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Two Birds with One Stone: Technology Adoption and Market Participation through Protection against Crop Failure

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Two Birds with One Stone:

Technology Adoption and Market Participation through Protection against Crop Failure

Wouter Zant*

Abstract

Most sub-Sahara African agriculture is rainfed and the key production risk is crop failure due to drought or insufficient rains. Major strategies for households to protect against the risk of crop failure are livestock rearing and storage of home produced food. Next to drought, SSA agriculture is characterized by low productivity and limited market participation, issues commonly addressed by promoting use of fertilizer and high-yielding varieties, and cultivation of high-return crops. For several reasons it is likely that protection against crop failure supports adoption of technology and cultivation of high-return crops. Against this background we explore empirically the relationship between technology adoption and market participation on the one hand and start-of-season stocks of staple food and livestock on the other hand, on the basis of 3 rounds of LSMS-ISA household survey data for Malawi (IHS-3, 4 and 5), and a panel version of these data (IHPS). We find statistically significant positive coefficients of maize stocks and livestock on technology adoption and market participation. Data and estimations support a model of developing country agriculture with seasonality, shocks and savings. In terms of policy the results suggest that supporting livestock rearing and food storage at the household level increases labour productivity in agriculture.

Key words: risk, savings, technology adoption, market participation, sub-Sahara Africa

JEL code: O13, O16, O33, Q12, Q16

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Introduction

Agriculture in sub-Sahara Africa is mainly rainfed and the dominant risk is a lack of rainfall or drought. Dependence on rainfall leads to large seasonality in crop prices (Gilbert et al., 2017), occasional crop failures, and large fluctuations in farmer revenues from crop cultivation. Farm households protect themselves against crop failures through food storage and livestock. In this paper we investigate what role these informal savings play in increasing the value marginal product of labour in agriculture, and in increasing welfare and growth in rural areas. We argue that these informal savings raise investment and are conducive to tackle the other key problems of sub-Saharan agriculture, low productivity and limited market participation. This claim is built up in two steps: first, by setting up and validating a conceptual model of developing country agriculture and, second, by estimating how savings drive technology adoption and market participation. The conceptual framework reflects the basics of rain-fed developing country agriculture: it incorporates seasonality, shocks and savings, and highlights the key role of savings in increasing the marginal value product of labour. The model identifies several mechanisms underlying the impact of savings on economic growth, both in the short run, through choices on off-farm and on-farm labour and in the long run, through risk mitigation, availability of funding, investment in inputs and crop choices. Savings allow to identify heterogeneity of farmers and to distinguish (un)successful and economically (not) viable agriculture. Next, we show how technology adoption, in the form of using inorganic fertilizer, and market participation, approximated with the share of market sales and cash crop area, is affected by start-of-season savings, in the form of food stocks and livestock. Both model verification and estimations are based on LSMS-ISA household survey data for Malawi, both cross sectional and panel (resp 2010, 2016, 2019 and 2010-2013-2016). Technology adoption (fertilizer use, use of high-yielding varieties and mechanization) is well researched in the literature, identifies a multitude of causes for low productivity, mostly employing rigorous experimental designs. Investigations often focus on single causes rather than investigate multiple simultaneous or interdependent causes inherent to the household economy. Empirical work is also biased towards outside solutions (credit, saving accounts, index-insurance, input subsidies, etc) rather than seeking opportunities within the constraints households face. Informal risk coping strategies have been researched primarily to measure adequacy of informal savings to meet food security goals or smooth consumption (Kazianga and Udry, 2006). However, employing a simulation approach elimination of ex-ante risk is shown to have major implication for economic growth (Elbers and Gunning, 2007). For these reasons we think that there is merit in looking at opportunities within the constraints that households face, opportunities that households create themselves by successfully accumulating savings which help them to step up investment and thereby increase productivity and welfare. We make two contributions: first we show that the assumptions underlying a stylized model of developing country agriculture (no capital market; seasonality; production shocks; off-farm labour, livestock and maize stocks as dominant coping strategies) are well supported by the empirical evidence. The model highlights the key role of savings and the heterogeneity of households some of whom are well performing with sufficient savings while others fail to achieve this. Secondly, we supply convincing empirical evidence that technology adoption, market participation, and cash crop area are positively correlated with start-of-season food stocks and start-of-season livestock.

The rest of this paper is organized as follows. In Section 1 we briefly summarize the relevant literature and position this paper. In Section 2 we propose a simple conceptual framework. In Section 3 we document data & data sources, verify the model assumptions and explain construction of variable for estimation. In Section 4 we formulate our empirical strategy. In Section 5 we present and discuss estimations. In Section 6 we indicate policy implications and caveats of this research. We summarize our results in Section 7.

1. Risk, technology adoption and market participation in sub-Sahara Africa

From thew introduction it follows that we address three major problems of developing country agriculture, associated with three strands of literature: literature on risk, savings, insurance and credit, literature on technology adoption, and literature on market participation and market access. A rigorous review is beyond the scope of this paper[1]: we briefly discuss elements of these literatures that are relevant to our investigation. Among development economists there is reasonable consensus that risk moves farm households into risk spreading and growing more reliable, but low input – low return crops for subsistence, rather than investing in costly and high risk inputs, and growing cash-crops to sell on the market[2]. Adequate insurance packages are therefore believed to encourage technology adoption and market participation. Livestock, storage of produced crops and mutual insurance arrangements are the major, so-called informal, techniques for farm households to cope with risk. Informal savings and mutual insurance arrangements are considered to be insufficient to adequately offset risks and smooth consumption, especially if risks are covariant rather than idiosyncratic. Alternative savings instruments are needed: however, formal bank accounts or savings accounts in sub-Saharan countries are shown not to be attractive for most households, even if subsidized (Dupas et al., 2015). Major reasons for limited attractiveness and low active usage are extreme poverty ("too poor to save"), high transaction costs and coexistence with several alternative types of informal savings (Dupas et al., 2015). In this context index insurance products – products that avoid adverse selection, moral hazard, high monitoring and administrative cost – may potentially close the missing insurance market gap. Unfortunately, formal index insurance schemes have a poor record as well. Rainfall index insurance schemes suffer from low take-up, attributed to a

[1] Useful literature reviews on risk are: Dercon, 2004, 2005; Mahul and Stutley, 2010; Miranda and Farrin, 2012; and on technology adoption: Jack, 2013; Magruder, 2018; Bridle et al., 2019; Suri and Udry, 2022.

[2] Next to risk, transaction costs are the other major cause that makes production for the market unattractive (see also paragraph on market participation and market access in this sectiobn).

variety of causes like unfamiliarity with formal insurance, lack of understanding and poor information dissemination (Cole et al. 2013, Ahmed et al., 2020), the extent of basis risk (Giné et al, 2008; Dercon et al. 2014; Jensen et al., 2016), and the interaction with informal insurance arrangements (Dercon et al. 2014) or credit (Giné and Yang, 2009; Karlan et al, 2014; Ahmed et al., 2020). The record of credit is less dim, but still faces severe problems due to asymmetric information, monitoring and collateral requirements. Finally, addressing the source of production risk through irrigation or through cultivation of risk mitigation crop varieties is an obvious complementary approach (Bridle et al, 2019) that has altogether received much less attention in the literature. In summary, formal savings and insurance instruments suffer from low take-up, partly due to interaction with informal savings, and credit faces severe contracting problems, while informal coping mechanisms are not sufficient to achieve food security and to smooth consumption. In this connection we argue that the role of informal savings in technology adoption and market participation is under-researched. We therefore investigate the impact of informal coping mechanisms in an integrated household framework that accounts for seasonality of smallholders' costs and revenues, and for the key agricultural risk, the risk of crop failure.

Market participation and market access is also impacted by risk (both production risk and other risks), but predominantly by transaction costs. Since the seminal article by Key, Sadoulet and de Janvry (2000), transaction costs are identified as a major driver of market access and market participation, and has triggered a dearth of supporting empirical work. Recent insights indicate that rural roads lead to lower input prices, larger availability of goods, increased use of fertilizer and improved seeds, higher agricultural productivity, changes in crop choice, increased sales of output, increased enrollment of children, and shifts out of school into the labour force of teenagers (Aggarwal, 2018; Aggarwal et al. 2018; Sotelo, 2020; and for a contrasting view Asher and Novosad, 2020), and that trade costs in developing countries tend to be large compared to developed countries, and drops in world market prices are primarily captured by intermediaries (Atkin and Donaldson, 2015). Information costs – an important part of transaction costs (trade costs) have substantial implication for prices, market efficiency and waste (Jensen, 2007; Aker, 2010; Aker and Fafchamps, 2014; Allen, 2014). Our investigations are confined to the risk explanation of market participation: how do risks (production, input, output) translate into household choices for marketable crops and selling on the market. For these risks similar coping mechanisms apply as for general production risk.

Technology adoption in developing country agriculture (use of fertilizer and high yielding seeds, mechanization) is well researched: a large part of the mostly RCT based evidence focuses on various causes of low returns or low profitability (fertilizer too expensive, too low soil quality (Matsumoto and Yamano, 2009); heterogeneity across farmers (Duflo et al, 2008; Suri, 2011; Foltz et al., 2012); need for costly complementary inputs (Beaman et al, 2014); low quality of fertilizer (Bold et al., 2017; Michelson et al., 2021); present biased preferences (Duflo et al., 2008, 2011). Also liquidity and credit constraints (lack of credit supply due to asymmetric information (Gine and Klonner, 2008; Karlan et al, 2014)) and information (networks and relatives (Conley and Udry, 2003; Bandiera & Rasul, 2006); both information on returns and technical knowledge (van Campenhout, 2021); extension services (Hörner et al., 2022; Naeher, D. and M. Schündeln, 2022)) are shown to affect technology adoption critically. More generally, constraints or inefficiencies are identified as major determinants of (low) technology adoption, including liquidity, savings, insurance and credit constraints; risk exposure; externalities; land, labour and input & output market inefficiencies; and informational inefficiencies (Jack, 2013; Magruder, 2018; Bridle et al., 2019; Suri and Udry, 2022). Moreover, heterogeneity across farm households in weather, soil and access to market is pervasive and explains widely diverging responses to policies and reduced effectiveness (Duflo et al. 2008; Suri, 2011; Suri and Udry, 2022). Also, and finally, inefficiencies and constraints at play in technology adoption in agriculture are interrelated: there is no single binding constraint (Jack, 2013; Suri and Udry, 2022). This interrelatedness suggests a structural modeling approach, rather than zooming in on one driver of technology adoption. Such an approach should incorporate seasonality and shocks, set out major interactions in the coping and investment behavior of farm households and seek to reveal their relationship with technology adoption (and market participation). In short: we therefore aim to explore the role of informal savings and risk coping strategies on investments in technology and on cultivation of high return crops to sell on the market.

Although we are not aware of other attempts in the empirical literature along these lines, a small body of literature – of particular relevance to our exploration – has recently emerged, that focuses on the interplay of seasonality in agricultural income, grain storage, informal savings, off-farm labour supply, credit and investment (Casaburi et al., 2013; Fink et al., 2014; Casaburi et al., 2014; Basu and Wong, 2015; Aggarwal et al. 2018; Burke et al., 2019; Devallade and Godlonton, 2023). Especially following improvements and availability of new on-farm storage technologies (hermetic storage bags) – this research has generated new insights on direct impacts of storage (spoilage, chemical use), and indirect impacts of storage on food security, on general equilibrium and on technology adoption[3] (Ricker-Gilbert and Jones, 2015; Basu and Wong, 2015; Aggarwal et al, 2018; Omotilewa et al. 2018; Burke et al. 2019; Tesfaye and Tirivayi, 2018; Brander et al., 2021). Outcomes support positive and substantial impacts of stocks of grain on food security (Basu and Wong, 2015; Omotilewa et al. 2018; Tesfaye and Tirivayi, 2018; Brander et al., 2021). Grain storage is shown to encourage intertemporal arbitrage and to support credit for investment (Burke et al, 2017; Aggarwal et al, 2018; Devallade and Godlonton, 2023). Devallade and Godlonton (2023) investigate the impact of

[3] With respect to technology adoption research focuses on the higher sensitivity of hybrid maize for post-harvest losses than traditional varieties, and the associated impact of advanced storage technologies, a different mechanism than the one proposed in this work.

offering warrantage to smallholder farmers, an inventory credit system that gives farmers the opportunity to store crop production and simultaneously access credit. Village level crop storage operates as a commitment device restricting farmers to access their grain for a fixed duration and realizing an arbitrage benefit from increased market prices. Revenues are spent on education, livestock and investment in fertilizer and high yielding varieties. Fink et al. (2014) show that farmers operate under credit constraints that forces them to make suboptimal decisions on on-farm and off-farm family labour, land use and crop choice. Interest-free maize loans during "the hungry season" (January to March) leads to a reallocation of labor from off-farm to on-farm, increases in local wages and improvements in food security. Overall these investigations approach opportunities against the background of the shocks, seasonality and constraints that agricultural households face.

2. Conceptual Framework

The interplay between seasonality, risk of insufficient rains, coping strategies of farmers, crop choices, cultivation practices and savings for investment – reflected in this last reviewed research – is the topic of the current paper. For this paper – and to fix ideas – we propose the following stylized model of smallholder agriculture in developing countries. We consider a two period framework for an agricultural household, where the first period is the growing season, indicated with subscript 1, and the second period the harvesting season, indicated with subscript 2. Farm households maximize utility from consumption and leisure over two periods given by

$$u(c_1, f_1) + \rho u(c_2, f_2), \tag{1}$$

where c is consumption, f is leisure and ρ is a discount rate for second period utility. Farm households have fixed and small sized endowments of land, and have three resources: agricultural income (y), off-farm wage income ($l_o w$) and depletion (or accumulation) of savings (Δs)[4]. Total labor is fixed ($\bar{l}$) and, in each period, allocated to work on the home farm (l_h), off-farm work (l_o) and leisure (f):

$$l_h + l_o + f = \bar{l}. \qquad (2)$$

The wage rate (w) is determined by the marginal (value) product of labor on the land of large farmers who hire labor to do chores on their land[5]. There is no capital market, and, hence, no credit. Seasonality and risk in agricultural production have implications for agricultural income (y_t), which is zero in period 1 and a random outcome in period 2. Period 2 agricultural income (y_2) is also a function of labor allocated to work on the home farm:

$$y_1 = 0 \text{ and } y_2 = \widetilde{y_2}(l_h), \qquad (3)$$

where a tilde expresses a risky outcome. Farmers face a period 1 budget constraint:

$$c_1 \leq l_{o,1}w - \Delta s_1, \qquad (4)$$

and a period 2 constraint:

$$c_2 \leq l_{o,2}w + y_2 - \Delta s_2. \qquad (5)$$

In the growing season households use their savings, possibly supplemented with income from off-farm labor, for consumption. In the harvesting period households collect their harvest, cash the proceeds of agricultural production and use this agricultural income (y_2) for consumption. Agricultural income is a risky outcome and we consider two options: a low income and a high income. If agricultural income is low due to, for example, a crop failure, farmers supplement this income with savings or income from off-farm labor. Conversely, if agricultural income is high, agricultural income is sufficient to meet consumption requirements and farmers do not need to rely on alternative resources. In practice, the incidence of a crop failure should not be much higher than 20% for viable agriculture.

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[4] We use s (savings) as a stock variable, and Δs as depletion (if $\Delta s < 0$) or accumulation (if $\Delta s > 0$) of savings.

[5] We envisage a continuum of farm households with cropland varying from small to large, similar to Foster and Rozenzweig, 2017, with the majority of farm households at the smaller end of the distribution.

How do seasonality, shocks and savings affect technology adoption and market participation? We identify both a current period effect and a future effect of savings. If savings in period 1 are insufficient for consumption, and resources need to be supplemented with off-farm wage income, productivity on the home farm decreases because of sub-optimal production decisions (Fink et al., 2014). Conversely, if the use of savings in period 1 is sufficient to meet consumption requirements, the farmer will use all labor for agricultural production at home ($l_{o,1} = 0$), leading to superior choices on agricultural production and higher productivity on the home farm. A crop failure ($y_2 = 0$) will further exhaust savings, carried over from period 1, and make off-farm wage income in period 2 also essential. Note that savings potentially need to cover a lack of resources due to seasonality (in period 1), and a lack of resources due to a possible crop failure (in period 2). Alternatively, a regular or bumper crop will take away the need for off-farm wage income ($l_{o,2}w = 0$): under these conditions farmers may allocate production proceeds to asset accumulation, to be carried over beyond period 2 ($\Delta s_2 > 0$). The future impact of savings runs through this channel: savings carried over beyond period 2, create certainty of resources in the next season and can (partially) be used for investment in technology (fertilizer, high yielding varieties) and risky crops (cash crops to sell on the market), in which case marginal productivity of labor in future agricultural production increases (Devallade and Godlonton, 2023).

In summary, the framework combines seasonality and risk of agricultural production and the interrelation across years through savings, and proposes two mechanisms underlying technology adoption and market participation. The framework has several testable implications. Household savings play a key role in food security, labor productivity in agriculture and growth of agricultural household income. Large positive savings help to optimize current decisions on crop choice and cultivation practices on the home crop land, and, for future periods, offers funding and drive investment in technology and shifts of resources to high return agriculture.

Conversely, if households allocate substantial shares of labor to off-farm employment, this will negatively affect current crop choice decisions and cultivation practices on the home crop land and depress opportunities for increasing labor productivity in agriculture in the future. The framework points at limits to economically sustainable smallholder agriculture: if farm households need to operate year after year through off-farm labor, this signals a low productivity level and little perspective on improvement. Under these circumstances it could be more efficient to leave agriculture altogether. The objective of this paper is to explore empirically if typical development economy informal savings, notably start-of-season staple food stocks and livestock, help to improve technology adoption (fertilizer use, adoption of high yielding varieties) and market participation (cash crop cultivation, increased market sales). We also explore how off-farm employment is associated with maize stocks and livestock, and verify the validity of the assumptions in the conceptual framework.

3. Data sources & data, model verification and variable construction

To investigate the relationship between storage, livestock and off-farm wage vis-a-vis technology adoption and market participation, we use the Malawian LSMS-ISA representative household survey data for the years 2010-11, 2016-17 and 2019-20, also known as IHS-3, IHS-4 and IHS-5 (IHS = Integrated Household Survey), both the cross-sectional versions and a panel version of the IHS data. The panel data cover the years 2010, 2013 and 2016. A major attraction of the cross-sectional data is the large the number of households (between 8,700 and 10,000 farm households, in a total of around 12,000 households). The panel data comprise less households (a maximum of 3,673 farm households) but their major attraction is that these data allow panel data estimation techniques.

Table 1 Descriptive Statistics of Malawi household surveys (IHS 3, 4, 5)

Variable	IHS-3 (2010)	IHS-4 (2016)	IHS-5 (2019)
households (ag, total)	10011 (12268)	9443 (12447)	8767 (11434)
region (N-C-S, %)	12.4-40.6-46.7	9.2-44.3-46.5	12.8-42.0-45.2
urban (%)	15.6	19.1	16.3
household head: sex (0/1)	0.756 (0.431)	0.691 (0.462)	0.671 (0.470)
household head: age	43.03 (16.49)	44.44 (16.38)	44.66 (16.33)
household head: education	0.784 (0.411)	0.765 (0.424)	0.755 (0.430)
household size	4.73 (2.18)	4.43 (1.93)	4.56 (2.01)
total crop area	1.85 (1.68)	1.55 (1.58)	1.68 (2.59)
share of maize area	0.714 (0.242)	0.673 (0.256)	0.559 (0.246)
share of hybrid maize area	0.311 (0.372)	0.224 (0.323)	0.203 (0.303)
maize yield, hybrid	594.9 (439.1)	538.2 (462.1)	609.8 (496.2)
maize yield, non-hybrid	432.1 (315.2)	374.6 (301.2)	444.3 (349.5)
maize stocks (0/1)	0.546 (0.498)	0.344 (0.475)	0.475 (0.499)
maize stocks (if >0)	73.85 (13.87)	49.53 (12.91)	39.92 (23.49)
livestock (0/1)	0.465 (0.499)	0.401 (0.490)	0.454 (0.498)
livestock (if >0)	0.153 (0.404)	0.163 (0.403)	0.159 (0.399)
ganyu (0/1)	0.466 (0.499)	0.663 (0.473)	0.745 (0.436)
wage from wage job (0/1)	0.171 (0.376)	0.113 (0.317)	0.140 (0.347)
self-employment (0/1)	(not recorded)	0.187 (0.390)	0.265 (0.441)
fertilizer use (0/1)	0.372 (0.483)	0.662 (0.473)	0.669 (0.470)
fertilizer use (if >0)	80.43 (49.28)	60.81 (47.40)	55.02 (47.37)
share of marketed output	0.166 (0.273)	0.137 (0.233)	0.186 (0.262)
cash crop area	0.154 (0.267)	0.147 (0.260)	0.199 (0.296)

Note to table: The table reports weighted averages with standard deviation in brackets, using the sample weights of the household survey. Continuous variables are winsorized at the 5% level at most. 0/1 is a binary variable; the first three lines reflect are (weighted) averages for the full survey (rather that the agricultural sector only): households is the number of households in the survey, N-C-S is the share of households in respectively the northern, central and southern region, urban is the share of urban households in the population. sex: male=1; age in years; education: no education=1; household size in numbers; total crop area in acres (1 acre = 0.4047 hectare); yield: production in kg per acre; maize stocks(0/1): non-zero start-of-season stocks=1; maize stocks (if >0): average start-of-season maize stocks per household member in kg, conditional on positive stocks; livestock (0/1): non-zero start-of-season livestock=1; livestock (if >0): average start-of-season livestock per household member in tropical livestock units, conditional on positive start-of-season livestock; ganyu (0/1): non-zero ganyu labour=1; wage from wage job (0/1): positive wage from wage job=1; self-employment (0/1): positive income from self-employment=1; fertilizer use (0/1): non-zero fertilizer use=1; fertilizer use (>0): average per acre fertilizer use in kg, conditional on positive fertilizer use; share of marketed output is the share of market sales in total production value (all crops); cash crop area is total crop area minus maize area, in acres per household member.

Agriculture and the economy of farm households in Malawi from 2010/2011 to 2019/2020 is described in Table 1, summarizing information extracted from three household surveys (IHS-3 to IHS-5). Slightly more than 80% of the Malawian population lives in rural areas, and is concentrated in the southern region (46%), with smaller shares moving northwards: around 34% in the central region and around 20% in the northern region. The remainder of the data refer to agricultural households, households that cultivate crops[6]. The number of household members per agricultural household is on average between 4 and 5. Around 24% to 33% of households is female headed. More than three quarter of agricultural households heads have no education and an average age of around 45. Agricultural households have a total crop area of 1.6 to 1.9 acres on average[7], of which the larger part is cultivated with maize (56%-71%). The share of total crop area cultivated with hybrid maize is between 20 and 31%. Average hybrid maize yields are around 40% higher compared to average non-hybrid varieties (non-hybrid: 420kg per acre (1030kg per hectare), hybrid: 580kg per acre (1435kg per hectare)). Drops in yield due to weather are slightly larger for non-hybrid maize (around 14% versus around 10%). Household maize stocks fluctuate heavily per season and much more than livestock: the share of households with maize stocks (and average stocks) varied from 55% (74kg) in 2010, to 34% (50kg) in 2016 and 49% (40kg) in 2019. Close to 50% of households owns livestock, which consists on average of one to two goats (1 goat = 0.1 tropical livestock units). Over the years livestock fluctuates less than maize stocks. Wage from ganyu labour (or casual labour) is earned by 46% to 75% of households (and likely fluctuates with last season crop outcome) with an average size between 0.003 to 0.045 per household member. Wage from regular jobs is earned by 11% to 17% of households with an average size between 0.005 to 0.019 per household member. Income from self-employment (only IHS4 and IHS5) is earned by 19% to 27% of households. Fertilizer is applied by 37% of the agricultural households in IHS-3 (2010/11), with a relatively high average quantity (74kg), and the share of fertilizer users increases to above 66% in IHS-4, and IHS-5 (2016/17, 2019/20), however, with smaller quantities (on average 46kg)[8]. Fluctuations in take-up and average quantity are likely to be related to Malawi's

[6] Only a small share of all households is exclusively breeding cattle (IHS3: xx%; IHS4: 4.8% and IHS5: 5.0%). These households are ignored in the empirical estimations: we focus on the majority of agricultural households that grow crops, possibly combined with rearing livestock.

[7] 1 acre = 0.4047 hectare.

[8] Fertilizer recommendation are around 50kg of nutrients per hectare (or around 20 kg per acre).

fertilizer and seed subsidy programs (FISP, from 2005 onwards). Only a limited share of agricultural output is sold on the market: on average this ranges from 14% to 19%. The limited share of markets sales characterizes Malawi agriculture as predominantly subsistence agriculture. Per household member cash crop area varies between 0.15 and 0.20 acres.

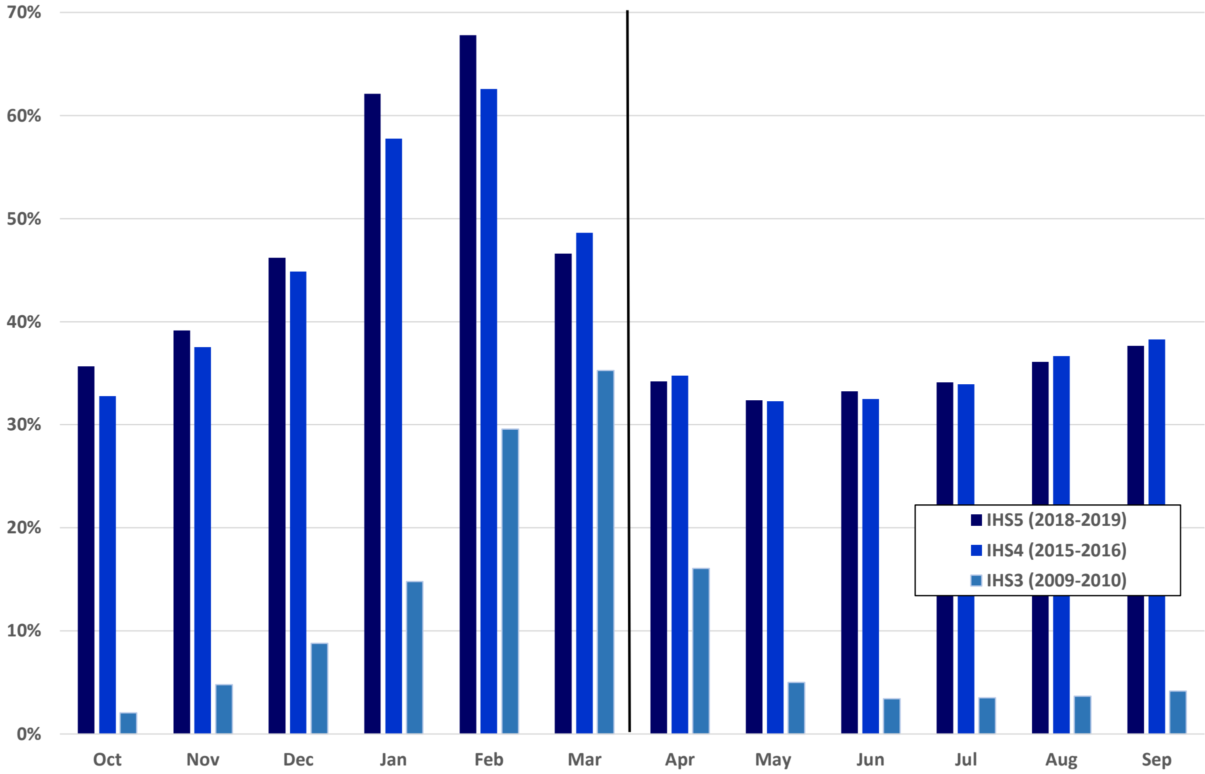
Table 2 Drought and irregular rainfall (IHS 3, 4, 5)

Variable	IHS-3 (2010)	IHS-4 (2016)	IHS-5 (2019)
Drought	[0.434 (0.497)]	[0.441 (0.497)]	0.233 (0.370)
irregular rainfall	(not recorded)	[0.704 (0.456)]	0.334 (0.448)

Note to table: The table reports the answers to the question (IHS5): "How many times in the last 3 years was your household negatively affected by (drought) (irregular rains)". IHS3 and IHS4 record shocks over the last 12 months. The IHS5 incidence of drought and irregular rains is converted to annuals. Numbers are sample weighted averages with standard deviation in brackets.

We proceed with verifying if the survey data support the assumptions of the conceptual framework. Evidence of drought and irregular rains as the dominant production risk in developing country agriculture abounds in the literature (. Table 1 reports average (annual) incidence of drought and irregular rains, reported by households as a major risk. Note that the IHS5 data record shocks over the last 3 years, while IHS3 and IHS4 record these over the last 12 months: this makes the IHS5 data more representative of long run incidence, while the IHS3 and IHS4 data reflect last season incidence. The table suggests that over a 3-year period farm households face, on average, a drought risk of 23% and an irregular rain risk of 33.4%. If these data reflect long run weather risk, it is equivalent to a drought once every 4-5 years and irregular rains occurring once every 3 years.

Figure 1 Food security during the season (IHS 3, 4, 5)



Note: Based on answers to the question: "During which months in the last 12 months did you experience a situation when you did not have enough food to feed the household?"

Everyone involved in agriculture will acknowledge seasonality. Nevertheless, we think it is insightful to show the depth of seasonality reflected in household resources. Unfortunately there is no monthly information on income in the LSMS-ISA survey data. Instead we explore the incidence of food shortages – the lack of income – over the season, which is shown in Figure 1. The Figure shows a regular and substantial increase in incidence of food shortages during the lean months, from November to April. For the IHS4 and IHS5 data the incidence increases from a low of 35 to 40% to a peak of more than 60%, while in the IHS3 data the incidence increases from a low of less than 5% to a peak of more than 30%. The major reason for food shortages reported by households is lack of food stocks (Table 3), which underscores the importance of food stocks as a major coping strategy to protect against food shortages, either due to crop failure or seasonality.

Table 3 Reasons for food shortage at the household level (IHS 3, 4, 5)

Variable	IHS-3 (2010)	IHS-4 (2016)	IHS-5 (2019)
Inadequate household food stocks	76.9%	65.4%	59.1%
Very high food prices on the market	12.5%	26.0%	25.4%
Other reasons	10.6%	8.6%	15.5%

Table 4 Credit (IHS 3, 4, 5)

loans for consumption	IHS-3 (2010)	IHS-4 (2016)	IHS-5 (2019)
from informal sources (0/1)	0.037 (0.189)	0.068 (0.252)	0.059 (0.236)
from formal sources (0/1)	0.003 (0.054)	0.041(0.197)	0.051 (0.220)
loans for investment			
from informal sources	0.059 (0.236)	0.058 (0.233)	0.076 (0.265)
from formal sources	0.028 (0.166)	0.062 (0.242)	0.118 (0.323)

Note: The table shows weighted mean values with standard deviations in brackets.

In the conceptual framework we assume that there is no credit market. Table 4 summarizes if households have loans, for what purpose (agricultural or non-agricultural investment, or consumption) and from which source (informal and formal, where a formal source is either an institutional organization or a commercial bank). We are particularly interested in credit or loans for consumption purposes, obtained from formal sources. Less than 5.1% of households (2010: 0.3% ; 2016: 4.1%; 2019: 5.1%) have a loan for consumption purposes from a formal credit institution. Since money is fungible, loans may be used for different purposes than recorded. Hence, we consider overall access to formal loans: at least 83% of all households have no loan from formal credit institutions for any purpose (2010: 96.9%; 2016: 89.7%; 2019: 83.1%). These low shares of 'credit for consumption' and high shares of 'no credit' apper to be sufficient support for the 'no credit market' assumption.

Table 5 Maize stocks and off-farm wage (IHS 3, 4, 5)

Variable	IHS-3 (2010)	IHS-4 (2016)	IHS-5 (2019)
no food (0/1)	0.513 (0.500)	0.792 (0.406)	0.732 (0.443)
no food months	1.541 (2.199)	5.942 (3.930)	5.552 (4.342)
off-farm wage (0/1)	0.583 (0.493)	0.733 (0.442)	0.808 (0.394)

Note: The table shows weighted mean values with standard deviations in brackets. No food (0/1): period without food during last 12 months=1; no food months: average number of months without food. Off-farm wage is the sum of ganyu wage and wage from regular wage employment (jobs).

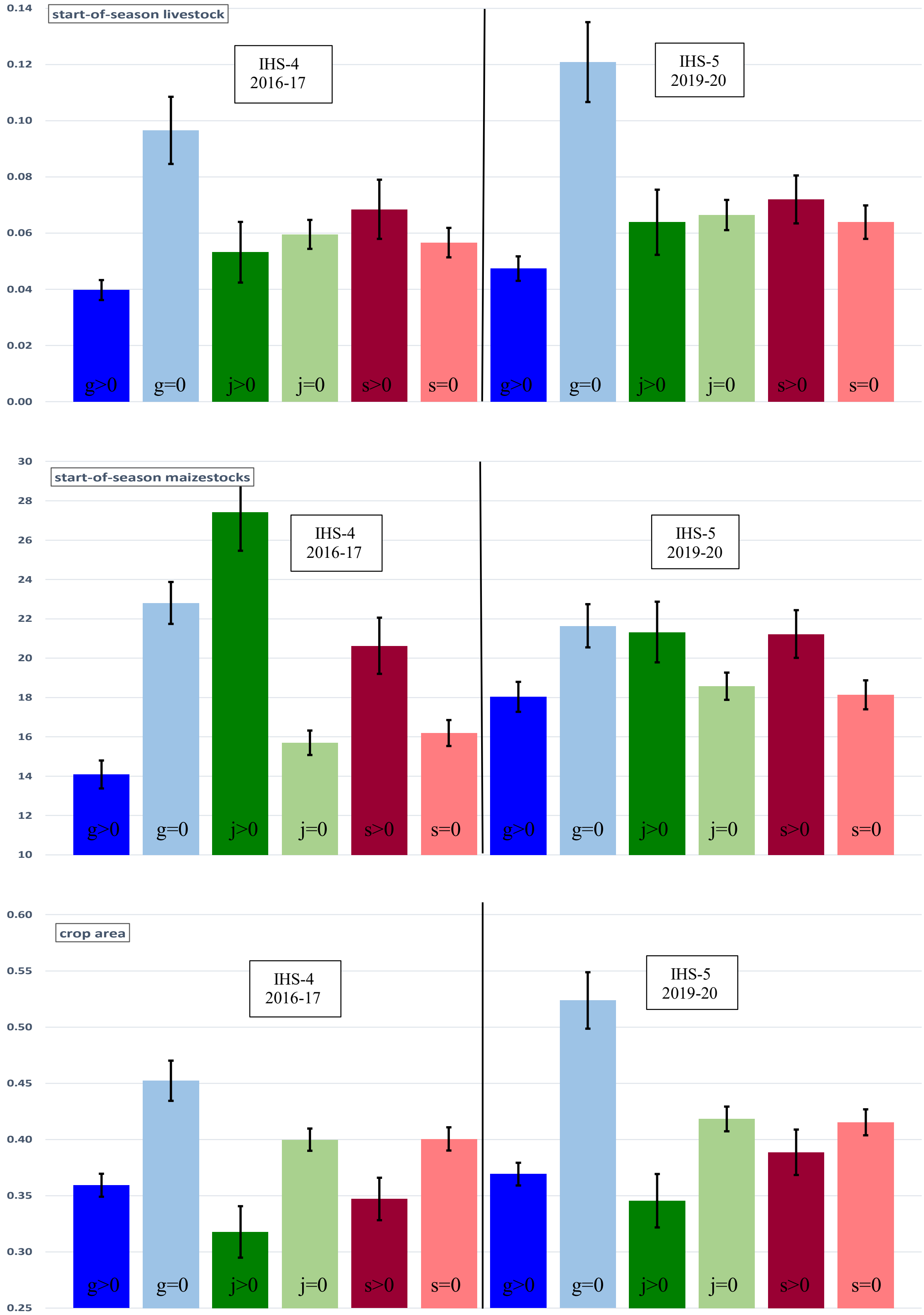
Average incidence of food shortages ('In the last 12 months, have you been faced with a situation when you did not have enough food to feed the household?') increased from 51% in 2010 to close to 80% in 2013, to decrease to 73% in 2016 (Table 5). The average number of months without food increased even stronger, from one and a half month in 2010 to close to six months in 2013 and 2016. A higher incidence of food shortages reflects a lower level of available resources (agricultural output, savings or off-farm wage). Following the conceptual framework we expect the share of households engaged in off-farm labour, and the size of average rewards from off-farm labour to fluctuate with the incidence of food shortage. This correlation is clearly supported: the share of households with off-farm wage increases from 58% to 81% jointly with the increased incidence of food shortages (Table 3).

Table 4 Stocks and crop area versus off-farm wage (IHS 3, 4, 5)

off-farm wage from ganyu labour	IHS-3 (2010)	IHS-4 (2016)	IHS-5 (2019)
livestock with off-farm wage > 0	0.042 (0.002)	0.040 (0.002)	0.047 (0.002)
livestock with off-farm wage = 0	0.079 (0.003)	0.097 (0.006)	0.121 (0.007)
F-test (p-value)	88.64 (0.0000)	79.37 (0.0000)	93.49 (0.0000)
maize stocks with off-farm wage > 0	69.32 (0.279)	14.09 (0.366)	18.04 (0.387)
maize stocks with off-farm wage = 0	76.60 (0.209)	22.81 (0.540)	21.65 (0.561)
F-test (p-value)	438.0 (0.0000)	178.9 (0.0000)	28.06 (0.0000)
crop area with off-farm wage > 0	0.399 (0.006)	0.359 (0.005)	0.369 (0.005)
crop area with off-farm wage = 0	0.484 (0.007)	0.452 (0.009)	0.524 (0.013)
F-test (p-value)	85.63 (0.0000)	78.19 (0.0000)	125.5 (0.0000)

Note: The table shows mean values with standard errors in brackets. Livestock is in tropical livestock units and maize stocks in kgs, both measured at the start of the period and per household member.

Figure 2 Off-farm wage versus stocks and crop area (IHS 4, 5)



Note: g: earnings from ganyu labour; j: earnings from wage jobs and s: earnings from self-employment.

According to our model off-farm activities are undertaken in case of lack of resources to purchase basic food needs. No off-farm activities implies that the household apparently has sufficient savings to cover the no-income period. We can empirically verify the claim if these two groups – households with earnings from off-farm labour and households without earnings form off-farm labour – have different savings.

The LSMS-ISA survey data distinguish three types of off-farm earnings: earnings from casual or ganyu labour, wage from wage jobs and earnings from self-employment. Ganyu labour is the most widespread source of off-farm earnings, while the share of households having earnings from job employment or self-employment are very modest (Table 1). In the case of earnings from ganyu labour average livestock, average maize stocks and average crop area per household member is systematically higher for households with no earnings from ganyu labour (Table 4, Figure 2, Appendix Table A1). No earnings from ganyu labour jointly with higher stocks supports our conceptual framework. However, in case of earnings from wage jobs and self-employment, there is no difference in livestock levels, while maize stocks are larger (instead of lower), suggesting a different (reverse?) role for these types of off-farm labour. Earnings from wage jobs and self-employment is also combined with smaller crop areas: for these households earnings from off-farm labour possibly support investments that lead to increases in productivity in agricultural activities.

In summary, we conclude that the Malawi survey data convincingly support the assumptions of the conceptual framework: households face a large production risk due to drought and insufficient rainfall, agricultural income follows a distinct seasonal pattern, savings are used to cover 'no-income' periods, there is no capital market and ganyu labour is a major coping instrument.

Finally, we briefly discuss how source data are used to construct variables for estimation. For the household data we construct a comprehensive crop balance covering all cultivation activities for each household, which identifies production and its uses at the household level, by five different crops, or crop aggregates[9]. Note that the crop balance is in quantities. Additionally, values for market sales (and production in IHS5) are recorded. Crop production needs to be consistent with uses: hence, crop production = home consumption + sales on the market + storage + other uses. Home consumption is recorded in IHS-5, but missing in IHS-3 and IHS-4, and therefore constructed on the basis of the crop balance[10]. A similar issue applies to value of crop production: not recorded in IHS-3 and IHS-4, but constructed using district average unit values of market sales[11]. Next, we use agricultural area by crop. Agricultural area data are built up from the household plot level. More crops per plot (mixed-cropping, intercropping) are dealt with by imposing an area distribution by crop that reflects the decreasing importance of the various crops[12]. Crop area that is not cultivated for several reasons (left fallow, rented out and given out for free) is accounted for. Area cultivated with maize also distinguishes hybrid maize among other types of maize (local, improved local and recycled hybrid), enabling to measure the adoption of hybrid maize. Unfortunately the hybrid maize area is not recorded in all survey rounds.

Fertilizer use by households is hard to measure properly: households grow several crops, on various plots, in different intensities (pure or mixed cropping, intercropping) and apply fertilizer (if any), differently, for different crops and plots, with different timing, using different quantities and qualities of fertilizer, and with either one or several treatments. Fertilizer use in the LSMS-ISA data is recorded with substantial detail. We propose two ways to construct a household variable reflecting fertilizer use: the first way calculates the per plot application of

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[9] We distinguish five major groups of crops: maize, groundnuts, tobacco, rice and other crops (mainly vegetables like pigeon peas, nkhwani and cow peas).

[10] Validity of the applied construction is verified with the help of IHS5 data. Constructed consumption of home produced maize – maize production minus uses (sales, storage and other uses) – stays within acceptable margins of error for around 80% of the households.

[11] Again, validity of the applied construction is checked with IHS5 data: estimations of cash crop shares using recorded and constructed value of produced crops are statistically very close.

[12] Estimation results are statistically similar if different (but still decreasing) weights are applied.

fertilizer (all types of fertilizer taken together, main crop, kg per acre) and selects the maximum application of fertilizer over all plots in a household; the second aggregates all quantities of fertilizer applied on all plots at the household level and divides this aggregate fertilizer application with total household crop area. Other candidates to measure technology adoption, like the use of improved varieties or the share of hybrid maize area, are considered but set aside, since these variables are not recorded in all survey rounds.

Market participation is measured with the share of market sales of all crops in the total production value (all by household). Since most produced agricultural output is not sold on the market, the construction of the share of market sales in total production requires an estimate of total production value. Total production value is constructed as the product of the household production quantity by crop (recorded in the survey) times the market price of the crop, summed over all crops cultivated by the household. Market prices at the household level are not available for crops that are not sold on the market. However, we do have unit values (sales value divided by sales quantity) for a limited number of (neighbouring) households. We use the median unit value by crop and by district as an approximation of market prices.

Cash crop area, another indicator of market participation is constructed in a crude way: it is assumed to be equivalent to non-maize area. More accurate indicators are potentially feasible but require several arbitrary assumptions. Crops like tobacco, cotton and sugar cane are genuine cash crops, that contribute 100% to cash crop area. In contrast, most other crops are more difficult to allocate. Groundnuts and rice are primarily sold on the market, but also consumed by the producing households. A similar problem arises with vegetables (beans, pigeon peas, nkhwani, etc): these crops are also both for home consumption and sold on the market. Also maize is mostly consumed at home but also sold on the market. A further complication arises in case of mixed cropping, which is particularly prevalent in the cultivation of vegetables.

The core explanatory variables in the household survey based estimations are start-of-season maize storage, start-of-season livestock and off-farm employment. Observations on maize storage in kg are available through post-harvest uses of maize production (home consumption, sales on the market, storage and other uses (gifts, reimbursements, animal feed, seed, losses)). Unfortunately this is end-of-season maize storage and not useful for our estimations[13]. The start-of-season maize storage (surprisingly not recorded) is therefore constructed on the basis of food security information, in particular the number of months during the last 12 months without food ('mark each month that the household did not have enough food'), combined with the cause for a food shortage ('inadequate household food stocks') and an average maize requirement per person and month. Note that the constructed nature of the maize stock variable is likely to decrease estimated coefficients and make these less accurate[14]. Livestock is the number of tropical livestock units, where the sub-Sahara specific weights for different types of livestock are obtained from FAO (2011). For reference: a goat, a popular type of livestock, is equivalent to 0.1 tropical livestock unit. In contrast with maize stocks, livestock is also recorded as a start-of-season variable ('how many units of livestock did your household own exactly 12 months ago?')[15]. Many households lack both types of savings (IHS-3: 26.8%; IHS-4: 41.0%; IHS-5: 30.0%). Off-farm employment contains both regular ('your main and secondary wage job over the last 12 months?'), casual off-farm wage ('did you engage in casual, part-time or ganyu labour, even if only for one hour, during the last 12 months?') and self-employment for non-agricultural businesses. Note that casual off-farm wage, unlike the other types of off-farm labour, is shown to fit our conceptual framework. Taking both types together

[13] Using end-of-season maize storage as explanatory variable would generate a perfect reverse causality relationship.
[14] The constructed nature of the start-of-season maize stocks make us hesitant to give much weight to comparing the size of coefficients of start-of-season maize stocks and start-of-season maize livestock.
[15] By using tropical livestock units we ignore the purchasing power of livestock and its terms of trade with staple food over the season. This terms of trade tends to deteriorate extremely during food shortages (Zant, 2022).

possibly creates heterogeneity[16]. Around 20%-42% of households earned no income from off-farm employment (IHS-3: 41.7%; IHS-4: 26.7%; IHS-5: 19.2%).

4. Empirical strategy

The empirical estimations are based on cross-sectional household surveys and panel data, respectively IHS-3 (2010-11), IHS-4 (2016-17) and IHS-5 (2019-20), and IHPS (2010, 2013 and 2016, see also data section). For the cross-sectional data we employ the following specification to measure how key outcome variables are correlated with different savings and off-farm wage:

$$y_i = \beta_0 + \beta_1 grain\ stock_{0,i} + \beta_2 livestock_{0,i} + \sum_k \beta_{4k} X_{ki} + \vartheta_j + \varepsilon_{it}, \quad (6)$$

where where y_i stands for per acre use of inorganic fertilizer, the share of agricultural production sold on the market and the share of cash crops in total crop area), X_k are k control variables and ϑ_j is a full set of j geographical areas (enumeration areas).

The panel data specification looks similar, though with a few important differences. For the panel data we employ a standard Two Way Fixed Effect specification (TWFE) and the differences are associated with this TWFE approach. The specification is:

$$y_{it} = \beta_0 + \beta_1 grain\ stock_{0,it} + \beta_2 livestock_{0,it} + \sum_k \beta_{4k} X_{kit} + \zeta_i + \theta_t + \varepsilon_{it}, \quad (7)$$

where the subscripts now denote household i at time t, and ζ_i and θ_t are household and time fixed effects. In both approaches the parameters of interest are β_1 and β_2: we expect $\beta_1$and β_2 to be positively correlated with technology adoption and market participation. We investigate if these parameters contribute in the expected way, if they are significant and elaborate on the size of the effects. Many households do not use fertilizer, leading to observations truncated at

[16] For some households off-farm wage is an internal solution to optimization. In contrast, in our framework off-farm wages occur in case of a lack of resources to meet consumption requirements, which is a corner solution.

zero. Likewise, share of market sales in production value is truncated at zero and 1. To account for the truncated dependent variable we employed the TOBIT estimation technique.

Note that all data used are observational (or non-experimental), which has clear ramifications for the interpretation of the results. Identification is based on the idea that start-of-season stocks are pre-determined. Consequently, estimations are exploratory and intended to find support for the conceptual framework.

5. Estimation results

The estimations recorded in Table 6 and 7 are the heart of this paper. Each table shows the estimations with the cross-sectional household surveys (respectively IHS-3, IHS-4 and IHS-5) under panels a to c, and the estimation results based on the panel data (IHPS) in the bottom panel, panel d. Throughout all estimations, the core explanatory variables (start-of-season maize stocks and start-of-season livestock, both per household member and in the tables abbreviated to *mzst* and *lvst*, are used in continuous and binary form (indicated with 0/1). The interpretation of the coefficients differs accordingly: the 'continuous-variables' specification allows to calculate the marginal impact of maize stocks and livestock (say 100 kg extra maize stored, or 1 extra goat), while binary variables reflect the generic effect of non-zero stocks or off-farm wage and allow a direct comparison of the relative effect of maize stocks and livestock. Unlike the continuous variables, the binary versions of variables have the attractive feature that they are not sensitive to outliers[17].

Estimations of the relationship between fertilizer use versus maize stocks and livestock are reported in Table 6. Estimation results based on the cross-sectional household surveys all have statistically significant coefficients for maize stocks and livestock, nearly all at the 1% level of accuracy. The panel data estimations livestock are slightly less accurate, but still

[17] Continuous variables are winsorized, at most, at the 5% level.

significant at well accepted levels. Given the smaller number of observations, jointly with household fixed effects that potentially absorb some explanation of stock variables, we are not worried about the slightly minor performance of the panel data estimations. Since the panel estimations control for household fixed effects, we consider the estimated coefficients superior (although coefficients do not differ drastically) and elaborate briefly on the economic interpretation. Assuming a household size of 5, estimated correlations suggest that at the margin an increase at the household level of 100kg of maize stocks raises per acre fertilizer use with 3.4 to 4.1 kg, while an increase at the household level of 5 goats (or 1 cow) raises fertilizer use with 4.4 to 4.8 kg. Looking at estimations with maize stocks and livestock as indicator variable (column (2 and (4)), we find that the coefficient of maize stocks and livestock are different but statistically the same (tests on equality could not be rejected[18]).

Estimations of the relationship between the share of market sales in production value and the cash crop area per household member versus maize stocks and livestock are reported in Table 7. Again, coefficients of maize stocks and livestock are statistically significant in all cross-sectional estimation, and mostly at the 1% level of accuracy. The panel estimations perform less well for the share of market sales (but still with positive signs and mostly significant), but in the cash crop area estimations are significant at conventional levels of confidence (mostly at the 1 % level). Estimated coefficients in the panel estimations are consistently on the low side, relative to their cross-sectional counterparts. Like in the case of fertilizer, we elaborate briefly on the economic interpretation of the coefficients. The estimation results on the share of market sales suggest that 100kg extra maize stocks is associated with a 0.009 percentage-point increase in the share of markets sales, while 5 extra goats (or 1 cow) leads to a 0.018 percentage point increase in the share of market sales. Finally, estimated correlations suggest that at the margin an increase at the household level of 100kg of maize

[18] Because of the constructed nature of the start-of-period maize stocks we have some reservations about the accuracy of the maize coefficient and, hence, also about comparisons with the livestock coefficient.

stocks raises cash crop area with 0.03 acres, while an increase at the household level of 5 goats (or 1 cow) raises cash crop area with 0.04 acres. Also for cash crop area, the generic effect of maize stocks and livestock is more or less equally sized (column (4)): test on equality could not be rejected at conventional levels of confidence .

Table 6a Fertilizer use vis-à-vis start-of-season maize stocks and livestock (IHS5)

	(1)	(2)	(3)	(4)
Dependent variable:	fertilizer use	fertilizer use	fertilizer use*	fertilizer use*
Mzst	0.099*** (0.039)		0.073*** (0.024)	
Lvst	48.92*** (7.843)		32.08*** (4.931)	
mzst (0/1)		18.67*** (2.070)		12.61*** (1.370)
lvst (0/1)		24.55*** (2.028)		14.57*** (1.357)
d(ea)	yes	Yes	yes	yes
pseudo R^2	0.0469	0.0491	0.0523	0.0542
Observations	8301	8301	8360	8360
Table 6b	**Fertilizer use vis-à-vis start-of-season maize stocks and livestock (IHS4)**			
Mzst	0.234*** (0.036)		0.215*** (0.031)	
Lvst	46.11*** (4.681)		37.02*** (3.788)	
mzst (0/1)		14.43*** (1.899)		13.41*** (1.625)
lvst (0/1)		20.09*** (1.671)		14.85*** (1.442)
d(ea)	yes	Yes	yes	yes
pseudo R^2	0.0459	0.0466	0.0478	0.0483
Observations	8989	8989	9195	9195
Table 6c	**Fertilizer use vis-à-vis start-of-season maize stocks and livestock (IHS3)**			
Mzst	1.155*** (0.155)		0.862*** (0.126)	
Lvst	48.90*** (9.973)		39.25*** (6.954)	
mzst (0/1)		27.67*** (3.781)		21.66*** (2.896)
lvst (0/1)		23.98*** (3.691)		17.55*** (2.823)
d(ea)	yes	Yes	yes	yes
pseudo R^2	0.0627	0.0631	0.0652	0.0655
Observations	9325	9325	9573	9573
Table 6d	**Fertilizer use vis-à-vis start-of-season maize stocks and livestock (IHPS)**			
Mzst	0.203*** (0.070)		0.171*** (0.051)	
Lvst	44.03** (22.17)		47.57*** (14.59)	
mzst (0/1)		14.58*** (5.574)		12.71** (3.965)
lvst (0/1)		11.42** (5.698)		9.528** (3.996)
d(hh)	yes	Yes	yes	yes
d(sy)	yes	Yes	yes	yes
pseudo R^2	0.1377	0.1376	0.1461	0.1457
Observations	3600	3600	3571	3571

Note: *fertilizer use* is the maximum kg use of inorganic fertilizer per household per acre, where the maximum is taken over all household plots. *Fertilizeruse** is the average per acre per household fertilizer use. *Mzst* and *lvst* are resp. per household member start-of-period maize stocks and start-of-period livestock. All estimations include household size, household crop area and interactions of household characteristics (age x educational attainment x sex, all of the household head). Equations are estimated using TOBIT (1-4). Standard errors in brackets are clustered by enumeration area (IHS-3 to IHS-5) and by household (IHPS).

Table 7a Market participation vis-à-vis start-of-season maize stocks and livestock (IHS5)

Dependent variable:	(1) market sales share	(2) market sales share	(3) cash crop area phhm	(4) cash crop area phhm
mzst[1]	0.065*** (0.021)		0.029*** (0.010)	
Lvst	0.221*** (0.032)		0.208*** (0.030)	
mzst (0/1)		0.051*** (0.011)		0.033*** (0.006)
lvst (0/1)		0.090*** (0.011)		0.062*** (0.006)
d(ea)	yes	Yes	yes	Yes
pseudo R^2	0.2710	0.2726	0.7830	0.7637
Observations	8544	8544	8658	8658

Table 7b Market participation vis-à-vis start-of-season maize stocks and livestock (IHS4)

mzst[1]	0.063*** (0.021)		0.053*** (0.012)	
Lvst	0.182*** (0.029)		0.206*** (0.046)	
mzst (0/1)		0.040*** (0.011)		0.032*** (0.007)
lvst (0/1)		0.093*** (0.011)		0.069*** (0.008)
d(ea)	yes	Yes	yes	yes
pseudo R^2	0.2638	0.2669	0.5222	0.5146
Observations	9302	9302	9380	9380

Table 7c Market participation vis-à-vis start-of-season maize stocks and livestock (IHS3)

mzst[1]	0.406*** (0.059)		0.122*** (0.025)	
Lvst	0.283*** (0.038)		0.161*** (0.028)	
mzst (0/1)		0.084*** (0.013)		0.028*** (0.007)
lvst (0/1)		0.149*** (0.013)		0.066*** (0.007)
d(ea)	yes	Yes	yes	yes
pseudo R^2	0.2652	0.2689	0.5887	0.5920
Observations	9600	9600	9709	9709

Table 7d Market participation vis-à-vis start-of-season maize stocks and livestock (IHPS)

mzst[1]	0.048** (0.024)		0.029*** (0.008)	
Lvst	0.191** (0.081)		0.072** (0.032)	
mzst (0/1)		0.032* (0.019)		0.017*** (0.006)
lvst (0/1)		0.038** (0.019)		0.021*** (0.006)
d(hh)	yes	Yes	yes	yes
d(sy)	yes	Yes	yes	yes
pseudo R^2	0.7933	0.7920	(3.788)[2]	(3.789)[2]
Observations	3381	3381	3442	3442

Note: *Cash crop share* is the share of markets sales of all crops in the total value of the harvested crop. *Cash crop area phhm* is household crop area per household member that is not cultivated with maize and not left fallow *Mzst*, and *lvst* are resp. per household member start-of-period maize stocks and start-of-period livestock. All estimations include household size, household crop area and interactions of household characteristics (age x educational attainment x sex, all of the household head). Equations are estimated using TOBIT (1,4), with lower and upper limit [0, 1] in (1,2) and a lower limit [0] in (3,4). Standard errors in brackets are clustered by enumeration area (IHS-3 to IHS-5) and by household (IHPS).

1) The units of maize stocks are expressed in 100kg, to keep the number of decimals manageable. 2) The pseudo R^2 is calculated as ($1-LL_x/LL_0$) and with a continuous dependent variable may have values above 1.

Overall the estimations support a strong positive and statistically significant correlation between fertilizer use, the share of commercial sales and cash crop area on the one hand, and, start-of-season maize stocks and start-of-season livestock on the other hand. The size of the coefficients tends to be similar for maize stocks and livestock. The results are suggestive of the impact of stocks on technology adoption and market participation.

6. Discussion

Prior to taking the estimations to the policy arena, an assessment of the results is needed. The objective of this research is to find empirical support for the mechanism that savings in the form of maize stocks and livestock promote technology adoption and market participation in sub-Sahara agriculture. Do the presented estimations offer this support? Both explanatory stock variables are pre-determined start-of-season variables and, hence, not the outcome of running season agricultural decisions. In other words, jointly with the evidence underlying the assumptions of the conceptual framework, the applied specification is a useful attempt at quantifying an *interesting correlation* between savings and technology adoption / market participation. However, the answer to the 'support' question can unfortunately not be fully affirmative. Rigorous inference of causal behavioural responses in agriculture on the basis of observational household survey data is difficult. A randomized intervention creating households with and without stocks is needed to infer causality. However, such a design is difficult to envisage in real world agriculture. Experimental designs also tend to consider a single cause and overlook interdependencies. Consequently, natural experiments and the current explorations appear to be workable alternatives.

In the explorations we did not take account of prices and policies, which we briefly discuss below. Prices of food vary in a regular way over the season and this variation is extreme in developing countries (Gilbert et al., 2017). How does seasonality in prices affect household behaviour, in particular with respect to technology adoption and market participation? A well-known response to price risk is to reduce sales or purchases from the market and increase subsistence farming (Fafchamp, 1992). Further, marketing behaviour of households is known to have a specific characteristic: sales are commonly concentrated in low price periods and purchases in high price periods. The typical ‘sell low and buy high’ behaviour of households (Burke et al. 2019) expresses that households are severely liquidity constrained and unable to benefit from potential arbitrage opportunities. Given that the food value of resources (like off-farm wage and most savings) decrease during the ‘high price’ lean season, seasonality in prices will further tighten the budget constraint. Hence, intuitively seasonal price fluctuation add an additional burden to the resource requirements that households face. A more rigorous treatment of the role of prices over the season awaits further research.

Fertilizer use in Malawi is supported through the Fertilizer Input Subsidy Program since 2005 (till 2019, followed by the Affordable Inputs Program (AIP)), and with varying intensities. FISP is shown to have impacted on fertilizer use and crop production (Jayne and Rashid, 2013; Jayne et al, 2016, 2018). However, fertilizer subsidies do not take away risk of drought, insufficient rains or other climatic hazards like flooding. At the household level input subsidies may relax the budget constraints. But it is unclear if these input subsidies have long run impacts on cultivation practices and savings, and lift farm households to higher welfare. Input subsidies do not necessarily capitalize on the strengths and qualities of households in their agricultural production. For well-performing farmers the subsidy is a nice benefit that is easily incorporated in existing practices: it will boost their production and savings, and their investment in future years. Poor performing farmers, however, who lack sufficient savings to work on their home plot, will not be able to supply the complementary labour and other inputs for fertilizer use: if they qualify for input subsidies, they will purchase the discounted fertilizer, re-sell it on the market and cash the subsidy. Only a few of these farmers will be in the position and triggered by the subsidy to step up production levels and increase savings. Again, more work is needed to reveal how FISP interacts with informal savings.

Taking the estimation results as evidence of the behavioural effect of stocks on technology adoption and market participation, leads to interesting policy implications. Apparently the incentive for farm households to use fertilizer, to switch crop cultivation to cash crops and to sell on the market, at least partly runs through adequate start-of-season maize stocks and start-of-season livestock. Policies aiming at improving productivity in agriculture and increasing incomes of farm households do a good job if they contain strategies that help, trigger or promote stock formation at the household level. Several alternatives qualify for this purpose: a major technique would be to subsidize modern and effective storage equipment (notably hermetic storage bags), both for individual household as well as for farmer groups. Such policies have experienced increased interest recently, but mainly in order to address alleged waste (Basu and Wong, 2015; Ricker-Gilbert and Jones, 2015; Omotilewa et al., 2018; Tesfaye and Tirivayi, 2018; Aggarwal et al., 2018; Brander et al., 2021). The estimations in the current work provide a broader justification for promoting food storage. The promotion of livestock and cattle breeding through the creation of farmers' organisations for dairy production and marketing infrastructure for trade in livestock could be an effective complementary policy. Livestock has the advantage of being widespread and reasonably stable over time[19], but has the disadvantage of losing value during food shortages (Zant, 2022). The last issue demands a timely marketing strategy where livestock (saving) is sold in exchange for food stocks (savings) directly after harvest when staple foods are cheapest and potential arbitrage returns are largest. Such a strategy makes an attractive alternative to the wide-spread selling-low and buying high behaviour of households.

[19] Maize stocks are much more sensitive to weather than livestock, which is confirmed by average size and, especially, the share of households with positive stocks (Table 1). This sensitivity is further confirmed if start-of-season and end-of-season maize stocks and livestock are compared (not shown).

7. Summary and conclusion

Like all farmers in the world, farmers in sub-Sahara Africa, are interested to increase income, or, in other words, to increase the marginal value product of their labour. Realizing a higher marginal value product of labour can potentially be achieved by increased technology adoption and increased market participation. Simultaneously, farmers deal with strong seasonality in income and high production risk due to drought by saving in food stocks and livestock. In this paper we explore empirically the relationship between technology adoption and market participation on the one hand and savings in the form of stocks of staple food and livestock on the other hand, on the basis of three rounds of LSMS-ISA cross section household surveys for Malawi (IHS-3, IHS-4 and IHS-5), and a panel version of these data (IHPS). Assumptions underlying a simple intertemporal model of developing country agriculture are well supported by these survey data. In the estimations we find statistically significant positive effects of maize stocks and livestock on fertilizer use, the share of sales in production, and the cash crop area per household member. Outcomes suggest an important role for policy to promote informal savings at the household level in the form of livestock or food stocks. Policies could be directed towards individual households or groups of households. Policies framed and channelled through farmers' organisations, cooperatives or village level organisations of direct stakeholders, are likely to create increased savings' commitment. Apart from enhancing technology adoption and market participation through increased savings, farm households additionally benefit from both higher selling prices for food jointly with more stabilised food prices due to general equilibrium impacts.

References

Aggarwal, S., 2018, ‘Do rural roads create pathways out of poverty? Evidence from India.’, *Journal of Development Economics*, 133, 375-395.

Aggarwal, S., B. Giera, D. Jeong, J. Robinson and A. Spearot , 2018, ‘Market Access, Trade Costs, and Technology Adoption: Evidence from Northern Tanzania’, NBER, wp 25253

Aggarwal, S., E. Francis and J. Robinson, 2018, ‘Grain Today, Gain Tomorrow: Evidence from A Storage Experiment with Savings clubs in Kenya’, *Journal of Development Economics*, 134, 1-15.

Ahmed, S., C. McIntosh and A. Sarris, 2020, ‘The Impact of Commercial Rainfall Index Insurance: Experimental Evidence from Ethiopia’, *American Journal of Agricultural Economics,* 102, 4, 1154-1176.

Aker, J.C., 2010, ‘Information for Markets Near and Far: Mobile Phones and Agricultural Markets in Niger’, *American Economic Journal: Applied Economics*, 2, 3, 46-59.

Aker, J.C. and M. Fafchamps, 2014, ‘Mobile Phone Coverage and Producer Markets: Evidence from West Africa’, *The World Bank Economic Review,* 29, 2, 262–292.

Allen, T., 2014, ‘Information Frictions in Trade’, *Econometrica*, 82, 6, 2043-2086.

Asher and Novosad, 2020, ‘Rural Roads and Local Economic Development’, *American Economic Review*, 110, 3, 797-823.

Atkin, D. and D. Donaldson, 2015, ‘Who’s Getting Globalized? The Size and Implications of Intra-national Trade Costs’, NBER, wp 21439.

Basu, K and M.Wong, 2015, ‘Evaluating Seasonal Food Storage and Credit Programs in East Indonesia’, *Journal of Development Economics*, 115, 200-216.

Bold, T, K.C. Kaizzi, J. Svensson, D. Yanagizawa-Drott, 2017, 'Lemon Technologies and Adoption: Measurement, Theory and Evidence from Agricultural Markets in Uganda', *The Quarterly Journal of Economics*, 132, 3, 1055–1100.

Bold, T, S. Ghisolfi, F. Nsonzi and J. Svensson, 2022, ‘Market Access and Quality Upgrading: Evidence from Four Field Experiments’, *American Economic Review,* 112, 8, 2518–2552

Brander, M., T. Bernauer and M. Huss, 2021, ‘Improved On-Farm Storage reduces Seasonal Food Insecurity of Smallholder Farmer Households – Evidence form a Randomized Controlled Trial in Tanzania’, *Food Policy*, 98.

Burke, M., L. Falcao Bergquist and E. Miguel, 2019, ‘Sell Low and Buy High: Arbitrage and Local Price Effects in Kenyan Markets’, *The Quarterly Journal of Economics,* 134, 2, 785-842.

Bridle, L., J. Magruder, C. McIntosh and T. Suri, 2019, ‘Experimental Insights on the Constraints to Agricultural Technology Adoption’, Agricultural Technology Adoption Initiative (ATAI), Abdul Latif Jameel Poverty Action Lab (J-PAL, MIT) and Center for Effective Global Action (CEGA, UC Berkeley), working paper.

Brune, L., X. Giné, J. Goldberg and D. Yang, 2016, ‘Facilitating Savings for Agriculture: Field Experimental Evidence from Malawi’, *Economic Development and Cultural Change*, 64, 2, 187-220.

Casaburi, L., Glennerster R. and T. Suri, 2013, ‘Rural Roads and Intermediated Trade: Regression Discontinuity Evidence from Sierra Leone’, mimeo.

Cole, S., X. Giné, J. Tobacman, P. Topalova, R. Townsend and J. Vickery, 2013, ‘Barriers to Household Risk Management: Evidence from India’, *American Economic Journal: Applied Economics*, 5, 1, 104–135.

Conley, T. G. and C. Udry, 2003, ‘Social learning through networks: The adoption of new agricultural technologies in Ghana’, *American Journal of Agricultural Economics*, 83, 668-673.

Dercon, S., 2004, ‘Growth and Shocks: Evidence from Rural Ethiopia’, *Journal of Development Economics* **74,** 2, 309-329.

Dercon, S., 2005, *Insurance against poverty*, Oxford University Press.

Dercon, S., Vargas Hill, R., Clarke, D., Outes-Leona, I., and Taffesse, A.S., 2014, ‘Offering rainfall insurance to informal insurance groups: Evidence from a field experiment in Ethiopia’, *Journal of Development Economics*, 106, 132–143.

Devallade, C. and S. Godlonton, 2023, ‘Locking Crops to Unlock Investment: Experimental Evidence on Warrantage in Burkina Faso’, *Journal of Development Economics*, 160, xxx-xxx.

Duflo, E., M. Kremer and J. Robinson, 2008, ‘How High Are Rates of Return to Fertilizer? Evidence from Field Experiments in Kenya’, *American Economic Review: Papers & Proceedings*, 98, 2, 482–488.

Duflo, E., M. Kremer and J. Robinson, 2011, ‘Nudging Farmers to Use Fertilizer: Theory and Experimental Evidence from Kenya’, *American Economic Review*, 101, 2350–2390.

Dupas, P., Karlan, D. Robinson, J. and Ubfal, D., 2018, Banking the Unbanked? Evidence from Three Countries. *American Economic Journal: Applied Economics*, 10(2), 257-` 297.

FAO, 2011, Guidelines for the preparation of livestock sector reviews, Animal Production and Health Guidelines. No. 5, Rome’.

Fafchamps, M., 1992., ‘Cash Crop Production, Food Price Volatility, and Rural Market Integration in the Third World’, American Journal of Agricultural Economics, 74, 1, 90-99.

Fafchamps, M. and B. Minten, 2012, ‘Impact of SMS-Based Agricultural Information on Indian Farmers’, *The World Bank Economic Review,* 27, February, 1-32.

Fink, G., B.K. Jack and F. Masiye, 2014, ‘Seasonal Credit Constraints and Agricultural

Labour Supply: Evidence from Zambia', NBER, wp 20218.

Foltz, J.D., U.T.Aldana and P.Laris, 2012, 'The sahel's silent maize revolution: analyzing maize productivity in Mali at the farm-level, NBER, wp 17801

Foster, A.D. and M.R. Rosenzweig, 2017, 'Are There Too Many Farms In The World? Labor-Market Transaction Costs, Machine Capacities And Optimal Farm Size', NBER, wp 23909.

Gilbert, C.L., L. Christiaensen and J. Kaminski, 2017, 'Food Price Seasonality in Africa: measurement and extent', *Food Policy*, 67, 119-132.

Giné, X., R. Townsend, and J. Vickery, 2008, 'Patterns of Rainfall Insurance Participation in Rural India', *World Bank Economic Review*, 22, 3, 539-566.

Giné, X. and D. Yang, 2009, 'Insurance, Credit, and Technology Adoption: Field Experimental Evidence from Malawi', *Journal of Development Economics*, 89, 1-11.

Hörner, D. A.Bouguen, M.Frölich, and M.Wollni, 2022, 'Knowledge and Adoption of Complex Agricultural Technologies: Evidence from an Extension Experiment', *The World Bank Economic Review*, 36, 1, 68–90.

Jack, B.K., 2013, 'Constraints on the Adoption of Agricultural Technologies in Developing Countries', Agricultural Technology Adoption Initiative (ATAI), Abdul Latif Jameel Poverty Action Lab (J-PAL, MIT) and Center for Effective Global Action (CEGA, UC` Berkeley), literature review.

Jayne, T. and S. Rashid, 2013, 'Input subsidy programs in sub-Saharan Africa: a synthesis of recent evidence', *Agricultural Economics*, 44. 547-562.

Jayne, T, N.M. Mason, W.J. Burke and J. Ariga, 2016, 'Agricultural Input Subsidy Programs in Africa: An Assessment of Recent Evidence', MSU International Development wp 145.

Jayne, T, N.M. Mason, W.J. Burke and J. Ariga, 2018, 'Review: Taking stock of Africa's second-generation agricultural input subsidy programs', *Food Policy*, 75, 1-14.

Jensen, N.D., C.B. Barrett, A.G. Mude, 2016, 'Index Insurance Quality and Basis Risk: Evidence from Northern Kenya', *American Journal of Agricultural Economics*, 98, 5, 1450-1469.

Kazianga, H. and Udry, C., 2006, 'Consumption smoothing? Livestock, insurance and drought In rural Burkina Faso', *Journal of Development Economics*, 79, 2, 413-446.

Karlan, D., R. Osei, I. Osei-Akoto and C. Udry, 2014, 'Agricultural Decisions after Relaxing Credit and Risk Constraints', *Quarterly Journal of Economics*, 129, 2, 597-652.

Key, N., E.Sadoulet and A. de Janvry, 2000, 'Transactions Costs and Agricultural Household Supply Response', *American Journal of Agricultural Economics*, 82, May, 245-259.

Magruder, J., 2018, 'An Assessment of Experimental Evidence on Agricultural Technology Adoption in Developing Countries', Annual Review of Resource Economics, 10, 299-316.

Mahul, O., and Stutley, C.J., 2010, *Government Support to Agricultural Insurance: Challenges and Options for Developing Countries,* World Bank, World Bank Publications.

Matsumoto, T and T. Yamano, 2009, 'Soil Fertility, Fertilizer, and the Maize Green Revolution in East Africa', *The World Bank*, PRWP 5158.

Michelson, H., A. Fairbairn, B. Ellison, A. Maertens and V. Manyong, 2021, 'Misperceived quality: Fertilizer in Tanzania', Journal of Development Economics 148.

Minten, B. and S. Kyle, 1999, 'The effect of Distance and Road Quality on Food Collection, Marketing Margins, and Traders' Wages: Evidence from the Former Zaire', *Journal of Development Economics*, 60, 467-495.

Miranda, M. J., and Farrin, K., 2012, 'Index Insurance for Developing Countries', *Applied Economic Perspectives and Policy*, 343, 391– 427.

Naeher, D. and M. Schündeln, 2022, 'The Demand for Advice: Theory and Empirical Evidence from Farmers in Sub-Saharan Africa', *The World Bank Economic Review*, 36, 1, 2022, 91–113.

Omamo, S.W., 1998, 'Transport Costs and Smallholder Cropping Choices: An Application to Siaya District, Kenya', *American Journal of Agricultural Economics*, 80, 116-123.

Omotilewa, O.J., J. Ricker-Gilbert, J.H. Ainembabazi and G. Shively, 2018, 'Does improved storage technology promote modern input use and food security? Evidence from a randomized trial in Uganda, *Journal of Development Economics*, 135, 196-198.

Renkow, M., D.G. Hallstrom and D.D. Karanja, 2004, 'Rural infrastructure, transactions costs and market participation in Kenya', *Journal of Development Economics*, 73, 349-367.

Ricker-Gilbert, J. and M. Jones, 2015, 'Does Storage Technology affect Adoption of Improved Maize Varieties in Africa? Insights from Malawi's Input Subsidy Program, *Food Policy*, 50, 92-105.

Sotelo, S., 2020, 'Domestic Trade Frictions and Agriculture', *Journal of Political Economy*, 128, 7, 2690-2738.

Suri, T, 2011, 'Selection and comparative advantage in technology adoption', *Econometrica*, 79, 1, 159-209.

Suri, T and C. Udry, 2022, 'Agricultural Technology in Africa', *Journal of Economic Perspectives*, 36, 1, 33-56.

Tesfaye, W. and N. Tirivayi, 2018, 'The impacts of postharvest storage innovations on food security and welfare in Ethiopia', *Food Policy*, 75, 52-67.

Zant, 2022, 'How Costly is using Livestock as a Savings Device?', *Food Security*, (forthcoming).

Appendix

Table A1 Stocks and crop area versus off-farm wage (IHS 3, 4, 5)

off-farm wage from ganyu labour	IHS-3 (2010)	IHS-4 (2016)	IHS-5 (2019)
livestock with off-farm wage > 0	0.042 (0.002)	0.040 (0.002)	0.047 (0.002)
livestock with off-farm wage = 0	0.079 (0.003)	0.097 (0.006)	0.121 (0.007)
F-test (p-value)	88.64 (0.0000)	79.37 (0.0000)	93.49 (0.0000)
maize stocks with off-farm wage > 0	69.32 (0.279)	14.09 (0.366)	18.04 (0.387)
maize stocks with off-farm wage = 0	76.60 (0.209)	22.81 (0.540)	21.65 (0.561)
F-test (p-value)	438.0 (0.0000)	178.9 (0.0000)	28.06 (0.0000)
crop area with off-farm wage > 0	0.399 (0.006)	0.359 (0.005)	0.369 (0.005)
crop area with off-farm wage = 0	0.484 (0.007)	0.452 (0.009)	0.524 (0.013)
F-test (p-value)	85.63 (0.0000)	78.19 (0.0000)	125.5 (0.0000)
off-farm wage from wage employment			
livestock with off-farm wage > 0	0.048 (0.004)	0.053 (0.006)	0.064 (0.006)
livestock with off-farm wage = 0	0.065 (0.002)	0.060 (0.003)	0.066 (0.003)
F-test (p-value)	15.15 (0.0001)	1.08 (0.2990)	0.15 (0.6983)
maize stocks with off-farm wage > 0	76.38 (0.363)	27.43 (1.000)	21.33 (0.787)
maize stocks with off-farm wage = 0	72.56 (0.198)	15.70 (0.318)	18.58 (0.352)
F-test (p-value)	85.22 (0.0000)	124.8 (0.0000)	10.20 (0.0014)
crop area with off-farm wage > 0	0.350 (0.009)	0.318 (0.012)	0.346 (0.012)
crop area with off-farm wage = 0	0.463 (0.005)	0.400 (0.005)	0.418 (0.006)
F-test (p-value)	110.41 (0.0000)	41.76 (0.0000)	29.85 (0.0000)
Off-farm wage from self-employment			
livestock with off-farm wage > 0		0.068 (0.005)	0.072 (0.004)
livestock with off-farm wage = 0		0.057 (0.003)	0.064 (0.003)
F-test (p-value)		3.86 (0.0496)	2.32 (0.1278)
maize stocks with off-farm wage > 0		20.63 (0.733)	21.23 (0.615)
maize stocks with off-farm wage = 0		16.20 (0.338)	18.14 (0.377)
F-test (p-value)		30.15 (0.0000)	18.34 (0.0000)
crop area with off-farm wage > 0		0.347 (0.010)	0.389 (0.010)
crop area with off-farm wage = 0		0.401 (0.005)	0.415 (0.006)
F-test (p-value)		23.67 (0.0000)	5.02 (0.0251)

Note: The table shows weighted mean values with standard errors in brackets. Livestock is in tropical livestock units and maize stocks in kgs, both measured at the start of the period and per household member. Crop area is in acres per household member.