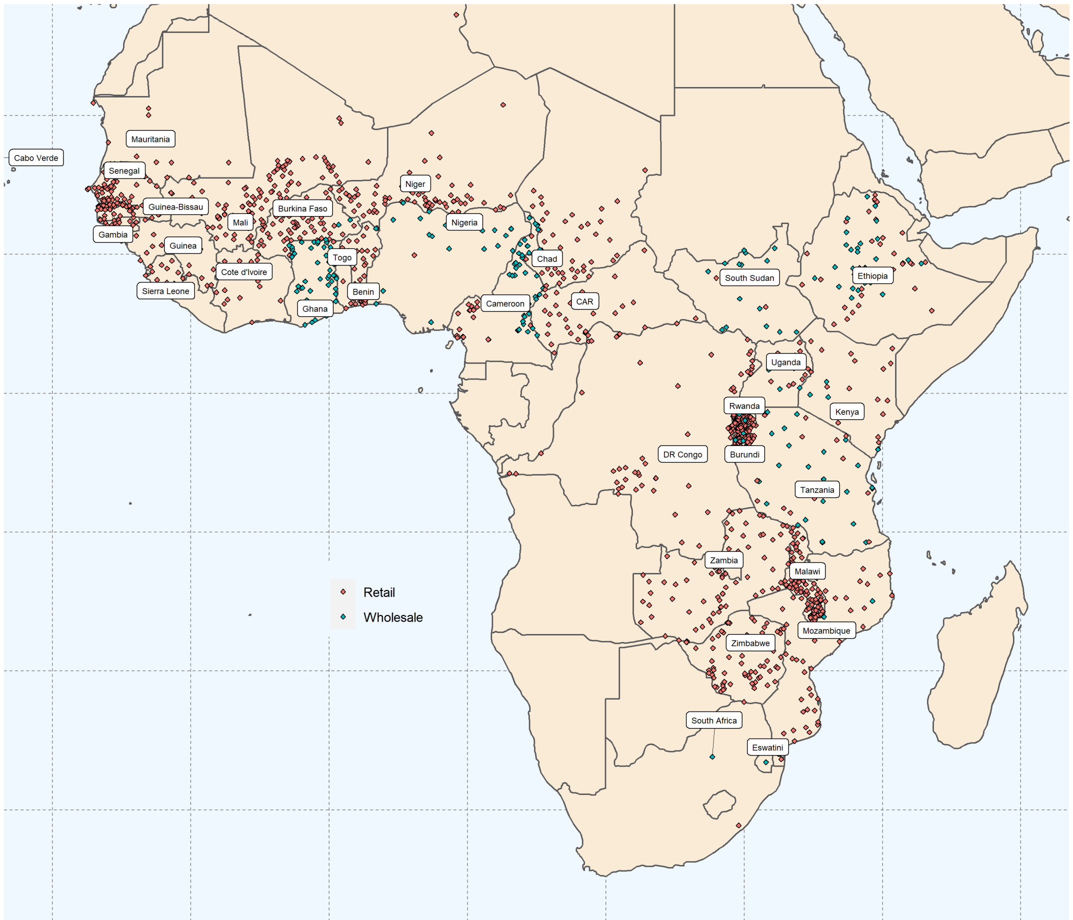


Table A7: Data availability for retail markets (Countries with one maize season)

| | | Total | Total | Number of markets | |
|---|---|---|---|---|---|
| Country | Commodity | Years | Markets | with $\geq$ 1 year | with $\geq$ 5 years |
| Burkina Faso | Maize (white) | 19 | 56 | 54 | 54 |
| Cabo Verde | Maize (local) | 14 | 2 | 2 | 2 |
| Cabo Verde | Maize (yellow) | 14 | 2 | 2 | 2 |
| Chad | Maize | 19 | 12 | 3 | 3 |
| Chad | Maize (white) | 19 | 47 | 43 | 12 |
| Ethiopia | Maize (white) | 15 | 43 | 28 | 22 |
| Gambia | Maize | 16 | 28 | 28 | 16 |
| Guinea | Maize | 7 | 15 | 12 | 0 |
| Guinea-Bissau | Maize | 15 | 29 | 10 | 1 |
| Malawi | Maize | 19 | 123 | 120 | 69 |
| Mali | Maize | 19 | 108 | 69 | 55 |
| Mauritania | Maize (local) | 3 | 13 | 5 | 0 |
| Mozambique | Maize (white) | 22 | 49 | 39 | 23 |
| Niger | Maize | 22 | 77 | 66 | 62 |
| Senegal | Maize (local) | 15 | 63 | 53 | 46 |
| Sierra Leone | Maize | 2 | 13 | 0 | 0 |
| South Sudan | Maize (white) | 14 | 16 | 10 | 5 |
| Zambia | Maize (white) | 19 | 71 | 70 | 66 |
| Zimbabwe | Maize | 12 | 105 | 28 | 5 |
| Total | Total | 285 | 872 | 642 | 443 |

[1] Total markets includes markets with any price data. Number of markets with at least one year indicates that both a harvest and planting season price were available for one crop year, and similarly for number of markets with at least 5 years.

Table A8: Data availability for wholesale markets (Countries with one maize season)

| | | Total | Total | Number of markets | |
|---|---|---|---|---|---|
| Country | Commodity | Years | Markets | with $\geq$ 1 year | with $\geq$ 5 years |
| Burkina Faso | Maize | 8 | 2 | 2 | 0 |
| Eswatini | Maize (white) | 17 | 1 | 1 | 1 |
| Ethiopia | Maize (white) | 22 | 27 | 17 | 13 |
| Mozambique | Maize (white) | 21 | 3 | 3 | 3 |
| South Africa | Maize (white) | 22 | 1 | 1 | 1 |
| South Africa | Maize (yellow) | 22 | 1 | 1 | 1 |
| South Sudan | Maize (white) | 4 | 15 | 8 | 0 |
| Total | Total | 116 | 50 | 33 | 19 |

[1] Total markets includes markets with any price data. Number of markets with at least one year indicates that both a harvest and planting season price were available for one crop year, and similarly for number of markets with at least 5 years.

Table A9: Data availability for retail markets (Countries with two maize seasons)

| Country | Commodity | Total Years | Total Markets | **Primary Season Number of markets** with $\geq$ 1 year | $\geq$ 5 years | **Second Season Number of markets** with $\geq$ 1 year | $\geq$ 5 years |
|---|---|---|---|---|---|---|---|
| Benin | Maize | 8 | 4 | 4 | 4 | 0 | 1 |
| Benin | Maize (white) | 13 | 51 | 51 | 51 | 2 | 7 |
| Burundi | Maize (white) | 15 | 68 | 64 | 68 | 12 | 21 |
| Cameroon | Maize | 15 | 35 | 25 | 5 | 5 | 5 |
| Cameroon | Maize (white) | 7 | 16 | 10 | 10 | 1 | 1 |
| Cameroon | Maize (yellow) | 7 | 16 | 10 | 10 | 1 | 1 |
| CAR | Maize | 18 | 33 | 28 | 28 | 3 | 10 |
| Cote d'Ivoire | Maize | 17 | 14 | 13 | 13 | 5 | 8 |
| DR Congo | Maize | 14 | 68 | 37 | 38 | 10 | 9 |
| Ghana | Maize | 3 | 19 | 19 | 18 | 0 | 0 |
| Ghana | Maize (yellow) | 3 | 18 | 17 | 16 | 0 | 0 |
| Kenya | Maize | 2 | 31 | 0 | 0 | 0 | 0 |
| Kenya | Maize (white) | 15 | 9 | 9 | 9 | 9 | 9 |
| Nigeria | Maize (white) | 6 | 16 | 15 | 15 | 0 | 0 |
| Nigeria | Maize (yellow) | 6 | 16 | 14 | 14 | 0 | 0 |
| Rwanda | Maize | 14 | 102 | 87 | 91 | 36 | 37 |
| Tanzania | Maize (white) | 6 | 26 | 25 | 15 | 25 | 15 |
| Togo | Maize (white) | 21 | 6 | 6 | 6 | 6 | 6 |
| Uganda | Maize | 9 | 2 | 2 | 1 | 2 | 1 |
| Uganda | Maize (white) | 11 | 16 | 14 | 5 | 6 | 2 |
| Total | Total | 210 | 566 | 450 | 417 | 123 | 133 |

[1] Total markets includes markets with any price data. Number of markets with at least one year for the primary (secondary) seasons includes markets with both a harvest and planting season price for the primary (secondary) maize seasons, and similarly for number of markets with at least 5 years.

Table A10: Data availability for wholesale markets (Countries with two maize seasons)

| Country | Commodity | Total Years | Total Markets | **Primary Season Number of markets** with $\geq$ 1 year | $\geq$ 5 years | **Second Season Number of markets** with $\geq$ 1 year | $\geq$ 5 years |
|---|---|---|---|---|---|---|---|
| Benin | Maize | 10 | 1 | 1 | 1 | 0 | 1 |
| Burundi | Maize | 10 | 3 | 3 | 3 | 2 | 2 |
| Cameroon | Maize | 10 | 38 | 33 | 31 | 5 | 5 |
| Cameroon | Maize (white) | 7 | 6 | 6 | 6 | 6 | 6 |
| Ghana | Maize | 16 | 44 | 19 | 18 | 15 | 15 |
| Ghana | Maize (yellow) | 3 | 13 | 13 | 12 | 0 | 0 |
| Kenya | Maize | 16 | 5 | 5 | 5 | 5 | 5 |
| Kenya | Maize (white) | 15 | 5 | 5 | 5 | 4 | 4 |
| Nigeria | Maize | 15 | 5 | 5 | 5 | 5 | 5 |
| Nigeria | Maize (white) | 19 | 16 | 15 | 15 | 13 | 14 |
| Nigeria | Maize (yellow) | 8 | 16 | 15 | 15 | 11 | 11 |
| Rwanda | Maize | 22 | 2 | 2 | 2 | 1 | 1 |
| Tanzania | Maize | 16 | 28 | 25 | 12 | 20 | 12 |
| Uganda | Maize | 16 | 5 | 5 | 3 | 3 | 1 |
| Total | Total | 183 | 187 | 152 | 133 | 90 | 82 |

[1] Total markets includes markets with any price data. Number of markets with at least one year for the primary (secondary) seasons includes markets with both a harvest and planting season price for the primary (secondary) maize seasons, and similarly for number of markets with at least 5 years.

Table A11: Missingness analysis for retail markets (Countries with one maize season)

| Country | Both prices exist | No harvest Price | No lean price | Mean Return | T-test |
|---|---|---|---|---|---|
| Malawi | 71.4% (986) | 11.4% (158) | 17.2% (237) | 80.1% | -6.549*** |
| Zambia | 85.7% (884) | 5.4% (56) | 8.9% (92) | 53.0% | -6.489*** |
| Niger | 83.9% (779) | 11.5% (107) | 4.6% (43) | 15.6% | 9.966*** |
| Mali | 79.7% (705) | 14.5% (128) | 5.9% (52) | 29.7% | 9.475*** |
| Senegal | 71.2% (459) | 16.6% (107) | 12.2% (79) | 19.7% | 4.541*** |
| Burkina Faso | 89.4% (455) | 10.0% (51) | 0.6% (3) | 24.9% | 16.281*** |
| Mozambique | 73.5% (330) | 14.0% (63) | 12.5% (56) | 71.7% | 0.091 |
| Ethiopia | 69.3% (199) | 19.2% (55) | 11.5% (33) | 34.8% | 3.189*** |
| Zimbabwe | 41.0% (100) | 33.6% (82) | 25.4% (62) | 30.7% | 2.251** |
| Chad | 79.8% (194) | 11.1% (27) | 9.1% (22) | 35.8% | 1.039 |
| Gambia | 69.5% (164) | 20.3% (48) | 10.2% (24) | 14.4% | 6.435*** |
| South Sudan | 48.6% (53) | 24.8% (27) | 26.6% (29) | 48.2% | 0.212 |
| Guinea | 68.3% (43) | 25.4% (16) | 6.3% (4) | 24.8% | 6.205*** |
| Guinea-Bissau | 46.6% (27) | 41.4% (24) | 12.1% (7) | 11.2% | 3.283*** |
| Cabo Verde | 88.0% (44) | 8.0% (4) | 4.0% (2) | 8.3% | 1.732 |
| Mauritania | 31.2% (10) | 43.8% (14) | 25.0% (8) | 2.4% | 2.997** |
| Sierra Leone | 0.0% (0) | 50.0% (13) | 50.0% (13) | | |
| Total | 75.7% (5432) | 13.7% (980) | 10.7% (766) | | 10.414*** |
| Overall average | | | | 41.7% | |

[1] Returns are calculated for each "market-year" for the lean season price over the previous harvest season price. The lean season price is defined as the maximum price of the three months prior to the subsequent harvest, and the harvest season price is the minimum price of the months defined as harvest season.

[2] The last column is a t-test by country of the proportion of market years missing the lean season price to missing harvest price. A negative (positive) statistic implies that lean season price was missing more (less) frequently.

Table A12: Missingness analysis for retail markets (Countries with two maize seasons)

| Country | Both prices exist for both seasons | Incomplete primary season | Incomplete second season | Incomplete due to other | Mean return primary season | Mean return second season |
|---|---|---|---|---|---|---|
| Rwanda | 71.2% (394) | 6.7% (37) | 4.2% (23) | 17.9% (99) | 32.8% | 33.9% |
| Burundi | 59.5% (267) | 6.2% (28) | 1.1% (5) | 33.2% (149) | 40.9% | 56.3% |
| DR Congo | 35.4% (101) | 4.9% (14) | 12.6% (36) | 47.0% (134) | 44.2% | 40.0% |
| Benin | 54.7% (134) | 10.2% (25) | 7.8% (19) | 27.3% (67) | 42.5% | 35.0% |
| Cameroon | 55.8% (101) | 7.2% (13) | 11.0% (20) | 26.0% (47) | 27.4% | 18.6% |
| Tanzania | 45.2% (75) | 0.0% (0) | 30.1% (50) | 24.7% (41) | 16.5% | 6.0% |
| Kenya | 52.3% (80) | 0.7% (1) | 0.0% (0) | 47.1% (72) | 12.1% | 15.1% |
| CAR | 57.3% (86) | 16.7% (25) | 6.7% (10) | 19.3% (29) | 32.1% | 71.9% |
| Togo | 95.2% (120) | 4.8% (6) | 0.0% (0) | 0.0% (0) | 39.5% | 37.5% |
| Uganda | 26.3% (31) | 2.5% (3) | 42.4% (50) | 28.8% (34) | 25.6% | 31.1% |
| Nigeria | 30.1% (34) | 12.4% (14) | 0.0% (0) | 57.5% (65) | 75.6% | 48.4% |
| Cote d'Ivoire | 68.5% (61) | 16.9% (15) | 1.1% (1) | 13.5% (12) | 29.6% | 48.9% |
| Ghana | 87.7% (64) | 0.0% (0) | 4.1% (3) | 8.2% (6) | 62.0% | 43.7% |
| Total | 57.3% (1548) | 6.7% (181) | 8.0% (217) | 28.0% (755) | | |
| Overall average | | | | | 35.2% | 39.2% |

[1] Returns are calculated for each "market-year" for the lean season price over the previous harvest season price. The lean season price is defined as the maximum price of the three months prior to the subsequent harvest, and the harvest season price is the minimum price of the months defined as harvest season.

[2] Missingness due to "other" could be because some combination of harvest and planting prices were missing in either season.

Figure A4: Missing price data for retail markets for single season countries

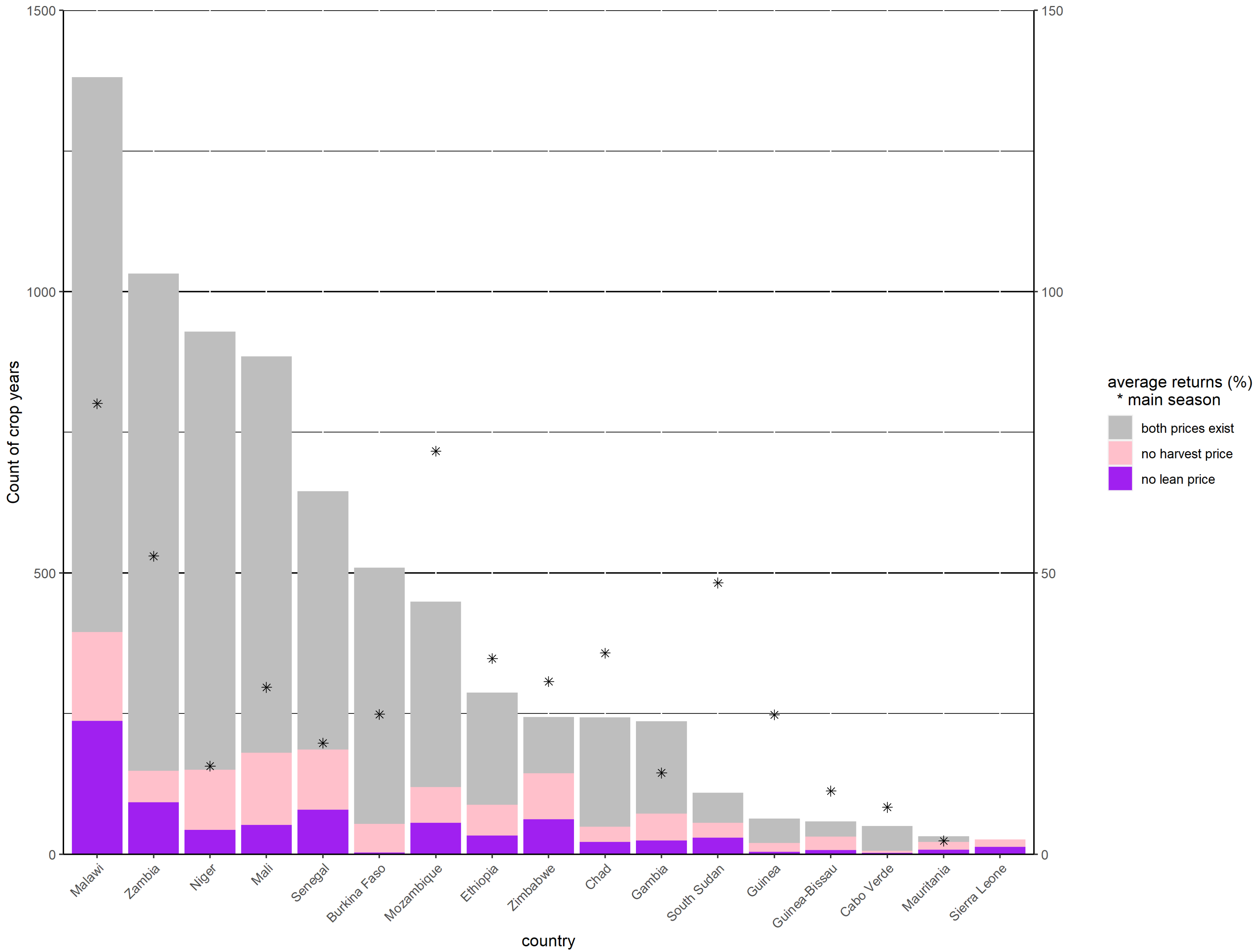


Figure A5: Missing price data for retail markets for double season countries

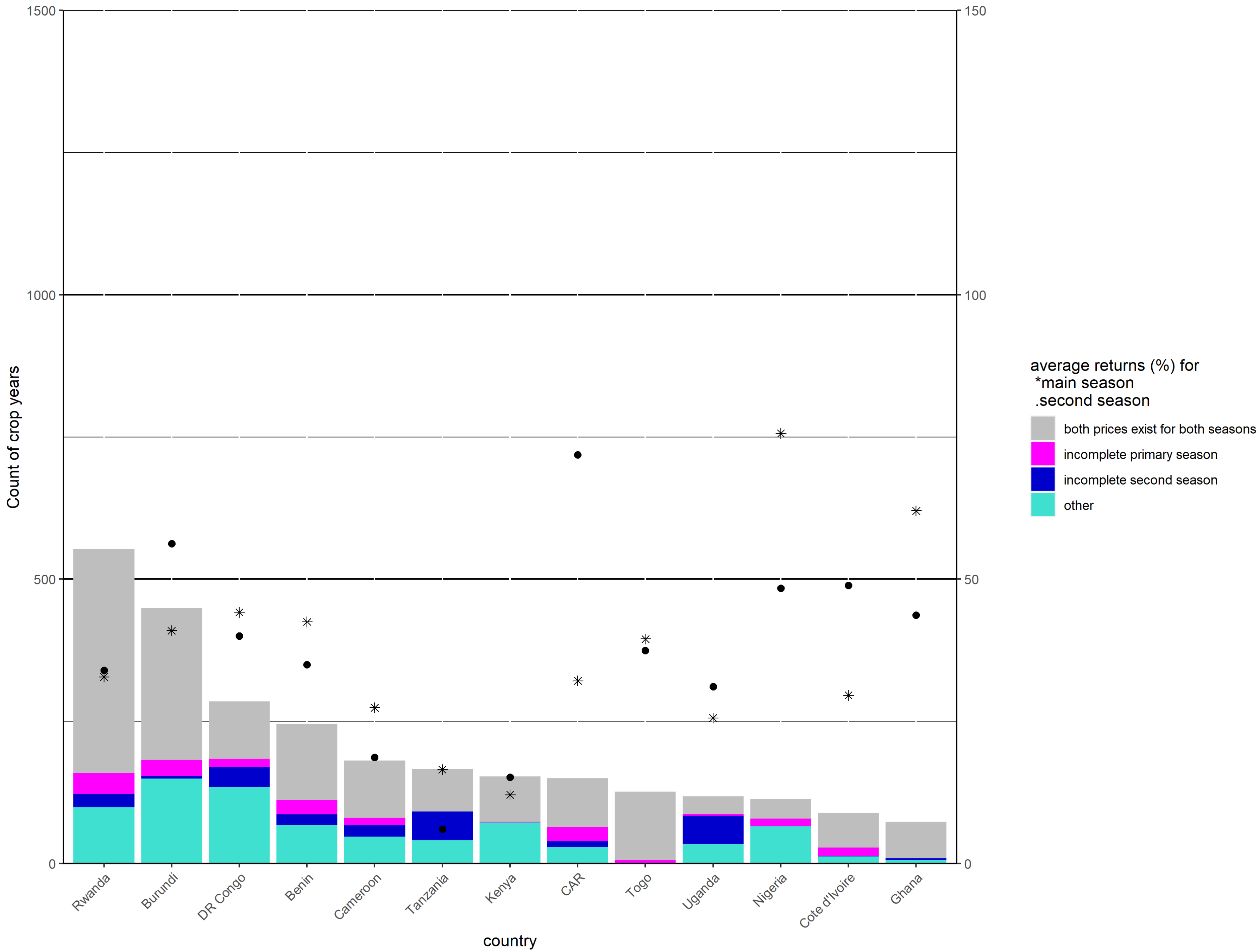


Table A13: Frequency and Magnitude of Negative Returns to Storage for Retail Markets
Nominal prices (Countries with one maize season)

| Country (1) | Commodity (2) | Years (3) | Number of Markets (4) | Number of Market-Years (5) | Frequency of Negative Returns (6) | Average Total Returns (7) | Average Positive Returns (8) | Average Negative Returns (9) |
|---|---|---|---|---|---|---|---|---|
| Burkina Faso | Maize (white) | 2002-2020 | 54 | 455 | 9.7% | 27.4% | 31.0% | -6.1% |
| Cabo Verde | Maize (local) | 2007-2019 | 2 | 22 | 36.4% | 11.2% | 20.0% | -4.0% |
| Cabo Verde | Maize (yellow) | 2007-2019 | 2 | 22 | 40.9% | 6.3% | 12.5% | -2.6% |
| Chad | Maize | 2003-2019 | 3 | 48 | 16.7% | 30.8% | 39.8% | -14.1% |
| Chad | Maize (white) | 2003-2020 | 43 | 146 | 21.2% | 42.5% | 56.9% | -11.0% |
| Ethiopia | Maize (white) | 2005-2019 | 28 | 199 | 24.6% | 61.9% | 85.4% | -10.2% |
| Gambia | Maize | 2005-2020 | 28 | 164 | 32.9% | 19.5% | 37.1% | -16.2% |
| Guinea | Maize | 2012-2020 | 12 | 43 | 20.9% | 35.7% | 48.6% | -13.2% |
| Guinea-Bissau | Maize | 2006-2020 | 10 | 27 | 59.3% | 12.6% | 46.9% | -11.0% |
| Malawi | Maize | 2002-2021 | 120 | 986 | 3.9% | 113.3% | 118.5% | -16.8% |
| Mali | Maize | 2002-2020 | 69 | 705 | 20.7% | 31.7% | 42.1% | -8.4% |
| Mauritania | Maize (local) | 2018-2020 | 5 | 10 | 40.0% | 3.7% | 13.3% | -10.7% |
| Mozambique | Maize (white) | 1999-2021 | 39 | 330 | 7.3% | 84.8% | 92.5% | -13.2% |
| Niger | Maize | 1999-2020 | 66 | 779 | 23.5% | 17.9% | 25.8% | -7.7% |
| Senegal | Maize (local) | 2006-2020 | 53 | 459 | 25.9% | 18.5% | 26.6% | -4.6% |
| South Sudan | Maize (white) | 2007-2021 | 10 | 55 | 12.7% | 127.8% | 149.8% | -23.2% |
| Zambia | Maize (white) | 2002-2021 | 70 | 884 | 9.7% | 66.3% | 74.4% | -8.9% |
| Zimbabwe | Maize | 2009-2021 | 28 | 100 | 11.0% | 35.0% | 40.8% | -12.0% |
| Total | | | 642 | 5434 | 15.6% | 53.7% | 65.2% | -9.1% |

[1] Monthly maize price data for retail markets from the WFP Global Food Prices Database for 2000-2021. Prices are nominal. National and subnational agricultural season data was reported from FAO-GIEWS via the University of Wisconsin.

[2] Columns (6)-(9): Returns are calculated for each "market-year" or "crop-year" for the lean season price over the previous harvest season price. The lean season price is defined as the maximum price of the three months prior to the subsequent harvest, and the harvest season price is the minimum price of the months defined as harvest season. The "Total" for these columns is an average across all market-year observations.

Table A14: Frequency and Magnitude of Negative Returns to Storage for Retail Markets
Nominal prices (Countries with two maize seasons)

| | | | Primary Season | | | | | | Second Season | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Country (1) | Commodity (2) | Years (3) | Number of Markets (4) | Number of Market-Years (5) | Frequency of Negative Returns (6) | Average Total Returns (7) | Average Positive Returns (8) | Average Negative Returns (9) | Number of Markets (10) | Number of Market-Years (11) | Frequency of Negative Returns (12) | Average Total Returns (13) | Average Positive Returns (14) | Averag Negati Return (15) |
| Benin | Maize | 2012-2019 | 4 | 11 | 27.3% | 25.0% | 38.1% | -10.1% | 4 | 12 | 8.3% | 22.6% | 25.3% | -7.0% |
| Benin | Maize (white) | 2006-2020 | 51 | 142 | 8.5% | 49.1% | 54.4% | -8.5% | 51 | 147 | 8.8% | 39.6% | 44.2% | -8.4% |
| Burundi | Maize (white) | 2007-2021 | 64 | 272 | 15.4% | 46.6% | 56.9% | -9.9% | 68 | 295 | 5.1% | 59.8% | 63.3% | -4.5% |
| Cameroon | Maize | 2004-2020 | 25 | 80 | 21.2% | 26.9% | 36.3% | -8.0% | 5 | 70 | 8.6% | 18.6% | 20.7% | -3.9% |
| Cameroon | Maize (white) | 2014-2020 | 10 | 21 | 23.8% | 31.9% | 43.9% | -6.6% | 10 | 22 | 22.7% | 21.9% | 28.6% | -1.0% |
| Cameroon | Maize (yellow) | 2014-2020 | 10 | 20 | 15.0% | 34.8% | 42.9% | -11.4% | 10 | 22 | 27.3% | 19.4% | 26.7% | 0.0% |
| Central African Republic | Maize | 2003-2020 | 28 | 96 | 37.5% | 35.4% | 64.5% | -13.0% | 28 | 111 | 8.1% | 73.4% | 81.0% | -12.8% |
| Cote d'Ivoire | Maize | 2004-2020 | 13 | 62 | 25.8% | 33.1% | 47.3% | -7.9% | 13 | 76 | 25.0% | 51.2% | 70.5% | -6.5% |
| DR Congo | Maize | 2007-2021 | 37 | 137 | 24.1% | 51.4% | 73.9% | -19.4% | 38 | 115 | 30.4% | 52.2% | 86.3% | -25.8% |
| Ghana | Maize | 2019-2020 | 19 | 36 | 8.3% | 77.3% | 84.3% | 0.0% | 18 | 34 | 5.9% | 56.4% | 59.9% | 0.0% |
| Ghana | Maize (yellow) | 2019-2020 | 17 | 31 | 3.2% | 76.9% | 79.5% | 0.0% | 16 | 30 | 6.7% | 51.8% | 55.6% | -1.7% |
| Kenya | Maize (white) | 2005-2020 | 9 | 80 | 27.5% | 20.6% | 34.0% | -14.6% | 9 | 81 | 24.7% | 27.7% | 43.0% | -19.1% |
| Nigeria | Maize (white) | 2013-2020 | 15 | 17 | 0.0% | 100.1% | 100.1% | 0.0% | 15 | 24 | 12.5% | 59.6% | 68.6% | -3.0% |
| Nigeria | Maize (yellow) | 2013-2020 | 14 | 17 | 5.9% | 90.6% | 97.7% | -23.6% | 14 | 24 | 4.2% | 53.6% | 56.1% | -2.1% |
| Rwanda | Maize | 2008-2021 | 87 | 417 | 17.3% | 43.2% | 55.0% | -13.1% | 91 | 431 | 12.8% | 38.4% | 45.1% | -7.0% |
| Somalia | Maize (white) | 1999-2021 | 24 | 230 | 34.3% | 44.8% | 79.2% | -21.0% | 23 | 235 | 24.7% | 72.6% | 100.9% | -13.7% |
| Tanzania | Maize (white) | 2015-2021 | 25 | 125 | 44.8% | 20.3% | 54.7% | -22.1% | 15 | 75 | 52.0% | 11.0% | 52.5% | -27.4% |
| Togo | Maize (white) | 2000-2020 | 6 | 120 | 25.0% | 45.7% | 65.2% | -12.9% | 6 | 126 | 14.3% | 41.2% | 48.6% | -3.3% |
| Uganda | Maize | 2009-2018 | 2 | 12 | 16.7% | 62.3% | 80.1% | -26.7% | 1 | 7 | 14.3% | 42.1% | 49.1% | 0.0% |
| Uganda | Maize (white) | 2010-2021 | 14 | 69 | 26.1% | 25.5% | 41.0% | -18.2% | 5 | 27 | 11.1% | 31.7% | 36.5% | -6.2% |
| Total | | | 474 | 1995 | 22.6% | 42.5% | 59.4% | -15.4% | 440 | 1964 | 15.8% | 47.5% | 58.8% | -13.1% |

[1] Monthly maize price data for retail markets from the WFP Global Food Prices Database for 2000-2021. Prices are nominal. National and subnational agricultural season data was reported from FAO-GIEW via the University of Wisconsin.

[2] Columns (6)-(9) and (12)-(15): Returns are calculated for each "market-year" or "crop-year" for the lean season price over the previous harvest season price. The lean season price is defined as the maximu price of the three months prior to the subsequent harvest, and the harvest season price is the minimum price of the months defined as harvest season. The "Total" for these columns is an average across market-year observations.

Table A15: Frequency and Magnitude of Negative Returns to Storage for Wholesale Markets
Nominal prices (Countries with one maize season)

| Country (1) | Commodity (2) | Years (3) | Number of Markets (4) | Number of Market-Years (5) | Frequency of Negative Returns (6) | Average Total Returns (7) | Average Positive Returns (8) | Average Negative Returns (9) |
|---|---|---|---|---|---|---|---|---|
| Burkina Faso | Maize | 2002-2011 | 2 | 4 | 0.0% | 42.5% | 42.5% | 0.0% |
| Eswatini | Maize (white) | 2003-2019 | 1 | 12 | 75.0% | 9.0% | 54.3% | -6.2% |
| Ethiopia | Maize (white) | 1999-2020 | 17 | 180 | 12.2% | 52.0% | 60.9% | -12.0% |
| Mozambique | Maize (white) | 1999-2020 | 3 | 47 | 2.1% | 82.1% | 84.4% | -25.6% |
| South Africa | Maize (white) | 1999-2021 | 1 | 21 | 14.3% | 42.8% | 53.1% | -19.3% |
| South Africa | Maize (yellow) | 1999-2021 | 1 | 21 | 14.3% | 36.8% | 44.3% | -8.0% |
| South Sudan | Maize (white) | 2012-2021 | 8 | 12 | 8.3% | 47.6% | 54.0% | -22.9% |
| Total | | | 33 | 297 | 13.1% | 53.0% | 62.8% | -11.5% |

[1] Monthly maize price data for wholesale markets from the WFP Global Food Prices Database for 2000-2021. Prices are nominal. National and subnational agricultural season data was reported from FAO-GIEWS via the University of Wisconsin.

[2] Columns (6)-(9): Returns are calculated for each ”market-year” or ”crop-year” for the lean season price over the previous harvest season price. The lean season price is defined as the maximum price of the three months prior to the subsequent harvest, and the harvest season price is the minimum price of the months defined as harvest season. The ”Total” for these columns is an average across all market-year observations.

Table A16: Frequency and Magnitude of Negative Returns to Storage for Wholesale Markets
Nominal prices (Countries with two maize seasons)

| | | | **Primary Season** | | | | | | **Second Season** | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Country (1) | Commodity (2) | Years (3) | Number of Markets (4) | Number of Market-Years (5) | Frequency of Negative Returns (6) | Average Total Returns (7) | Average Positive Returns (8) | Average Negative Returns (9) | Number of Markets (10) | Number of Market-Years (11) | Frequency of Negative Returns (12) | Average Total Returns (13) | Average Positive Returns (14) | Average Negative Returns (15) |
| Benin | Maize | 2001-2011 | 1 | 4 | 0.0% | 30.2% | 30.2% | 0.0% | 1 | 6 | 16.7% | 46.6% | 58.9% | -15.1% |
| Burundi | Maize | 2011-2020 | 3 | 19 | 15.8% | 35.4% | 45.5% | -18.5% | 3 | 20 | 10.0% | 58.1% | 64.9% | -2.9% |
| Cameroon | Maize | 2010-2020 | 33 | 96 | 19.8% | 24.0% | 31.2% | -5.4% | 31 | 92 | 10.9% | 26.1% | 30.8% | -13.1% |
| Cameroon | Maize (white) | 2014-2020 | 6 | 35 | 17.1% | 26.8% | 35.1% | -12.9% | 6 | 42 | 14.3% | 22.8% | 27.0% | -2.5% |
| Ghana | Maize | 2005-2020 | 19 | 180 | 10.0% | 59.4% | 66.9% | -8.9% | 18 | 205 | 9.8% | 46.3% | 52.1% | -7.6% |
| Ghana | Maize (yellow) | 2019-2020 | 13 | 23 | 0.0% | 86.0% | 86.0% | 0.0% | 12 | 22 | 4.5% | 55.7% | 58.5% | -1.1% |
| Kenya | Maize | 2005-2021 | 5 | 60 | 26.7% | 40.3% | 61.8% | -18.9% | 5 | 62 | 25.8% | 33.9% | 56.6% | -31.3% |
| Kenya | Maize (white) | 2005-2020 | 5 | 56 | 23.2% | 39.7% | 57.0% | -17.4% | 5 | 56 | 28.6% | 31.0% | 53.5% | -25.5% |
| Nigeria | Maize | 2001-2016 | 5 | 43 | 32.6% | 8.6% | 20.2% | -15.3% | 5 | 49 | 10.2% | 20.5% | 23.9% | -9.9% |
| Nigeria | Maize (white) | 2003-2020 | 15 | 102 | 37.3% | 38.4% | 71.8% | -17.8% | 15 | 106 | 10.4% | 41.7% | 47.3% | -7.4% |
| Nigeria | Maize (yellow) | 2013-2020 | 15 | 73 | 28.8% | 45.3% | 70.0% | -15.9% | 15 | 74 | 0.0% | 49.4% | 49.4% | 0.0% |
| Rwanda | Maize | 2000-2021 | 2 | 18 | 5.6% | 24.0% | 28.1% | -44.8% | 2 | 17 | 17.6% | 19.5% | 25.7% | -9.3% |
| Tanzania | Maize | 2005-2021 | 25 | 281 | 19.9% | 44.4% | 59.9% | -17.8% | 12 | 163 | 34.4% | 25.9% | 53.2% | -26.3% |
| Uganda | Maize | 2005-2021 | 5 | 40 | 22.5% | 42.5% | 59.9% | -17.5% | 3 | 20 | 20.0% | 30.4% | 39.5% | -5.8% |
| Total | | | 152 | 1030 | 20.8% | 42.3% | 57.5% | -15.6% | 133 | 934 | 16.2% | 36.0% | 46.6% | -19.1% |

[1] Monthly maize price data for wholesale markets from the WFP Global Food Prices Database for 2000-2021. Prices are nominal. National and subnational agricultural season data was reported from FAO-GIEWS via the University of Wisconsin.

[2] Columns (6)-(9) and (12)-(15): Returns are calculated for each "market-year" or "crop-year" for the lean season price over the previous harvest season price. The lean season price is defined as the maximum price of the three months prior to the subsequent harvest, and the harvest season price is the minimum price of the months defined as harvest season. The "Total" for these columns is an average across all market-year observations.

Table A17: Share of retail market-years for which farmers should optimally forgo storage by farmer risk tolerance (based on variation in returns using nominal prices in single season countries)

| Country | Commodity | Number of Markets | Risk Neutral and Low Risk Aversion R$\in [0, 1)$ | Moderate Risk Aversion R$\in [1, 3)$ | High Risk Aversion R$\in [3, 5)$ |
|---|---|---|---|---|---|
| Burkina Faso | Maize (white) | 54 | 0.0% | 0.6% | 9.1% |
| Chad | Maize (white) | 12 | 0.0% | 4.2% | 52.5% |
| Ethiopia | Maize (white) | 22 | 2.8% | 65.8% | 96.7% |
| Gambia | Maize | 16 | 0.0% | 42.0% | 94.7% |
| Malawi | Maize | 69 | 0.4% | 29.5% | 88.3% |
| Mali | Maize | 55 | 0.0% | 9.6% | 63.3% |
| Mozambique | Maize (white) | 23 | 0.0% | 14.2% | 63.0% |
| Niger | Maize | 62 | 0.5% | 1.7% | 21.5% |
| Senegal | Maize (local) | 46 | 0.7% | 1.6% | 4.0% |
| Zambia | Maize (white) | 66 | 0.0% | 3.2% | 22.4% |
| Total | | 425 | 0.4% | 17.2% | 51.6% |

[1] Risk tolerance is calculated using the first and second moments of the returns to storage for the primary maize season for each retail market in single season countries with five or more crop years available, and countries with nine or more markets available. Prices are nominal

Table A18: Share of retail market-years for which farmers should optimally forgo storage by farmer risk tolerance with an interest rate of 5% (based on variation in returns using nominal prices in single season countries)

| Country | Commodity | Number of Markets | Risk Neutral and Low Risk Aversion R$\in [0, 1)$ | Moderate Risk Aversion R$\in [1, 3)$ | High Risk Aversion R$\in [3, 5)$ |
|---|---|---|---|---|---|
| Burkina Faso | Maize (white) | 54 | 2.0% | 5.4% | 22.5% |
| Chad | Maize (white) | 12 | 0.0% | 15.8% | 70.2% |
| Ethiopia | Maize (white) | 22 | 3.2% | 72.0% | 96.7% |
| Gambia | Maize | 16 | 9.8% | 67.5% | 95.2% |
| Malawi | Maize | 69 | 0.4% | 33.0% | 90.4% |
| Mali | Maize | 55 | 0.7% | 20.5% | 82.2% |
| Mozambique | Maize (white) | 23 | 0.0% | 17.1% | 70.0% |
| Niger | Maize | 62 | 3.5% | 12.3% | 38.9% |
| Senegal | Maize (local) | 46 | 10.7% | 15.7% | 25.0% |
| Zambia | Maize (white) | 66 | 0.0% | 4.4% | 27.3% |
| Total | | 425 | 3.0% | 26.4% | 61.8% |

[1] Risk tolerance is calculated using the first and second moments of the returns to storage for the primary maize season for each retail market in single season countries with five or more crop years available, and countries with nine or more markets available. Prices are nominal.

Table A19: Share of retail market-years for which farmers should optimally forgo storage by farmer risk tolerance (based on variation in nominal lean season prices) in single season countries

| Country | Commodity | Number of Markets | Risk Neutral and Low Risk Aversion R∈ $[0, 1)$ | Moderate Risk Aversion R∈ $[1, 3)$ | High Risk Aversion R∈ $[3, 5)$ |
|---|---|---|---|---|---|
| Burkina Faso | Maize (white) | 54 | 8.5% | 11.6% | 18.5% |
| Chad | Maize (white) | 12 | 11.1% | 18.9% | 30.8% |
| Ethiopia | Maize (white) | 22 | 28.9% | 38.5% | 49.1% |
| Gambia | Maize | 16 | 28.2% | 43.9% | 81.6% |
| Malawi | Maize | 69 | 23.5% | 50.8% | 93.3% |
| Mali | Maize | 55 | 8.8% | 18.6% | 45.3% |
| Mozambique | Maize (white) | 23 | 14.9% | 35.9% | 67.7% |
| Niger | Maize | 62 | 16.7% | 20.9% | 28.0% |
| Senegal | Maize (local) | 46 | 19.4% | 21.5% | 23.2% |
| Zambia | Maize (white) | 66 | 14.7% | 35.9% | 71.5% |
| Total | | 425 | 17.5% | 29.7% | 50.9% |

[1] Risk tolerance is calculated using the first and second moments of the lean season price for the primary maize season for each retail market with five or more crop years available, and countries with nine or more markets available. The certainty equivalent return of the risk of storage is compared to the harvest price each market-year. Prices are nominal.

Table A20: Share of retail market-years for which farmers should optimally forgo storage by farmer risk tolerance with an interest rate of 5% (based on variation in predicted returns using nominal prices) in single season countries

| Country | Commodity | Number of Markets | Risk Neutral and Low Risk Aversion R∈ $[0, 1)$ | Moderate Risk Aversion R∈ $[1, 3)$ | High Risk Aversion R∈ $[3, 5)$ |
|---|---|---|---|---|---|
| Burkina Faso | Maize (white) | 54 | 2.0% | 2.0% | 2.0% |
| Chad | Maize (white) | 12 | 0.0% | 4.2% | 12.5% |
| Ethiopia | Maize (white) | 22 | 0.0% | 10.2% | 56.7% |
| Gambia | Maize | 16 | 5.1% | 13.0% | 17.0% |
| Malawi | Maize | 69 | 0.0% | 0.9% | 3.7% |
| Mali | Maize | 55 | 0.3% | 2.1% | 3.5% |
| Mozambique | Maize (white) | 23 | 0.0% | 0.0% | 0.0% |
| Niger | Maize | 62 | 2.4% | 3.5% | 7.9% |
| Senegal | Maize (local) | 46 | 8.3% | 13.1% | 16.6% |
| Zambia | Maize (white) | 66 | 0.0% | 0.0% | 0.0% |
| Total | | 425 | 1.8% | 4.9% | 12.0% |

[1] Risk tolerance is calculated using the first and second moments of the returns to storage for the primary maize season for each retail market in single season countries with five or more crop years available, and countries with nine or more markets available. The predicted return is based on market level OLS regressions of returns on harvest price and crop year using nominal prices.