Technology Adoption and Market Participation through Household Savings for Food Security: Two Birds with One Stone?

Wouter Zant and Bart van den Boom*

Abstract

Most agriculture in sub-Sahara Africa is rainfed and the key production risk is crop failure due to drought or insufficient rains. Additionally, agricultural production and income follows a strong and regular seasonal pattern, with virtually no income in the lean season. Farm households protect themselves against crop failure and seasonal income shortages through savings in the form of food stocks, livestock and cash. In this paper we develop and test an inter-seasonal model of farm households for whom hiring labour is rare and obtaining a consumptive loan is impossible. The framework describes how accumulated household savings for food security improve productivity and create funding for investment in inputs and commercial crops, and thereby supports technology adoption and market participation. On the basis of Malawi LSMS-ISA household survey data (pooled cross-sections and panel) we explore these mechanisms and we find significant positive impacts of savings on technology adoption and market participation. Results suggest that supporting food storage, livestock rearing and cash savings at the household level helps to increase productivity in agriculture.

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

JEL code: O13, O15, O16, O18, O33, Q11, Q12, Q16, R23

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1. Introduction

Agriculture in sub-Sahara Africa is mainly rainfed and the dominant risk is a lack of rainfall or drought resulting in crop failure. Dependence on rainfall also leads to large fluctuations in farmer revenues over the season, and crop prices show a distinct regular seasonal pattern (Gilbert et al., 2017; Zant, 2023). Farm households protect themselves against crop failures and seasonal income fluctuations through several forms of informal savings, mainly food stocks, livestock and cash. 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). Next to these risks, sub-Sahara agriculture is characterized by notoriously low levels of productivity, associated with low levels of technology (fertilizer use, use of high-yielding varieties and mechanization), and dominated by subsistence farming and limited market participation. The literature on technology adoption and market participation is vast and identifies a multitude of causes, including the abovementioned risks associated with rainfed crop production and related price volatility, profitability (Duflo et al., 2008, 2011), heterogeneity (Suri, 2011), high fertilizer costs (Matsumoto and Yamano, 2009), low fertilizer quality (Bold et al, 2017; Michelson et al., 2021), limited knowledge (Hörner et al., 2022; Beaman et al., 2021), finance (Karlan et al, 2014; Mobarak and Saldanha, 2022) and high transaction costs (Renkow et al., 2004; Manda et al., 2020).

In this paper we connect these issues, arguing that informal savings increase labour input on the home crop area, increase labour productivity in agriculture, raise the use of fertilizer and high yielding seeds, and nudge farmers to grow crops to sell on the market. In other words, household savings accumulated for food security help to improve productivity and market participation, the other key problems of sub-Saharan agriculture. This claim is built up in two steps: first, by setting up and validating a conceptual model of rain-fed developing country agriculture and, second, by estimating if and to what extent start-of-season savings encourage technology adoption and market participation. The conceptual framework reflects the basics of smallholder agriculture: it incorporates seasonality, shocks and savings, and highlights the key role of accumulated start-of-season savings in increasing the marginal product of labour. The primary mechanism that the framework identifies is that adequate savings establish food security, allow more on-farm work, make off-farm work less necessary, and make funding available for investment. Hence, savings intended to mitigate risk of crop failure and seasonality in income, impact on economic growth through choices on off-farm and on-farm labour, through availability of funding, and through investment in inputs and crop choices. Empirically, start-of-season savings and off-farm earnings are, therefore, an expression of, mostly unobserved, soil quality and talents & skills in farming, and allow to identify heterogeneity of farmers and to distinguish (less) successful and economically (less) viable agriculture. Next to validating the conceptual framework, we estimate empirically how technology adoption, in the form of the use of fertilizer, and share of market sales in total production value are affected by start-of-season savings. Both model verification and estimations are based on LSMS-ISA household survey data for Malawi, (pooled cross sections (2010, 2016, 2019) and panel (2010-2013-2016)). Malawi is a good case study for this purpose since the larger part of the population is engaged in agriculture, since agriculture is nearly fully rainfed and suffers from occasional droughts, since there is a strong seasonality in agricultural income, since credit for consumption is negligible, since most agricultural households are subsistence households that practice low input, low productivity agriculture and since the incidence of poverty, especially in rural areas, is high.

We make two contributions: first we show that the assumptions underlying a stylized model of developing country agriculture with seasonality and weather shocks and with informal savings jointly with frictions on the labour and capital market are well supported by the empirical evidence. The model highlights the key role of start-of-season savings: unlike other research, like Fink et al. (2020) who argue that "informal (savings) alternatives are low-return", we claim that the internal rate of return of informal household savings is large[1] and that household savings are informative about the economic viability of household agriculture. The ordering of coping strategies (start-of-season savings versus ganyu labour), that follows from the conceptual model, is also well supported by the empirical evidence. Secondly, we provide empirical evidence that technology adoption and market participation are positively correlated with start-of-season savings (maize stocks, livestock and cash). We find a generic impact of start-of-season savings on fertilizer use and market participation that is modest, yet positive and statistically significant.

The rest of this paper is organized as follows. In Section 2 we summarize the literature and position this paper. In Section 3 we propose a stylized conceptual framework. In Section 4 we document data and data sources, and explain construction of variables. In Section 5 we verify the model assumptions and explore the model implications. In Section 6 we formulate our empirical strategy. In Section 7 we present and discuss estimations, followed by an exploration of heterogeneity in impacts in Section 8. In Section 9 we indicate policy implications, caveats of this research and summarize our results.

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

From the introduction it follows that we consider three major problems of developing country agriculture, associated with three strands of literature: literature on risk, (informal) savings, insurance and credit, literature on technology adoption, and literature on market participation

[1] When the return on holding maize stocks is approximated with the within-season arbitrage returns on maize prices, returns can be well above 100%, even in a regular season.

and market access. A rigorous review is beyond the scope of this paper[2]: we briefly discuss elements of these literatures that are relevant to our investigation.

Risk, informal savings, insurance and credit

Among development economists there is consensus that risk tends to move farm households into risk spreading and growing less risky, low input – low return crops for home consumption, rather than investing in more risky technologies and growing cash-crops to sell on the market, where prices are uncertain. Adequate insurance packages are therefore believed to support technology adoption and market participation. Livestock, storage of produced crops, cash savings and mutual insurance arrangements are the major informal risk-coping strategies of farm households. Yet, informal savings and mutual insurance arrangements can be insufficient to adequately offset risks, especially if risks are large and covariate rather than small and idiosyncratic. Alternative formal savings instruments such as savings accounts, insurance policies and credit are needed. However, such instruments are unavailable or unattractive for most households in sub-Saharan countries, even if subsidized (Dupas et al., 2015). Major reasons are extreme poverty ("too poor to save") and high transaction costs, in comparison with several alternative types of informal savings (Dupas et al., 2015). In this context index-insurance products that avoid adverse selection, moral hazard, and high monitoring & administrative costs, may potentially fill part of the gap. Unfortunately, index-insurance schemes have a poor record as well. Rainfall index insurance schemes suffer from low take-up, attributed to a 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

[2] Useful literature reviews on risk are: Dercon, 2004, 2005; Mahul and Stutley, 2010; Miranda and Farrin, 2012; on technology adoption: Jack, 2013; Magruder, 2018; Bridle et al., 2019; Suri and Udry, 2022; and on market access and market participation: Barrett, 2008 and Chamberlain et al. 2013.

credit (Giné and Yang, 2009; Karlan et al, 2014; Ahmed et al., 2020). The record of formal credit is less dim, but still faces severe problems due to asymmetric information, monitoring and collateral requirements. In summary, while informal coping mechanisms can be insufficient for food security and stable consumption, formal savings, insurance and credit 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.

Technology adoption

Technology adoption in developing country agriculture (use of fertilizer and high yielding seeds, mechanization) is well researched. The mostly RCT based evidence focuses on a wide range of causes of low returns and low profitability, associated with low technology adoption: 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 constraints (networks and relatives: Conley and Udry, 2003; Bandiera & Rasul, 2006; information on returns and technical knowledge: van Campenhout, 2021; extension services: Hörner et al., 2022; Naeher and 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).

Market participation

Market participation and market access are impacted 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 highlight the importance of roads: rural roads lead to lower prices, a better availability of inputs, increased use of fertilizer and improved seeds, changes in crop choice, increased sales of output, and increased enrollment of children (Aggarwal, 2018; Aggarwal et al. 2018; Sotelo, 2020; and for a contrasting view Asher and Novosad, 2020). In addition, 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 appear to have have substantial implications for prices, market efficiency and waste (Jensen, 2007; Aker, 2010; Aker and Fafchamps, 2014; Allen, 2014).

Implications for theory and empirics

The role of informal savings in risk coping, technology adoption and market participation appears to be under-researched. We therefore investigate this role 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. By the same token we investigate how risk coping strategies translate into fertilizer use (and use of high yielding varieties), and into household choices for marketable crops and selling on the market. The interrelatedness is a recommendation for a structural modeling approach, rather than zooming in on one aspect. Indeed, the literature suggests the use of an integrated framework to explore the role of various types of informal savings as risk coping strategies, on technology adoption and market participation.

Although we are not aware of similar 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, 2020; 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 such as hermetic storage bags, this research has generated new insights on direct impacts and indirect impacts of this type of informal savings (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 grain stocks on food security (Basu and Wong, 2015; Omotilewa et al. 2018; Tesfaye and Tirivayi, 2018; Brander et al., 2021). Moreover, grain storage is shown to encourage within season arbitrage and to support credit for investment (Burke et al, 2019; Aggarwal et al, 2018). For example, Devallade and Godlonton (2023) investigate the impact of 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. Another example is to address seasonal liquidity through subsidized loans. Fink et al. (2014, 2020) show that high credit costs may force farmers 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) lead to a reallocation of labor from off-farm to on-farm, to increases in local wages and to improvements in food security. Overall these investigations seek opportunities against the background of shocks and seasonality, and consider options to relax constraints of farm households.

3. Conceptual framework for smallholder farmers

In this section we develop a dynamic model to describe consumption-production patterns of smallholder farmers in SSA. The point of departure is the maximization of lifetime utility under an inter-seasonal budget constraint, where we assume that both the capital and the labor market are incomplete (LaFave and Thomas, 2016; Fink et al., 2020). Our model considers two frictions that are common to farmers in SSA: labor market frictions and capital market frictions. First, household crop production is typically constrained by household labor. Hiring workers from outside the household is uncommon: it is expensive due to transaction costs, inefficient due to monitoring costs (Foster and Rosenzweig, 2017, 2022) and burdensome since liquidity constrained households need to pay wages before the harvest. A second friction concerns the capital market. Borrowing for consumption during the regular hungry season or after a crop failure is uncommon as farmers lack collateral, and interest rates on loans for consumption are either prohibitively high or such loans are simply not available. Consequently, household food consumption is typically constrained by own accumulated savings.

Labor market frictions make on-farm productivity higher compared to off-farm wages. On-farm household labor will enjoy a wage premium above the off-farm wage. The wage premium is uncertain though, because it only manifests itself at the time of the harvest. After a season with regular rains and a good harvest, the wage premium is positive and even more positive when there is a bumper crop. Good seasons help farmers to accumulate savings in the form of food stocks, livestock or cash, which increases next season food security, helps to capture next season wage premium and contributes to cover next season fertilizer expenditure.

However, in case of a crop failure, the wage premium disappears as efforts during the growing season render nil, fertilizer applied is wasted and on-farm productivity is negligible.

Next, the absence of opportunities to borrow during the hungry season or after a crop failure imply that farmers must rely on their own production and their own savings retained from the previous season to smooth consumption, both within a season, and from one season to another. Therefore, they will try to avoid the risk of depleting their accumulated savings, even when replenishment with future harvests can be expected.[3] Likewise, the lack of borrowing opportunities to supplement depleted savings adversely affects the purchase of current season fertilizer and opportunities to capture the wage premium.

Formally, let T denote the number of seasons during the farmer's lifetime or time horizon with each season $t = 1,2, \ldots, T$ starting immediately after the previous harvest, lasting throughout the growing season, and ending with the harvest. The farmer cultivates $\overline{A}$ acres of land and there are $\overline{l}$ workers in the household.[4] In order to survive, the main concern of the farmer is to avoid consumption below a certain subsistence minimum $\underline{c}$, where consumption is measured in kilograms per season per household.[5]

The farmer's preferences are represented by the sum of utilities over all seasons, where utility is the logarithm of consumption relative to subsistence and future utilities are discounted at rate $\rho \leq 1$:[6]

$$U = \sum_{t=1}^{T} \rho^{t-1} \, log\left(\frac{c_t}{\underline{c}}\right) \tag{1}$$

[3] Note that, if farmers can indeed replenish accumulated savings in the future, borrowing from a complete capital market could take away some of the concerns of depletion of savings.

[4] For example, a typical farmer cultivates about 2 acres with 4 family workers.

[5] When farmers, in line with the UN health guidelines, try to make sure that workers consume no less than 1800 Kcal per person per day, the equivalent of around 500 grammes of maize, and some consumption requirements of the dependents are added, subsistence consumption of the typical farm with 4 family workers would be in the order of magnitude of 800 kg of maize, or the equivalent thereof. This is also in line with annual maize consumption requirements in the SSA context (Jayne et al. (2010), Finke et al. (2020)).

[6] The logarithmic utility was first proposed by Bernoulli (1954) and exhibits decreasing marginal utility and diminishing risk aversion. Discount rate ρ could be 0.95, for example, implying a discounting factor of 0.63 in season 10.

One may note that utility is zero when the farmer is precisely consuming at subsistence $c_t = \underline{c}$, while utility becomes negative below subsistence and positive above subsistence[7]. Moreover, marginal utility of consumption equals $\underline{c}/c_t$ and equals one at subsistence, increases sharply as consumption approaches zero and gradually decreases as consumption is well above subsistence.

Next, we consider how the farmer can get an income to support the best possible consumption path. Farmers earn income from labor: they allocate time of household workers, either to on-farm work or off-farm work, denoted respectively with l_t and l_t^o. Total household labor is fixed by the number of household workers: $l_t + l_t^o \leq \bar{l}$. On-farm agricultural work is the main activity and renders a harvest at the end of the season. As regards technology, we assume that the production depends on household labor used l_t and fertilizer F_t applied, according to a standard constant-returns-to-scale Cobb-Douglas production function. The area harvested is denoted A_t and, in a season with sufficient rainfall for a good harvest, $A_t = \overline{A}$, meaning that the harvested area equals the farm size. A crop failure is modelled as a harvested area lower than the farm size, or even zero in case of a total crop failure. We will assume that in such cases there is still a small arbitrary small area harvested. Accordingly, production is:

$$q_t = (A_t/\overline{A})\, \beta\, {l_t}^{(1-\alpha)}\, {F_t}^{\alpha} \qquad (2)$$

Where q_t is current season production, $0 < A_t \leq \overline{A}$, $0 < \alpha < 1$ is the fertilizer share and $\beta > 0$ is a scale factor on farm productivity.[8] Gross income from previous season's agricultural production minus the cost of applying fertilizer in the current season ($p\, q_{t-1} - p^F F_t$) constitute the resources available in the current season. Note that each season starts after the

[7] Our way of dealing with subsistence consumption differs from the utility function $u(c_t) = log(c_t - \underline{c})$, after Stone (1954). The latter cannot deal with consumption falling at or below subsistence, while our specification $u(c_t) = log\left(\frac{c_t}{\underline{c}}\right)$ can. Hence, it is more apt to describe situations of food shortages.

[8] For example, at reference yield of 600 kg, 2 family workers and 60 kg of fertilizer per acre and at prices in the order of magnitude of p = 0.75\$ = 750MWK per kg of maize and p^F = 1.5\$ = 1500MWK per kg of fertilizer, the yield function parameters could take values $\alpha \approx 0.2$ and $\beta \approx 152$.

harvest of the previous season and ends with the next harvest. Hence, the fertilizer must be paid for in advance, while the crop produced only becomes available in the next season.

The production function incorporates household labor and fertilizer as major inputs for maize farmers in SSA and ignores hired labor. Smallholder farmers rarely hire labor. They do participate in local labor markets though, by working for others after a season with crop failure and by offering their labor during the hungry season prior to the harvest.[9] The off-farm work is assumed to have a constant marginal labor productivity that is reflected in a positive, yet generally low wage rate $w^o > 0$.[10] The off-farm labor renders an additional income in the current season, which, together with the above farm income, makes up the total resources denoted y_t:

$$y_t = p\ q_{t-1} - p^F F_t + w^o\ l_t^0 \tag{3}$$

The farmer can spend all resources and consume $p\, c_t = y_t$ accordingly. Added to this, the farmer may want or need to tap from start-of-season savings, if any, denoted $s_t \geq 0$. Conversely and more importantly, the farmer may desire to economize on consumption, replenish and / or accumulate savings and thereby securing end-of-season savings $s_{t+1} \geq 0$ for future use. Accordingly, the farmer's options to consume are governed by the budget constraint:

$$p\, c_t + s_{t+1} \leq y_t + s_t \tag{4}$$

In summary, our model describes a farmer who chooses a production and consumption path that maximizes the lifetime utility subject to a time allocation constraint that reflects dependency on household labor (labor market friction) and a budget constraint that reflects dependency on household savings (capital market friction). The full model is as follows:

[9] In the Malawi household data, smallholders indeed rarely hire work and many supply 'ganyu' labor, while large farmers do hire labor and do not need 'ganyu' earnings. (See Fink et al. 2020 for a discussion on rural labor markets in Zambia)

[10] An order of magnitude could be w° ≈ 150$ for an entire season, just sufficient to survive at maize price p ≈ 0.75$ and consumption requirement 200 kg.

$$maximize \qquad \sum_{t=1}^{T} \rho^{t-1} \log\left(\frac{c_t}{\underline{c}}\right) \tag{5}$$

$(c_t, l_t, F_t, l_t^0, s_{t+1}) \geq 0$

subject to

$l_t + l_t^o \leq \bar{l} \qquad (\mu_t)$

$p\, c_t + s_{t+1} \leq y_t + s_t \qquad (\lambda_t)$

$y_t = p\, q_{t-1} - p^F F_t + w^o\, l_t^o$

$q_{t-1} = (A_{t-1}/\overline{A})\, \beta\, {l_{t-1}}^{(1-\alpha)}\, {F_{t-1}}^{\alpha}$

where $\mu_t > 0$ and $\lambda_t > 0$ denote the marginal utility of household labor and income, respectively[11].

The model describes the options and choices in response to the various factors that are given to the farmer, or, at least, beyond the scope of the choice for a production-consumption path.[12] The attainable lifetime utility is a function of these factors and, hence, varies with farm characteristics $(\overline{A}, \bar{l}, \underline{c})$, with initial production $q_0 = (A_0/\overline{A})\ \beta\, {l_0}^{(1-\alpha)}\, {F_0}^{\alpha}$ and start-of-season savings s_1, with market conditions regarding crop and fertilizer prices and off-farm wages (p, p^F, w^o), and, finally, with future harvest conditions $(A_1, \dots, A_{T-1})$.

We note that choice variables $(c_t, l_t, F_t) > 0$ will always be greater than zero: consumption will be positive because of mounting marginal utility near zero, while production inputs will be positive because of mounting productivity near zero. However, the other two variables $(l_t^0, s_{t+1}) \geq 0$ may hit their zero lower bound: off-farm work will be zero as and when household labor is more productive on the farm than it is on the local 'ganyu' labor market, while end-of-season savings will be zero as and when the marginal utility of income in the current season becomes higher than the marginal utility in the next season

The conceptual framework has a number of implication that can explored empirically:

[11] In mathematics, these marginal utilities are called the shadow-price or Lagrange-multiplier of the constraints.
[12] See annex for the derivation of for optimality conditions for all choice variables.

Implication 1. Households have two coping instruments for food security: start-of-season savings (empirically indistinguishable from last season production[13]) and off-farm ganyu labour. Savings are pre-determined, while off-farm ganyu labor may be supplied during the season. The different returns from on-farm and off-farm work due to labor market frictions, makes households prefer to rely, in the first place, on accumulated start-of-season savings ($s_t + p\ q_{t-1}$) and, if savings are depleted, to turn to off-farm ganyu labour. The underlying mechanism creates a negative relationship between start-of-season savings and supply of off-farm ganyu labour. In terms of the conceptual model this reads: $\partial l_t^o / \partial s_t < 0$ and $\partial l_t^o / \partial q_{t-1} < 0$, where we iterate that the two effects are empirically indistinguishable.

Implication 2. On-farm labour is more productive than off-farm work. Consequently, households that are forced to work off-farm due to a lack of start-of-season savings, have a lower (crop area) productivity relative to households that do have sufficient start-of-season savings. In terms of the conceptual model this reads: $\partial(q_t/\overline{A})/\partial l_t^o < 0$.

Implication 3. Start-of-season savings also enable households to purchase inputs and to invest in growing commercial crops. Hence, we expect a positive impact of start-of-season savings on fertilizer use and market participation. In terms of the conceptual model this reads: $\partial F_t/\partial s_t > 0$ and $\partial F_t/\partial q_{t-1} > 0$; $\partial(q_t/\overline{A})/\partial s_t > 0$ and $\partial(q_t/\overline{A})/\partial q_{t-1} > 0$ and once again, the two effects are empirically indistinguishable.

[13] The model distinguishes start-of-season savings (s_t) and last-season production (q_{t-1}). In the empirical data last season production is fully reflected in start-of-season savings: in the running season last season maize production is either stored, sold on the market and saved in the form of cash, or used to purchase livestock. Hence, in the empirical work start-of-season savings is equivalent to ($s_t + q_{t-1}$) in the conceptual model.

4. Data sources, data description and variable construction

Data sources and data description

To investigate the relationship between start-of-season food stocks, livestock and cash savings 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). We run pooled estimations with the cross-sectional data, and complement this with panel estimations, using 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: per survey between 8,700 and 10,000 farm households, in a total of around 12,000 households. The panel data comprise much less households (a maximum of 3,673 farm households) but their major attraction is that these data allow panel data estimation techniques.

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). The picture that emerges is one of a rural society with smallholder farmers who generally have little education and grow a large part of their own staple food at low yields. 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.

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) (0/1)	0.124-0.406-0.467	0.092-0.443-0.465	0.128-0.420-0.452
urban (0/1)	0.156	0.191	0.163
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)
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)
cash savings (0/1)	0.364 (0.481)	0.397 (0.489)	0.707 (0.455)
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)
share of cash crop area	0.290 (0.243)	0.335 (0.259)	0.433 (0.258)

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 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; 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.

The remainder of the data refer to agricultural households, households that cultivate crops[14].

The number of household members per agricultural household is on average between 4 and 5.

[14] Only a small share of all households is exclusively breeding cattle (IHS3: 3.9%; IHS4: 4.8% and IHS5: 5.0%). These households are excluded from the empirical estimations: we focus on households that grow crops, possibly combined with rearing livestock, which is the majority of households.

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[15], 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%).

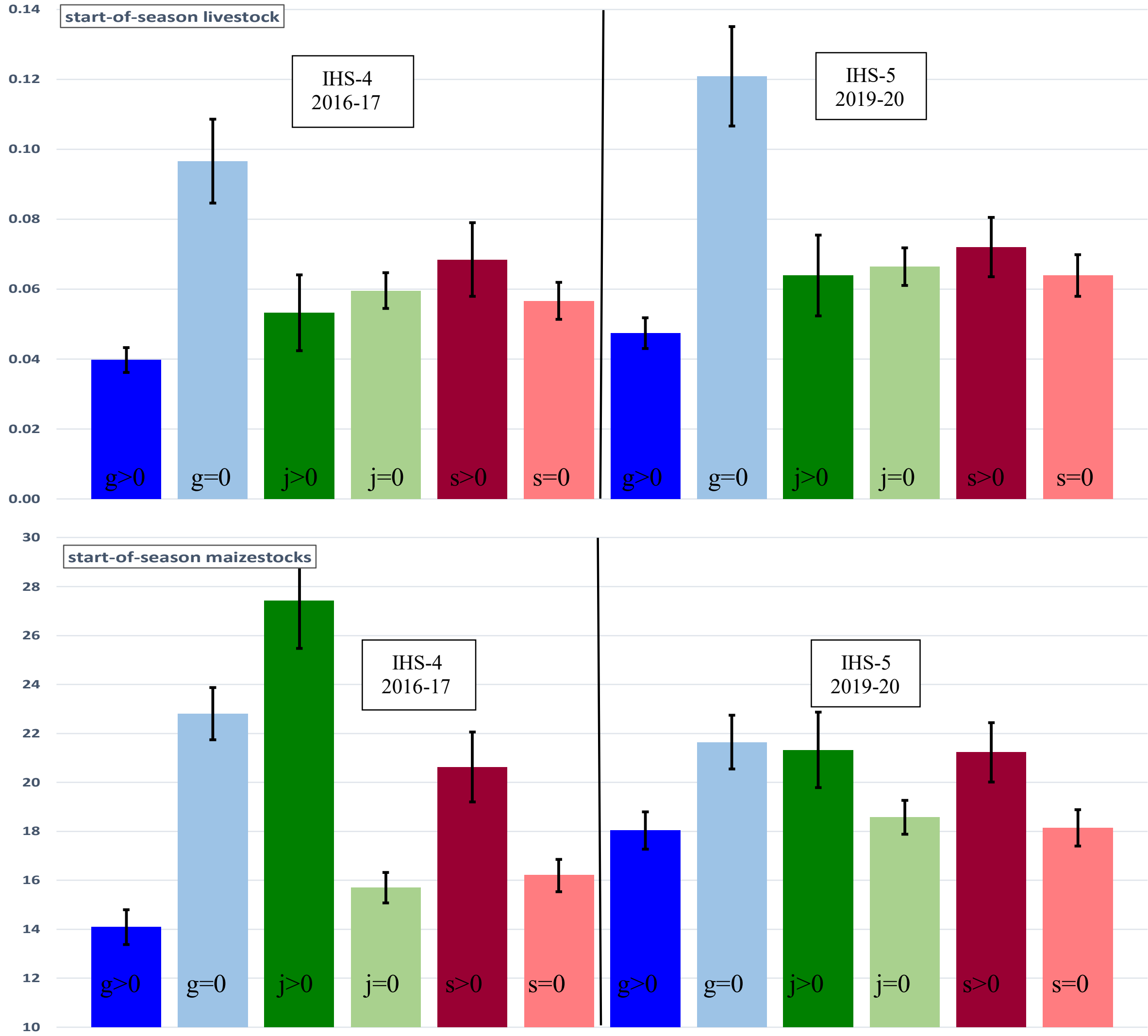
Household maize stocks fluctuate heavily per season and much more than livestock: the share of households with maize stocks varied from 55% in 2010, to 34% in 2016 and 49% in 2019. It is likely that average sizes of stocks fluctuates proportionally with the share of households with maize stocks. Close to 50% of households owns livestock, which consists on average of one to two goats (1 goat = 0.1 tropical livestock units). 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)[16]. Fluctuations in take-up and average quantity are likely to be influenced by Malawi's fertilizer and seed subsidy programs (Farm Input Subsidy Program (FISP) which started in 2005, and which transformed into Affordable Inputs Programme (AIP), from 2020 onwards). Only a limited share of agricultural output is sold on

[15] 1 acre = 0.4047 hectare.
[16] Fertilizer recommendations are around 50kg of nutrients per hectare (or around 20 kg per acre).

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.

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 jobs or from self-employment are modest (Table 1): 47% to 75% of households report to have ganyu earnings while 11% to 17% have wage income from off-farm jobs and 19% to 27% report earnings from self-employment.

Figure 2 Types of off-farm wage versus start-of-season savings (IHS 4, 5)



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

We explore how the different types of off-farm labour fit in the conceptual model. In the case of earnings from ganyu labour average start-of-season livestock and maize stocks is systematically higher for households with no earnings from ganyu labour (Figure 2). This supports the idea set out in the conceptual framework that households engage (more) in ganyu labour as a coping mechanism, if start-of-season savings are depleted. In contrast, this regularity does not show up in case of earnings from wage jobs and self-employment: there is no difference in start-of-season livestock, while maize stocks are larger (instead of lower), suggesting a different (reverse?) role for these types of off-farm labour. These types of off-farm labour likely reflect supply of labour with a higher marginal labour productivity than can be realized in agricultural activities. In the remainder of this paper we focus on ganyu labour, since it is the quantitatively dominant type of off-farm labour and, unlike the other types of off-farm labour, appears to function as a coping mechanism in case of a lack of resources.

Constructing variables for verification and estimation

We briefly discuss how IHS survey data are used to construct variables to verify the conceptual frame work and variables for estimation (see Appendix for more details). Our exercise centres around the role of start-of-season savings: we identify start-of-season maize stocks, start-of-season livestock and start-of-season cash savings. Start-of-season maize stocks are (surprisingly) not recorded, and therefore constructed on the basis of food security information. In particular, we exploit answers to three questions: "In the last 12 months, have you been faced with a situation when you did not have enough food to feed the household?", "During the last 12 months, in which month have you been faced with a food shortage in the household?" and "What was the cause of the food shortage in the household?". Households that report no food shortage in the household are assumed to have positive and sufficient maize stocks to preserve food security throughout the year[17,18].

In contrast with maize stocks, livestock is recorded as a start-of-season variable ('how many units of livestock did your household own exactly 12 months ago?'). Different types of livestock are converted into tropical livestock units, where the sub-Sahara specific weights for different types of livestock are obtained from FAO (2011). As a reference: a goat, a popular type of livestock, is equivalent to 0.1 tropical livestock units. Many households lack both start-of-season maize stocks and start-of-season livestock (IHS-3: 26.8%; IHS-4: 41.0%; IHS-5: 30.0%).

The final variable that covers start-of-season informal savings, cash savings kept at home, is most likely the most important type of informal savings[19]. Unfortunately, start-of-season cash savings is also not recorded. However, we do know if outlays on inputs are funded through own savings. This recorded information is assumed to offer an indicator of cash savings available at the start of the season. An approximation of the amount of savings with the size of the outlays is not possible: these survey questions are not answered!

The dependent variables in the estimations are fertilizer use (reflecting investment in technology), share of market sales and share of cash crop area (the latter two reflecting market participation). We will use two measures of fertilizer use: the first calculates the per plot

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[17] The table below summarizes the distribution of households by start-of-season maize stocks and by survey.

Farm households and start-of-season maize stocks

	IHS3	IHS4	IHS5
Positive and sufficient maize stocks	50.9%	22.8%	29.0%
Positive but insufficient maize stocks	40.0%	53.4%	47.9%
No maize stocks	9.1%	23.9%	23.1%

[18] It is tempting to exploit the monthly food security information combined with assumptions on per person per day maize requirements to construct a continuous start-of-season maize stock variable. Such a variable allows to estimate the marginal impact of, say 100kg pp extra start-of-season maize stocks. However, estimates become sensitive to assumptions underlying the constructed nature of the variable and this path is therefore not followed.

[19] Fink et al., 2020 reports for Zambia farm households: "By far the most common savings strategy, reported by 76.7 percent of households, is saving money at home."

application of fertilizer (all types of fertilizer taken together, kg per acre and plot) and selects the maximum application of fertilizer over all plots in a household (for each household i with plot j, we calculate max $((\sum_k fertilizer\ use_{ijk})/plot\ area_{ij})$ where k is the type of fertilizer). The second way aggregates for each household all quantities of fertilizer (of all types k) applied on all plots j at the household level and divides this aggregate fertilizer application with total household crop area $((\sum_{jk} fertilizer\ use_{ijk})/total\ crop\ area_i)$.

We employ the share of market sales of all crops n in total crop production value $(share\ of\ market\ sales_i = \sum_n crop\ sales_{ni}\ /(\sum_n (production_{ni}\ x\ price_{ni})$ for each household i as our first measure of market participation. With a large part of crop production used for home consumption and not sold on the market, many crop prices are missing, and the total value of crop production by household needs to be constructed. For these households the (shadow) price of crop n of household i in district o is approximated with the average sales unit value by crop[20] and district $(price_{ino} = mean(sales\ value_{ino}/sales\ quantity_{ino}))$, exploiting sales unit values of (neighbouring) households. The validity of this approximation is verified with IHS5 data, where crop production value for all households is recorded. Next, the share of cash crop area, the second measure of market participation, is constructed as non-maize area in total crop area by household $(share\ of\ cash\ crop\ area_i = 1 - (maize\ area_i/total\ crop\ area_i)$ and uses the same aggregation into main crops as in the case of crop production. 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[21]. Crop area that is not cultivated for several reasons (left fallow, rented out and given out for free) is removed from total crop area.

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[20] Note that for this purpose crops, both production and sales, are aggregated into five main crops (maize, groundnuts, tobacco, rice and other crops (mainly vegetables like pigeon peas, nkhwani and cow peas).
[21] Estimation results are statistically similar if different (but still decreasing) weights are applied.

5. Verifying model assumptions and model implications

Verification of model assumptions: seasonality

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 2 reports incidence of drought and irregular rains, over the seasons recorded as reference season in the IHS data. The table indicates shares of households affected by either a drought or irregular rains, varying from a low of 25% to a high of 88%, and thereby reflecting the differences between season. The three year recall data from IHS-5 (not in the table) show that 60% of households were affected by drought or irregular rainfall during the last three seasons, of which 12% even during two seasons. These numbers translate into an approximate probability of drought or irregular rainfall to 1 time every 5 years[22] and represents a large production risk in agriculture, which requires substantial accumulation of savings to anticipate on crop failure.

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

Variable	IHS-3		IHS-4		IHS-5	
	0809	0910	1415	1516	1718	1819
drought & irregular rainfall	0.608	0.404	0.880	0.814	0.332	0.256
	(0.488)	(0.491)	(0.325)	(0.389)	(0.471)	(0.437)
drought	n.a.	n.a	0.498	0.412	0.145	0.084
			(0.500)	(0.492)	(0.353)	(0.278)
irregular rainfall	n.a.	n.a	0.756	0.683	0.239	0.203
			(0.429)	(0.465)	(0.427)	(0.402)

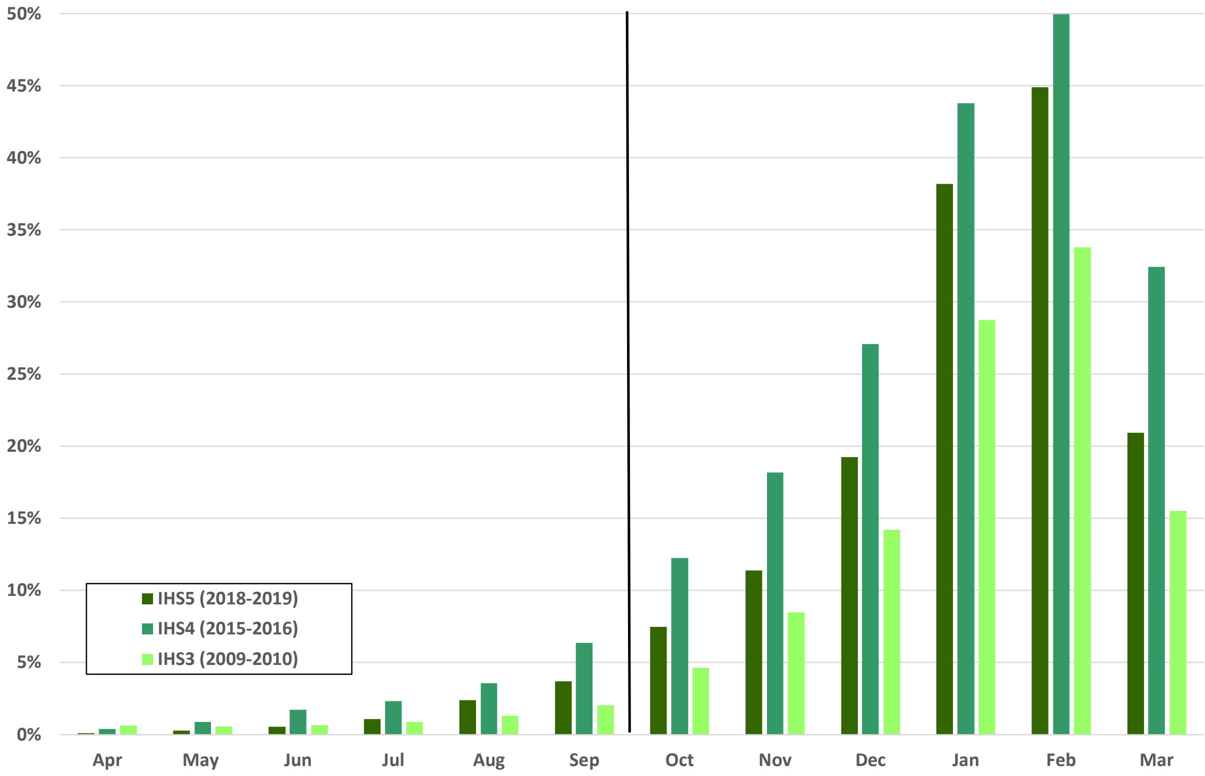
Note: The table is based on the answers to the question (IHS5): "How many times in the last 3 years (IHS5) / in the last 12 months (IHS3 and IHS4) was your household negatively affected by drought and / or irregular rains" and reports the weighted share of households affected by drought and / or irregular rainfall over the past 12 months. Robust standard errors clustered by enumeration area are in brackets.

Everyone involved in agriculture is aware of seasonality. To illustrate the depth of seasonality we explore the incidence of food shortages 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

[22] Such a frequency of droughts corresponds with long run rainfall data from meteorological weather stations (not reported, available from the author).

months, from October to March, with a peak in February. The monthly incidence increases from a low of less than 5% in the post-harvest season, from April to September, to a peak ranging from close to 35% (season 2009-2010), to 45%-50% (season 2015-2016, 2018-2019). Aggregated over the entire season the incidence of food shortage is nearly twice as large in 2015-2016 relative to 2009-2010. Even in seasons with a low incidence of food shortage, the drop in resources during the hungry season represents a major and predictable challenge for farm households, requiring substantial accumulation of savings.

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?". Restricted to households with crop area.

The major reason for food shortages reported by households is lack of food stocks (Table 3): a minimum share of households of 70% and a maximum of 90% mention inadequate food stocks as the reason for a household food shortage. This piece of information underscores the importance of food stocks as primary coping strategy to protect against food shortages.

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

Variable	IHS-3		IHS-4		IHS-5	
	0809	0910	1415	1516	1718	1819
inadequate household food stocks	0.868	0.895	0.804	0.843	0.774	0.698
	(0.339)	(0.307)	(0.397)	(0.363)	(0.419)	(0.459)
very high food prices on the market	0.058	0.064	0.128	0.120	0.136	0.162
	(0.054)	(0.244)	(0.335)	(0.325)	(0.342)	(0.369)
other reasons	0.074	0.041	0.067	0.037	0.091	0.140
	(0.262)	(0.199)	(0.251)	(0.188)	(0.288)	(0.347)

Note: The table reports weighted share of farm households by the major reason for a household food shortage and is restricted to those farm households that report a food shortage. Robust standard errors clustered by enumeration area are in brackets.

Verification of model assumptions: household labor versus ganyu labor

In the conceptual framework crop production depends on household labor and it is assumed that (the bulk of the) farmers do not hire workers. Table 4 shows that this is largely the case, the majority of farmers do not hire workers (hired labour = 0, row 1+row 2: 71%-80%). A substantial but modest part of this group exclusively works on the home farm (ganyu=0 & hired labour=0: 18%-47%). However, a quite larger part of this group needs to sell ganyu labour for food security (ganyu>0 & hired labour=0: 53%-83%).

Table 4 Households by labour market status (IHS 3, 4, 5)

Variable	IHS-3		IHS-4		IHS-5	
	0809	0910	1415	1516	1718	1819
ganyu>0, hired labour=0	0.419	0.375	0.523	0.590	0.606	0.621
ganyu=0, hired labour=0	0.324	0.339	0.222	0.216	0.130	0.139
ganyu=0, hired labour>0	0.176	0.207	0.142	0.111	0.130	0.111
ganyu>0, hired labour>0	0.082	0.080	0.113	0.083	0.135	0.129

Note: The table reports weighted share of farm households by labour market status: positive (ganyu>0) or no ganyu labour (ganyu=0) sold on the market, and positive (hired labour>0) or no labour hired on the market (hired labour=0).

Verification of model assumptions: household savings versus credit

In the conceptual framework we assume that there is no credit market. Table 5 summarizes if households have loans, for what purpose (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[23]. A maximum of 5.7% and, on average, 3.3% of households have a loan for consumption purposes from a formal credit institution. Note, however, that loans may be used for other purposes than recorded, since money is fungible. If we consider total access to formal loans for consumption and agricultural investment, during all seasons more than 90% of all farm households have no such loans from formal credit institutions. With the distinct seasonal nature of agricultural production and income, and the associated need for credit to fund the lean season consumption, our benchmark is a "close to 100%" use of credit. Hence, the reported shares of 'credit for consumption' and 'no credit' are sufficient support for the 'no credit market' assumption[24].

Table 5 Credit (IHS 3, 4, 5)

	IHS-3		IHS-4		IHS-5	
	0809	0910	1415	1516	1718	1819
loans for consumption						
from informal sources (0/1)	0.037	0.033	0.071	0.066	0.048	0.064
	(0.190)	(0.178)	(0.257)	(0.248)	(0.213)	(0.244)
from formal sources (0/1)	0.004	0.002	0.042	0.039	0.057	0.047
	(0.064)	(0.048)	(0.201)	(0.194)	(0.232)	(0.211)
loans for agricultural investment						
from informal sources (0/1)	0.039	0.026	0.034	0.021	0.038	0.033
	(0.194)	(0.159)	(0.182)	(0.144)	(0.191)	(0.178)
from formal sources (0/1)	0.008	0.011	0.019	0.022	0.049	0.045
	(0.090)	(0.105)	(0.136)	(0.146)	(0.216)	(0.208)
Total loans (0/1) for consumption and agricultural investment, formal and informal	0.088	0.072	0.167	0.148	0.192	0.189
	(0.285)	(0.259)	(0.362)	(0.355)	(0.394)	(0.391)

Note: The table shows the share of households that make use of credit for consumption and for agricultural investment, with standard deviations in brackets. Numbers are based on answers to the question: "Over the past 12 months, did you or anyone else in this household borrow on credit from someone outside the household or from an institution for business or farming purposes, receiving either cash or inputs?". Robust standard errors clustered by enumeration area are in brackets.

[23] Loans from informal sources like local money lenders tend to charge prohibitively high interest rates and are therefore less attractive (Burke et al., 2018).

[24] As a robustness check we have also run estimations with the sample of farm households without formal credit (see Appendix).

Verification of model implications: the negative relationship between start-of season savings and ganyu labor.

We further explore the relationship between weather shocks, food security, start-of-season savings, ganyu labour and productivity that follow from the conceptual model. 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?') increases from 51% in 2010 to close to 80% in 2016, to decrease to 71% in 2019. A higher incidence of food shortages is a consequence of a lower level of previous season agricultural output and a lower level of start-of-season savings. Following the conceptual framework we expect the share of households engaged in off-farm ganyu labour to fluctuate with the incidence of food shortage. Table 6 shows that the share of households with earnings from ganyu labour reporting food-shortages varies from 62% to 83%, while this share varies from 33% to 52% if households report no food-shortages. In all crop seasons the former share is significantly higher. The average number of months without food (conditional on having no food) ranges from 3 to 4 months.

Table 6 Household food shortages and earnings from ganyu labour (IHS 3, 4, 5)

household food shortage	IHS3		IHS4		IHS5	
	share of households with earnings from ganyu labour					
	0809	0910	1415	1516	1718	1819
yes	0.641	0.615	0.701	0.741	0.834	0.821
	(0.019)	(0.010)	(0.014)	(0.008)	(0.009)	(0.008)
no	0.358	0.325	0.360	0.431	0.499	0.516
	(0.025)	(0.009)	(0.020)	(0.016)	(0.020)	(0.015)
F-test (p-value)	87.9	547.8	219.8	359.0	253.1	379.4
	(<0.001)	(<0.001)	<0.001)	<0.001)	<0.001)	<0.001)
Number of months with no food*	3.3	2.9	4.1	4.4	2.9	3.2
	(0.114)	(0.070)	(0.085)	(0.073)	(0.064)	(0.052)

Note: The table reports the share of households that have earnings from ganyu labour, for households with and without food shortages, and the average number of months without food. The incidence of food shortage is based on answers to the question: "In the last 12 months, have you been faced with a situation when you did not have enough food to feed the household?" (*) conditional on non-zero number of no-food months. Robust standard errors clustered by enumeration area are in brackets.

Table 7a Start-of-season savings and earnings from ganyu labour (IHS 3, 4, 5)

start-of-season savings	IHS3 share of hhs with ganyu earnings		IHS4 share of hhs with ganyu earnings		IHS5 share of hhs with ganyu earnings	
	0809	0910	1415	1516	1718	1819
1 0	0.670	0.648	0.735	0.763	0.826	0.806
	(0.026)	(0.014)	(0.017)	(0.011)	(0.022)	(0.016)
2 >0	0.320	0.284	0.349	0.363	0.441	0.472
	(0.042)	(0.014)	(0.035)	(0.024)	(0.031)	(0.021)
1=2	51.09	348.3	92.06	238.0	106.0	165.2
	(<0.001)	(<0.001)	(<0.001)	(<0.001)	(<0.001)	(<0.001)

Note: see below

Table 7b Drought and earnings from ganyu labour (IHS 5)

drought in previous season	IHS5 share of hhs with ganyu earnings	
	1718	1819
1 yes	0.777	0.794
	(0.020)	(0.013)
2 no	0.721	0.719
	(0.012)	(0.009)
1=2	6.50	27.84
	(0.011)	(<0.001)

Note: see below

Table 7c Drought, start-of-season savings and earnings from ganyu labour (IHS 5)

	drought in previous season	start-of-season savings	share of hhs with ganyu earnings	
			1718	1819
1	yes	0	0.833	0.844
			(0.052)	(0.031)
2	no	0	0.825	0.796
			(0.024)	(0.018)
3	yes	>0	0.474	0.570
			(0.083)	(0.049)
4	no	>0	0.437	0.453
			(0.033)	(0.022)
1=2			0.02	1.75
			(0.995)	(0.186)
3=4			0.18	4.98
			(0.675)	(0.026)

Note: The tables reports the share of households that have earnings from ganyu labour, for households with and without start-of-season savings (Table 6a), with and without a drought shock in the previous season (Table 6b, only IHS 5) and the combination of these (Table 6c, only IHS 5); Robust standard errors clustered by enumeration area are in brackets; *Drought* is an indicator (0/1) reflecting the incidence of drought and irregular rains in the previous season ('Was your household affected by drought or irregular rains during the last 12 months?'); *Start-of-season savings* is an indicator with a value of 1 if households have both start-of-season maize stocks, livestock and cash savings (for definitions: see data section), and zero elsewhere. Less restrictive construction of start-of-season savings generate similar (but slightly weaker) results (not shown, available from the author).

According to our model off-farm activities are undertaken in case of lack of resources to purchase basic food needs. Alternatively, households with sufficient savings to cover the hungry period, caused either by regular seasonality or by crop failure, are less likely to require earnings from ganyu labour. We explore this claim by cross-tabulating ganyu labour and start-of-season savings both ways: by showing the share of households with ganyu earnings with and without start-of-season savings, and jointly with drought shocks (Table 7), and by showing the share of households with start-of-season savings with and without ganyu earnings (Table 8)[25].

The evidence in Table 7 shows the share of households with ganyu earnings with and without start-of-season savings and with and without drought shocks. The share estimates indicate that an exogenous drought shock leads to a larger share of ganyu earning households. Also, in most seasons the share of ganyu earning households is hardly affected by a drought shock if there are no start-of-season savings. The evidence suggests that farmers engage in off-farm ganyu labour if food-stocks are depleted, rather than choosing on-farm and off-farm labour on the basis of an equilibrium market wage (Fink et al, 2020).

The reverse relationship – the share of households with positive start-of-season savings with and without earnings from ganyu labour – is shown in Table 8, and indicates for all types of savings and nearly in all seasons, larger share of households with start-of-season savings if there are no earnings from ganyu labour. Evidence reported both in Table 7 and Table 8, and in the appendix all support the negative relationship between ganyu labour and start-of-season savings, and confirm that start-of-season savings help households in the first place to establish food security in the hungry season, while ganyu labour is the option of last resort, if start-of-season savings are depleted.

[25] Additionally, we show the share of households engaged with ganyu labour under different combinations of start-of-season savings and we estimate earnings from ganyu labour on start-of season savings, jointly with a set of controls (Appendix).

Table 8 Earnings from ganyu labour and start-of-season savings (IHS 3, 4, 5)

Earnings from ganyu labour	IHS3		IHS4		IHS5	
	share of households with start-of-season maize stocks					
	0809	0910	1415	1516	1718	1819
0	0.555	0.661	0.386	0.401	0.578	0.512
	(0.023)	(0.010)	(0.018)	(0.014)	(0.020)	(0.016)
>0	0.284	0.386	0.132	0.150	0.213	0.196
	(0.023)	(0.012)	(0.010)	(0.007)	(0.012)	(0.008)
F-test (p-value)	91.8	475.4	182.8	313.4	300.4	375.6
	(<0.001)	(<0.001)	(<0.001)	(<0.001)	(<0.001)	(<0.001)
	share of households with start-of-season livestock					
	0809	0910	1415	1516	1718	1819
0	0.562	0.529	0.446	0.489	0.581	0.545
	(0.021)	(0.010)	(0.019)	(0.015)	(0.023)	(0.016)
>0	0.503	0.458	0.398	0.419	0.494	0.438
	(0.021)	(0.011)	(0.015)	(0.011)	(0.016)	(0.010)
F-test (p-value)	5.1	31.8	5.1	23.2	11.7	38.8
	(0.0258)	(<0.001)	(0.0251)	(<0.001)	(<0.001)	(<0.001)
	share of households with start-of-season cash savings					
	0809	0910	1415	1516	1718	1819
0	0.388	0.441	0.470	0.499	0.686	0.750
	(0.026)	(0.011)	(0.019)	(0.014)	(0.022)	(0.013)
>0	0.272	0.293	0.356	0.372	0.669	0.741
	(0.021)	(0.010)	(0.016)	(0.012)	(0.015)	(0.008)
F-test (p-value)	16.1	161.9	29.3	66.2	0.54	0.36
	(<0.001)	<0.001)	(<0.001)	(<0.001)	(0.4628)	(0.5513)
	# of start-of-season livestock*					
	0809	0910	1415	1516	1718	1819
0	0.187	0.200	0.233	0.238	0.255	0.254
	(0.024)	(0.014)	(0.023)	(0.016)	(0.037)	(0.018)
>0	0.104	0.108	0.128	0.112	0.124	0.109
	(0.009)	(0.007)	(0.013)	(0.007)	(0.009)	(0.005)
F-test (p-value)	11.9	40.5	18.1	59.7	11.8	66.2
	(<0.001)	(<0.001)	(<0.001)	(<0.001)	(<0.001)	<0.001)

Note: The table reports the share of households with start-of-season savings, for households with and without earnings from ganyu labour; Start-of-season maize stocks, livestock and own savings are indicator variables with a value of 1 in case of positive savings and zero elsewhere. # of livestock is livestock is in tropical livestock units measured at the start of the period per household member. Robust standard errors clustered by enumeration area are in brackets. * Conditional on non-zero livestock.

Verification of model implications: the negative relationship between ganyu labor and productivity and the positive relationship between start-of season savings and productivity

Finally, we show how the supply of ganyu labour is related with productivity. Table 9 tabulates per acre productivity in maize cultivation for households that supply (any) ganyu labour and households that do not supply ganyu labour, combined with whether households hire or do not hire ganyu labour. Note that the bulk of the farm households either supply and do not hire ganyu labour (row1), or do not supply and do not hire ganyu labour (row2): these two groups comprise around three quarters of all farm households. Households that supply ganyu labor have systematically lower area productivity relative to households that do not supply ganyu labour. The difference with the most relevant group (no ganyu labour supplying or hiring, row 2) is modest, but significant: it ranges from 53 to 140 kg per acre (mean 84kg per acre, evaluated at the mean a +20%). The difference in area productivity becomes large if households that supply ganyu labour (row 1) is compared with households that hire ganyu labour (row 3 and 4): per acre production is 70 to 296 kg per acre larger, an increase of 35% to 59%, evaluated at the mean.

Table 9 Ganyu labour & hired labour versus productivity (IHS 3, 4, 5)

			IHS-3		IHS-4		IHS-5	
	ganyu sold	ganyu hired	0809	0910	1415	1516	1718	1819
1	> 0	= 0	437.1	422.0	402.6	349.0	422.5	451.6
			(22.1)	(8.1)	(14.2)	(9.9)	(16.2)	(14.4)
2	= 0	= 0	542.1	486.1	456.0	431.9	562.7	511.1
			(26.0)	(9.0)	(20.2)	(19.3)	(45.6)	(26.9)
3	> 0	> 0	596.4	491.3	589.4	561.0	623.5	559.1
			(51.9))	(16.9)	(35.4)	(33.2)	(42.3)	(29.2)
4	= 0	> 0	674.1	655.4	609.5	615.0	654.9	747.8
			(38.2)	(13.4)	(30.3)	(27.3)	(39.5)	(32.9)
F-test (p-value)		1=2	413.3	2794	658.2	872.5	415.1	675.4
			(<0.001)	(<0.001)	(<0.001)	(<0.001)	(<0.001)	(<0.001)

Note: The table shows average area productivity in maize cultivation (kg per acre) for households with and without earnings from ganyu labour, and with and without hired labour. Robust standard errors clustered by enumeration area are in brackets. The first two groups of households (no hiring of labour, with or without ganyu sold) represent jointly between 72% to 79% of all households in the IHS surveys.

We have cross-tabulated in Table 10 combinations of start-of-season savings with area productivity: in nearly all seasons per acre production with no start-of-season savings (the first row: 0-0-0) is significantly smaller than per acre production if households have any type of start-of-season saving. In the extreme, if households have all type of savings, per acre production rises from around 357 kg/acre to around 657 kg/acre, an increase of 57% to 111% (average, median: 85.3%, 86.9%).

In summary, we find that the Malawi survey data convincingly support the assumptions underlying the conceptual framework: households face a large production risk due to drought and irregular rains, agricultural income follows a distinct seasonal pattern, and there is no capital market. Additionally, we presented empirical support for the relationships that follow from the conceptual framework: savings are used to cover 'no-income' periods, and ganyu labour is a major coping instrument, in case there are no start-of-season savings. Finally, zero (positive) ganyu labour corresponds with higher (lower) area productivity in maize cultivation on the home farm. Moreover, households with hired labour have higher area productivity relative to households that do not use hired labour, and only use family labour.

Table 10 Combinations of start-of-season savings versus productivity (IHS 3, 4, 5)

maize stocks – livestock – cash savings	IHS-3		IHS-4		IHS-5	
	0809	0910	1415	1516	1718	1819
0 – 0 – 0	377.6	347.5	370.3	306.2	386.0	392.6
	(27.1)	(10.6)	(18.0)	(12.0)	(31.9)	(28.9)
1 – 0 – 0	466.2	457.2	501.8	441.6	495.3	593.9
	(39.7)	(12.8)	(42.7)	(36.1)	(49.4)	(61.4)
0 – 1 – 0	465.4	404.2	392.8	325.9	395.1	411.9
	(31.0)	(13.7)	(21.7)	(17.8)	(34.5)	(38.5)
0 – 0 – 1	538.0	470.7	525.1	462.7	421.0	424.0
	(57.8)	(21.8)	(27.2)	(22.5)	(34.7)	(19.0)
1 – 1 – 0	628.7	525.6	597.7	536.8	631.0	603.2
	(50.7)	(13.7)	(53.0)	(48.7)	(46.1)	(49.2)
1 – 0 – 1	741.3	628.4	668.1	704.0	603.9	704.6
	(53.6)	(19.4)	(51.4)	(45.7)	(54.6)	(45.7)
0 – 1 – 1	624.8	505.8	476.9	465.8	492.1	490.4
	(67.6)	(16.3)	(27.9)	(24.4)	(28.6)	(22.0)
1 – 1 – 1	642.3	660.1	582.3	646.7	710.0	703.4
	(38.6)	(15.1)	(43.6)	(36.1)	(46.6)	(30.9)

Note: The table shows average area productivity in maize cultivation (kg per acre) for different combinations of start-of-season savings. Robust standard errors clustered by enumeration area are in brackets.

6. Empirical strategy

The empirical estimations are based on pooled 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 the impact of different types of start-of-season savings on technology adoption and market participation:

$$y_i = \beta_0 + \beta_1 grain\ stock_{0,i} + \beta_2 livestock_{0,i} + \beta_3 cash\ savings_{0,i} +$$

$$\sum_k \beta_{4k} X_{ki} + \vartheta_j x \theta_t + \varepsilon_{it}, \tag{6}$$

where y_i for each household i, denotes per acre use of inorganic fertilizer, the share of agricultural production sold on the market or the share of cash crop area in total crop area, X_k are k household characteristics, and ϑ_j is a full set of j geographical areas (districts) and θ_t is survey-round. Errors (ε_{it}) are clustered at the level of the enumeration area, which addresses unobserved shocks at the level of enumeration areas, and correlation of shocks across years.

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:

$$y_{it} = \beta_0 + \beta_1 grain\ stock_{0,it} + \beta_2 livestock_{0,it} + \beta_3 cash\ savings_{0,it} +$$

$$\sum_k \beta_{4k} X_{kit} + \zeta_i + \theta_t + \varepsilon_{it}, \tag{7}$$

where the subscripts now denote household i at time t, and ζ_i and θ_t are household and time fixed effects. Errors (ε_{it}) are clustered at the household level, which addresses unobserved household level shocks and correlation of shocks across years. By including household fixed effects, the panel data addresses unobserved heterogeneity between households: this is the key advantage relative to estimations based on cross sectional household survey data. Such heterogeneity includes issues like land status, soil quality, plot fertility, farm specific skills and expertise, and managerial experience. In both approaches the parameters of interest are β_1, β_2 and β_3: we expect β_1, β_2 and β_3 to be positive, indicating a positive impact of start-of-season savings on 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 zero. Likewise, share of market sales in production value is truncated at zero and 1. To account for the truncated nature of the dependent variable we employed the TOBIT estimation technique.

We further explore heterogeneity in impact by interacting the start-of-season savings variables with a measure of heterogeneity:

$$y_i = \beta_0 + Z_h * [\beta_1 grain\ stock_{0,i} + \beta_2 livestock_{0,i} + \beta_3 cash\ savings_{0,i}] + \sum_k \beta_{4k} X_{ki} + \vartheta_j x \theta_t + \varepsilon_{it}, \quad (8)$$

$$y_{it} = \beta_0 + Z_h * [\beta_1 grain\ stock_{0,it} + \beta_2 livestock_{0,it} + \beta_3 cash\ savings_{0,it}] + \sum_k \beta_{4k} X_{kit} + \zeta_i + \theta_t + \varepsilon_{it}, \quad (9)$$

where Z_h is our measure of heterogeneity distinguishing h different classes. We consider two measures of heterogeneity: crop area and involvement in the labour market. The first heterogeneity measure is straightforward: we identify a specific number of class sizes of (average) total crop area, in our case three. The latter measure splits up farm households into a group that supplies ganyu labour, a group that hires ganyu labour, a group that does neither of these two, and a group that does both.[26]

Note that data used are observational, which has ramifications for the interpretation of the results. The interpretation of the estimated correlations as causal relationships reflecting the impact of start-of-season stocks is based on the idea that start-of-season savings are pre-determined (or exogenous). Since, for each household, outcomes of successive agricultural seasons are not independent, there is ground to challenge this assumption. To control for potential endogeneity of start-of-season savings (both livestock, food stocks and cash savings), we propose to instrument these variables with the incidence of shocks during the last 12 months[27], assuming that the incidence of shocks represent adequate proxies of effective exposure of households to risks. We use the following shocks, in order of importance:

[26] The group of households that both supplies ganyu labour and hires ganyu labour is the smallest in size: in the pooled data this group is around 10% of all households. The group that supplies ganyu labour is the largest (52%), next comes the group that does not supply and does not hire ganyu labour (23%) and finally the group that hires labour (15%).

[27] The exact survey questions read: 'During the last 12 months, was your household affected negatively by any of the following [SHOCK]? Rank the three most significant shocks you experienced - most severe, second most severe, and third most severe'. In IHS5 the recall period is extended to "the last three years".

drought, irregular rains, unusually low prices for agricultural output, unusually high costs of inputs, unusually high food prices, serious illness or accident of household member(s), unusually high level of pests and diseases of crops, unusually high level of livestock diseases, and theft of money, valuables, assets and, or agricultural output. The incidence of these risk events combined goes a long way in capturing the major types of risk exposure of sub-Sahara African farm households (Dercon et al, 2005).

7. Estimation results

The estimations reported in Table 11 and 12 show outcomes based on pooled cross-sectional household surveys (respectively IHS-3, IHS-4 and IHS-5) in the upper panel, and outcomes based on panel data (IHPS) in the bottom panel. Throughout all estimations, the core explanatory variables (start-of-season maize stocks, start-of-season livestock, and start-of-season cash savings) are used in binary form, indicated with 0/1[28]. In our estimations, the coefficients of binary (treatment) variables reflect the generic effect of non-zero start-of-season savings and allow a direct comparison of the relative effect of maize stocks, livestock and cash savings[29]. The binary variables have the attractive feature that they are not sensitive to outliers[30].

Estimations of the relationship between fertilizer use versus maize stocks, livestock and cash savings are reported in Table 11. Estimation results based on the pooled cross-sectional household surveys have coefficients for maize stocks, livestock and cash savings, all statistically significant at the 1% level of accuracy. Coefficients based on the panel data estimations are both smaller in size slightly and less accurate (but still significant at well

[28] Only start-of-season livestock is available as a continuous variable: both start-of-season maize stocks and start-of-season cash are not recorded (see the data section for details how the indicator variable is constructed). With only 1 out of 3 start-of-season savings variables in continuous form, we have refrained from showing estimations that make use of the continuous livestock variable.
[29] Assuming that the applied approximations are valid.
[30] Note that continuous variables are winsorized, at most, at the 5% level.

accepted levels). This is due to the smaller number of observations, jointly with household fixed effects that potentially absorb part of the explanation of stock variables. Since the panel estimations control for heterogeneity across households, by controlling for time invariant household effects, we consider the estimated coefficients superior. Coefficients of maize stocks and livestock are statistically the same (tests on equality could not be rejected), but smaller than the coefficient of cash savings.

Table 11a Fertilizer use vis-à-vis start-of-season savings (IHS 3, 4 & 5, pooled)

Dependent variable:	(1) fertilizer use	(2) fertilizer use*
maize stocks (0/1)	26.7*** (1.5)	23.0*** (1.2)
livestock (0/1)	17.5*** (1.3)	10.6*** (1.1)
cash savings (0/1)	58.7*** (1.7)	45.8*** (1.4)
d(district x year)	yes	yes
pseudo R^2	0.0437	0.0443
Observations	27133	27698
Table 11b Fertilizer use vis-à-vis start-of-season savings (IHPS, panel)		
maize stocks (0/1)	11.7** (5.8)	14.2*** (4.3)
livestock (0/1)	12.4** (5.7)	8.3** (4.0)
cash savings (0/1)	22.8*** (6.0)	18.2*** (4.2)
d(household)	yes	yes
d(survey year)	yes	yes
pseudo R^2	0.1420	0.1478
Observations	3522	3549

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. *Maize stocks*, *livestock* and *cash savings* are start-of-season informal savings. (0/1) are indicator variables: 1 if informal savings are >0, and zero elsewhere. 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, with a lower limit [0]. Robust standard errors in brackets are clustered by enumeration area (IHS-3 to IHS-5) and by household (IHPS). ***, ** and * indicate statistical significance at the 1%, 5% and 10% level respectively.

We elaborate briefly on the economic interpretation of the coefficients. Let's assume that a farm household has positive start-of-season savings of all types[31]: such a household would use 47kg (41kg) per acre. Evaluated at the average per acre fertilizer use (see Table 1), this result suggests that positive values of all types of start-of-season savings leads to an increase in per

[31] Estimations with full interactions of the different start-of-season savings variables generates similar supporting but are not shown to save space.

acre fertilizer use, ranging from 51% to 58%. Note that this is a maximum impact. However, scoring positive on less types of start-of-season savings, still yields large increase in per acre fertilizer use.

Estimations of the relationship between the share of market sales in production value and the share of cash crop area versus maize stocks, livestock and cash savings are reported in Table 12. Again, coefficients of start-of-season savings are statistically significant in all pooled cross-sectional estimations, and mostly at the 1% level of accuracy, while coefficients in the panel estimations are lower in size and less accurate (but still with positive signs and mostly significant). Focusing on the panel estimation results, we find that coefficients of all start-of-season saving are statistically the same in the share of market sales estimation. In the share of cash crop area the coefficient of maize stocks is insignificant and different from the other savings variables: given the construction of the dependent variable this is not surprising.

Table 12a Market participation vis-à-vis start-of-season savings (IHS 3, 4 & 5, pooled)

Dependent variable:	(1) market sales share	(2) cash crop area share
maize stocks (0/1)	0.055^{***} (0.008)	-0.016^{***} (0.004)
livestock (0/1)	0.120^{***} 0.007)	0.066^{***} (0.004)
cash savings (0/1)	0.142^{***} (0.008)	0.034^{***} (0.005)
d(district x year)	yes	yes
pseudo R^2	0.1505	0.2798
observations	27713	28020

Table 12b Market participation vis-à-vis start-of-season savings (IHPS, panel)

maize stocks (0/1)	0.040^{*} (0.024)	0.005 (0.015)
livestock (0/1)	0.049^{**} (0.022)	0.029^{**} (0.013)
cash savings (0/1)	0.048^{*} (0.026)	0.028^{**} (0.014)
d(household)	yes	yes
d(survey year)	yes	yes
pseudo R^2	0.6955	0.9799
observations	3238	3476

Note: *Market sales share* is the share of markets sales of all crops in the total value of the harvested crop. *Cash crop area share i*s the share of the household crop area that is not cultivated with maize and not left fallow. *Maize stocks*, *livestock* and *cash savings* are start-of-season informal savings. (0/1) are indicator variables: 1 if informal savings are >0, and 0 elsewhere. 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, with a lower and an upper limit [0, 1]. Robust standard errors in brackets are clustered by enumeration area (pooled estimation, IHS-3 to IHS-5 in upper panel) and by household (IHPS in lower panel). ***, ** and * indicate statistical significance at the 1%, 5% and 10% level respectively.

Like in the case of fertilizer, we elaborate briefly on the economic interpretation of the coefficients. Using the same assumption as before, the estimation results on the share of market sales suggest that if farm households have positive values of all types of start-of-season savings, there share of commercial sales in total production value is 14%-point higher. Evaluated at the average share of commercial sales (Table 1), this implies an increase from 14%-19% to 28%-32%. Again, these are maximum impacts associated with positive values of all types of start-of-season savings: scoring positive on only 1 or 2 types of start-of-season savings generates smaller but still substantial increases in the share of commercial sales[32].

Overall the estimations support a 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 savings on the other hand. All impacts are moderate, but consistently positive and nearly all statistically significant. The results are thereby suggestive of the impact of start-of-season savings on technology adoption and market participation.

We investigated the robustness of our estimation results in several ways. Identifying cash-crop area empirically on the basis of crop type information is problematic. Many crops are both sold on the market and used for home consumption. Also households make different decisions for the same crop, and these decisions may additionally vary by season. Different types of cropping systems (mixed cropping, intercropping, etc.) further complicates defining cash crop area. Of the few genuine cash crops - crops like tobacco, cotton and sugar cane, crops that contribute 100% to cash crop area – only tobacco is of importance. In order to explore if results are sensitive to (inevitable) arbitrary definitions of cash crop area, we decided to re-estimate using the share of tobacco and groundnut area in total crop area as our dependent variable. Next, the key role of start-of-season savings applies under the condition that credit markets do not supply credit for agricultural investment or for consumption. The

[32] Again, these claims are supported by estimation using full interaction of types of start-of-season savings.

data support that the use of credit is rare. There are, however, some households that use credit and apparently have access to credit: these households may blur the estimation results. We therefore re-estimated all equations after re-moving households from the estimation sample that report to have used credit during the last 12 months, either for agricultural investment, or for consumption purposes. Finally, we re-estimated all equations, both pooled and panel, with the omission of a survey round of observations: these estimation should shed light on the issue whether the results are dominated by one of the survey years. To save space we only present results for leaving out survey round 2015 (seasons 2014/15 and 2015/16) in the pooled estimations, and survey round 2013 in the panel estimations. All robustness checks generate estimation results that are qualitatively similar, but with variation in the size of impacts, also across the different components of start-of-season savings, and generally with lower sized impacts in the panel estimations (all estimations are documented in the Appendix). Overall, these outcomes further support our claim that start-of-season savings are a major determinant of technology adoption and market participation.

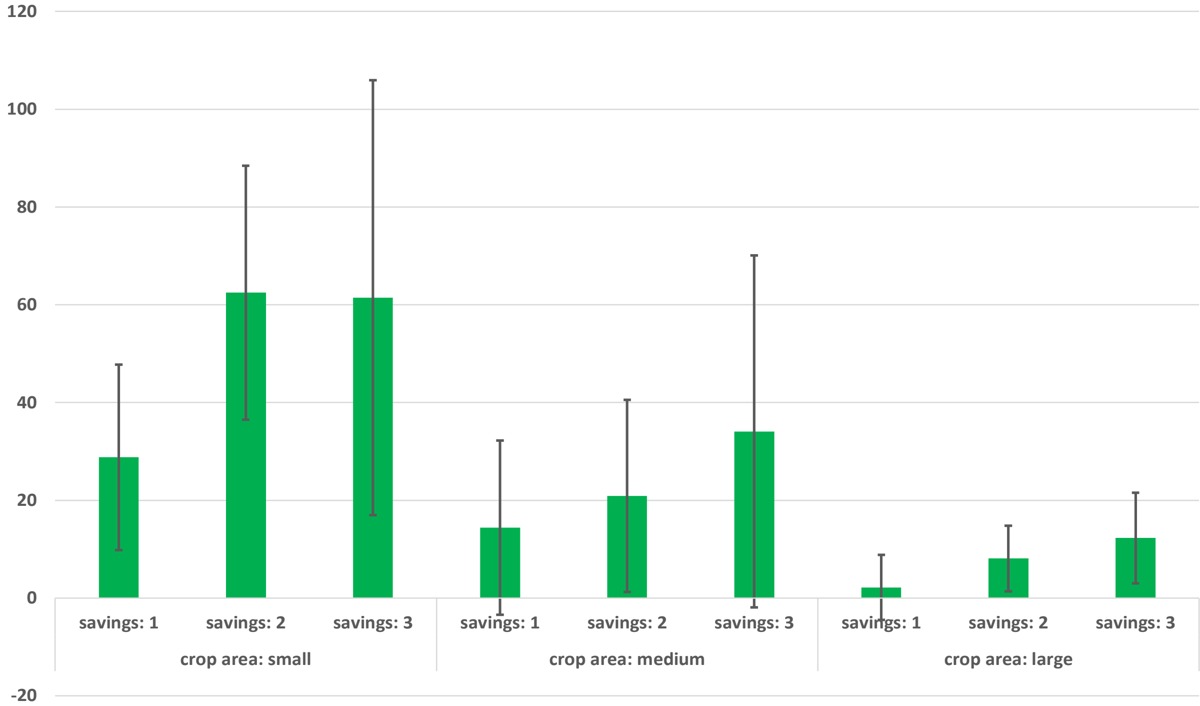
8. Heterogeneity of impacts

As introduced in the empirical strategy, we consider two measures of heterogeneity: crop area and involvement in the labour market. One may suspect strong overlap in these two measures since households that hire labour are likely also households with larger crop areas and, also the reverse, that households selling ganyu labour are predominantly households with small crop areas: surprisingly, however, the overlap is limited.

Heterogeneity by crop area

Figure 3 and show impact by crop area and the combination of start-of-season savings, where crop area is divided in three parts. The striking feature of the plots is that in the case of fertilizer use, the bulk of the significant impacts originates from households with smaller sized crop area. Conversely, in the case of market participation, significant impacts originate from households with large (panel) and medium (both pooled and panel) sized crop area. Households with smaller sized crop area are not triggered by start-of-season savings to sell output on the market. Overall the heterogeneity of impacts is largely similar[33] if we use the pooled cross-sectional data (see Appendix).

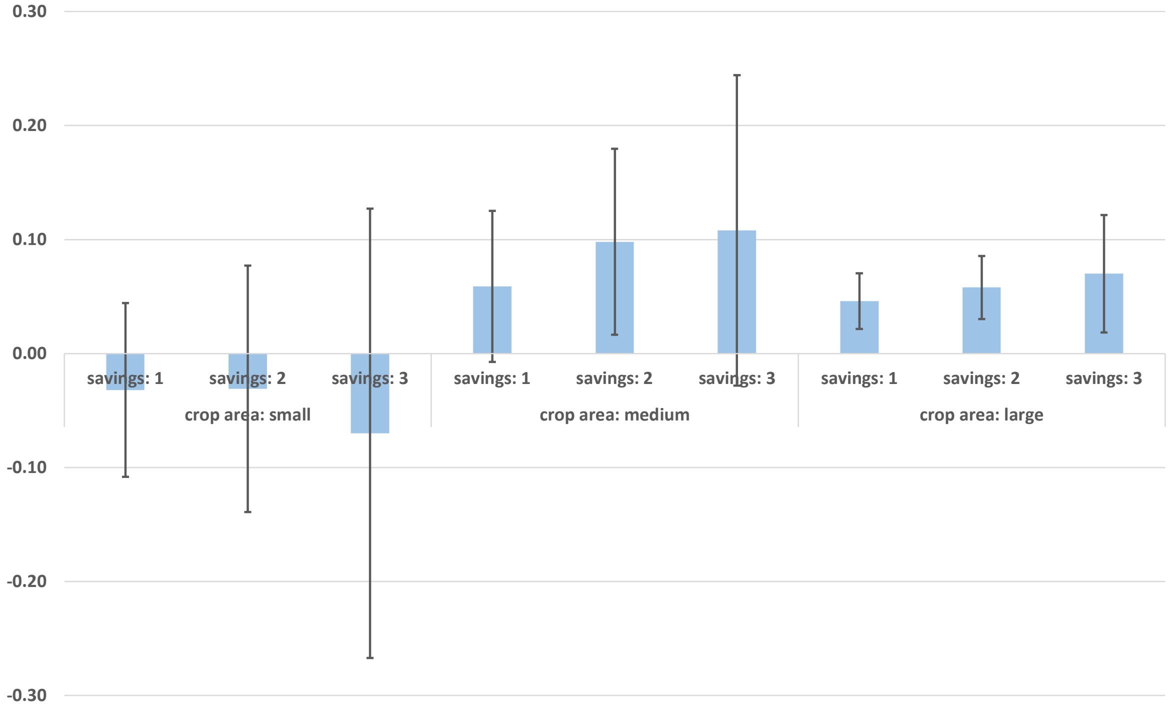
Figure 3 Impact of start-of-season savings on fertilizer use by crop area



Note: see next Figure.

[33] The panel data generate smaller sized coefficients and larger standard errors, associated with the smaller number of observations and the household fixed effects.

Figure 4 Impact of start-of-season savings on the commercial sales' share by crop area

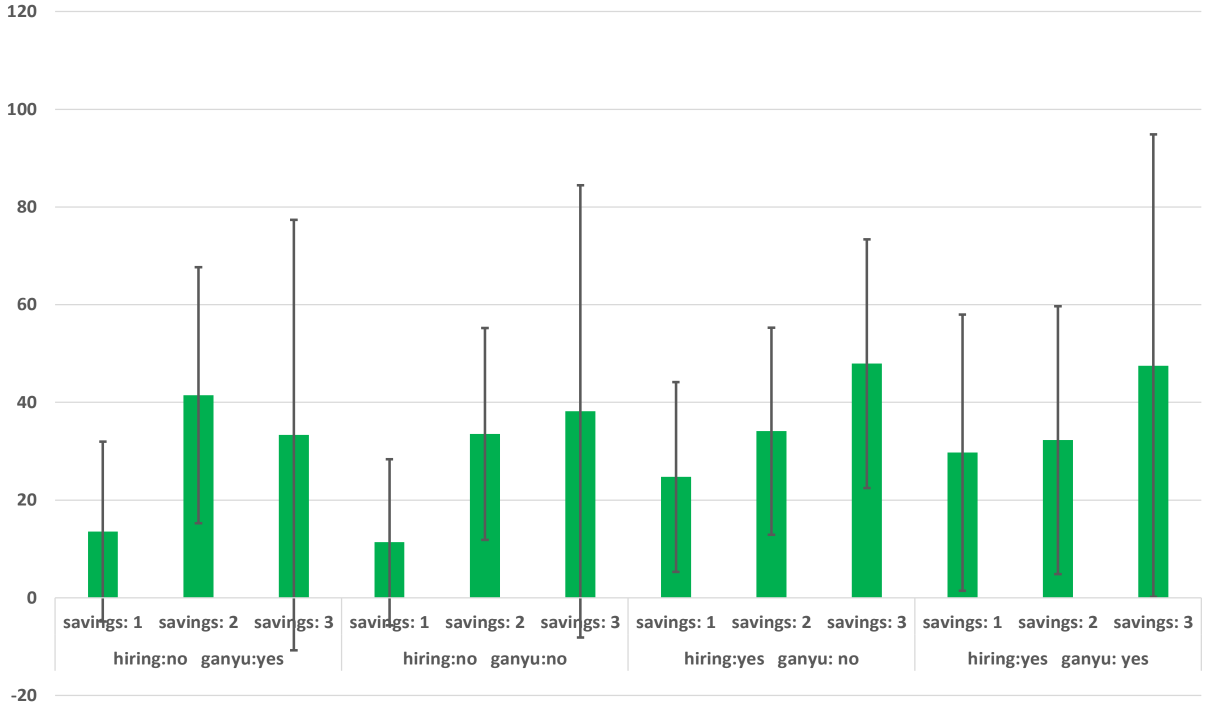


Note: Estimations based on IHPS (panel: 2010, 2013, 2016); Savings: 1, 2 or 3 denote resp. 1, 2 or all 3 types of start-of-season savings (maize stocks, livestock and cash). No start-of-season savings is the omitted category (all crop area). Crop area: small 0-0.9 acres; medium 0.9-1.8 acres and large >1.8 acres.

Heterogeneity by labour market status

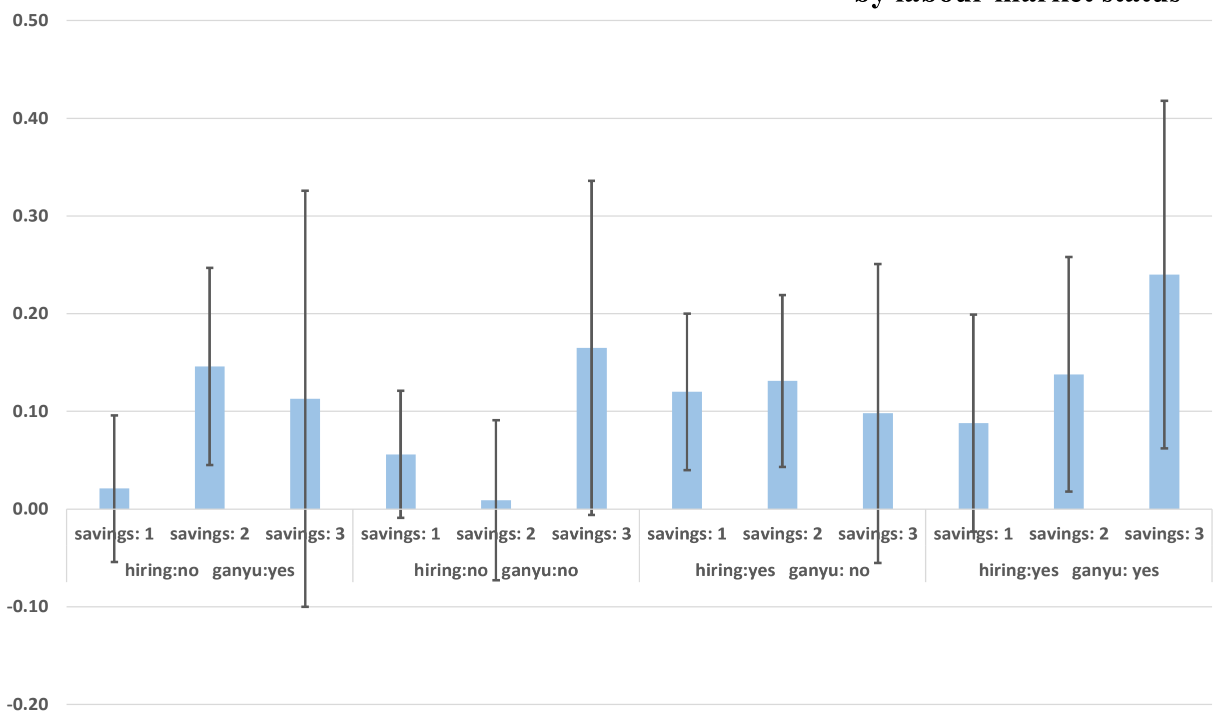
We finally investigate if impact is systematically correlated with labour market status. We distinguish four different classes (1. supplying ganyu labour, not hiring labour; 2. not supplying ganyu labour, not hiring labour; 3. not supplying ganyu labour, hiring labour; and 4. supplying ganyu labour, hiring labour). We are particularly interested in the first two categories, since these categories are most important in terms of number of households and since these categories particularly reflect the assumptions underlying the conceptual framework. Results are mixed: The panel data do not show a consistent pattern of significant impacts. However, the pooled data show significant impacts, both in fertilizer use and the share of commercial sales, increasing in start-of-season savings, and overall larger for households that hire labour.

Figure 5 Impact of start-of-season savings on fertilizer use by labour market status



Note: see next Figure

Figure 6 Impact of start-of-season savings on the commercial sales' share by labour market status



Note: Estimations based on IHPS (panel: 2010, 2013, 2016); Savings: 1, 2 or 3 denote resp. 1, 2 or all 3 types of start-of-season savings (maize stocks, livestock and cash). No start-of-season savings is the omitted category (all labour status). Labour market status: 1. hired labour = 0, ganyu labour > 0; 2. hired labour = 0, ganyu labour = 0; 3. hired labour > 0, ganyu labour = 0; 4. hired labour > 0, ganyu labour > 0.

9. Discussion and conclusion

Causal inference

Prior to discussing policy implications, an appraisal 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 support 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 informal start-of-season savings and technology adoption / market participation. However, the answer to the 'support' question can unfortunately not be fully affirmative. The dynamics of agricultural production reflected in the conceptual framework shows that the carryover to the following period is the outcome of a choice, and consequently start-of-season savings are endogenous. The endogeneity of start-of-season savings makes a causal interpretation of behavioural responses in agriculture on the basis of observational household survey data problematic[34]. To further support a causal interpretation, we have re-run the estimations with instrumented start-of-season stocks[35].

[34] Experimental evidence, widely regarded as the gold standard for causal inference, is not without its difficulties. Experimental designs are often hard to envisage in real world agriculture, occasionally imposing interventions that are strange to farm households and to developing country agriculture. Long run dynamic impacts, or the perspective on such impacts, are rare. Occasionally, feasibility of experiments appears to drive research design. Also, as indicated in the literature review, there is no single binding constraint (Jack, 2013; Suri and Udry, 2022). RCTs investigate the impact of a single policy and have difficulties to address multiple and interdependent constraints inherent to agriculture. Explicitly taking account of these interdependencies strikes as a fruitful undertaking, and makes natural experiments or the current exercise based on modelling and observational data interesting and useful alternatives.

[35] Inspired by a celebrated quote on causal inference ("A good way to do econometrics is to look for good natural experiments and use statistical methods that can tidy up the confounding factors that nature has not controlled for us." (McFadden)), we are keen to find a 'good natural experiment' in start-of-season stocks or assets, rather than instrumenting. So far, however, without success.

The results of these instrumental variable estimations (for the pooled data), reported in the appendix, are less convincing: coefficients are less accurately estimated, and often not significant at conventional levels of confidence.

Overall, specifications with continuous stock variables are performing worse than those with indicator variables. Also, start-of-season livestock is performing better in terms of significance than start-of-season maize stocks: we attribute the first to the general errors and inaccuracies of continuous variables and the second to the constructed nature of the start-of-season maize stocks.

Most notably: panel estimations completely disintegrate. We think this is partly because of the smaller number of observations (as also is the case for Table 9 and Table 10 estimations) and partly because much of the (incidence of) risk, and the joint effect of these risks, is absorbed by household fixed effects. Nevertheless, the instrumental variable estimations on the basis of pooled cross-sectional data often do have statistically significant coefficients or coefficients that come close to statistical significance and have the expected sign (see Table A2 and A3). We conclude that the base estimations are supported by the instrumental variable evidence.

Food prices and fertilizer subsidy policies

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 (Fafchamps, 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 based assets decrease during the 'high price' lean season (Zant, 2023), 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 (FISP) since 2005, followed by the Affordable Inputs Program (AIP) since 2020, 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[36]. But it is unclear if these input subsidies have long run impacts on cultivation practices and savings, and lift farm households to a structurally higher level of welfare. Input subsidies do not necessarily capitalize on the strengths and qualities of households in their agricultural production skills. For skilled farmers with good soils 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. Unskilled farmers with poor soils, 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 (Beaman, et al, 2013): if they qualify for input subsidies, they are likely to 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

[36] To see how input subsidies affect the budget constraint we need to expand the conceptual framework with inputs and input costs, affecting respectively agricultural production (in period 2) and available resources (in period 1).

and increase savings. Again, more work is needed to reveal how FISP interacts with informal savings and production efforts of different households.

Implications of analysis

Accepting 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[37], but has the disadvantage of losing value during food shortages (Zant, 2023). 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

[37] 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).

potential arbitrage returns are largest. Such a strategy makes an attractive alternative to the wide-spread selling-low and buying high behaviour of households.

In summary

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 by increased market participation. Simultaneously, farmers use savings to protect themselves against income fluctuations due to seasonality and production risk due to drought. In this paper we explore empirically the relationship between technology adoption and market participation on the one hand and informal start-of-season savings (maize stocks, livestock and cash savings) on the other hand, on the basis of three pooled 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 stylized inter-seasonal model of developing country agriculture are well supported by these survey data. In the estimations we find statistically significant positive effects of start-of-season maize stocks, livestock and cash savings on fertilizer use, the share of sales in production, and the share of cash crop area. Outcomes suggest an important role for policy to promote informal savings at the household level. 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 effects.

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.

Barrett, C.B., 2008, Smallholder Market Participation: Concepts and Evidence from eastern and southern Africa, *Food Policy*, 33, 4, 299-317.

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

Beaman, L., D. Karlan, B. Thuysbaert and C. Udry, 2013, 'Profitability of Fertilizer: Experimental Evidence from Female Rice Farmers in Mali', American Economic Review: Papers & Proceedings 2013, 103, 3, 381–386, doi.org/10.1257/ aer.103.3.381.

Beaman, L., A. BenYishay, J. Magruder and A.M. Mobarak, 2021, ‘Can Network Theory-Based Targeting Increase Technology Adoption?’, *American Economic Review*, 11, 6, 1918–43.

Bernoulli, D., 1954, ‘Exposition of a New Theory on the Measurement of Risk’, *Econometrica*, 22, 23–36.

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.

Chamberlain and T.S.Jayne, 2013, 'Unpacking the Meaning of 'Market Access': Evidence from Rural Kenya', *World Development*, 41, 245-264; doi.org/10.1016/j.worlddev.2012.06.004

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., J.Hoddinott and T.Woldehanna, 2005, 'Shocks and Consumption in 15 Ethiopian Villages, 1999-2004', *Journal of African Economies,* 14, 4, 559-585.

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.

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.

Fink, G., B.K. Jack, F.Masiye, 2020, 'Seasonal Liquidity, Rural Labor Markets, and Agricultural Production', *American Economic Review*, 110, 11, 3351-3392.

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.

Foster, A.D. and M.R. Rosenzweig, 2022, 'Are There Too Many Farms In The World? Labor-

Market Transaction Costs, Machine Capacities And Optimal Farm Size', *Journal of Political Economy*, 130, 3, 636-680.

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 Intern. Dev. 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.

LaFave, D. and D.Thomas, 2016, 'Farms, Families, and Markets: New Evidence on Completeness of Markets in Agricultural Settings', *Econometrica*, 84, 5, 1917-1960.

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

Manda, J. A.D. Alene, A.H. Tufa, S. Feleke, T. Abdoulaye, L.O. Omoigui and V. Manyong, 2020, 'Market participation, household food security, and income: The case of cowpea producers in northern Nigeria', *Food and Energy Security*, 9, e211.

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.

Mobarak A.M. and N.A. Saldanha, 2022, 'Remove barriers to technology adoption for people in poverty', *Nature Human Behaviour*, 6, 480–482.

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.

Rockafellar, R.T., 1970, *Convex Analysis*, Princeton University Press: Princeton Landmarks in Mathematics and Physics.

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

Stone, R., 1954, 'Linear Expenditure Systems and Demand Analysis: An Application to the Pattern of British Demand', *Economic Journal*, 64, 255, 511–527.

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, 2023, ‘How Costly is using Livestock as a Savings Device?’, *Food Security*, 15, 77–110, doi.org/10.1007/s12571-022-01316-6

Appendix

The optimal production-consumption path of our model

The choice for $(c_t, l_t, F_t) > 0$ and $(l_t^0, s_{t+1}) \geq 0$ and the corresponding $(\mu_t, \lambda_t) > 0$ in model (5) are fully characterized by the following first-order-conditions (FOC).[38]

FOC for optimal consumption:

$$\rho^{t-1}\, \underline{c} = \lambda_t\, p\, c_t, \text{ which implies: } \lambda_{t+1}\, c_{t+1} = \rho\, \lambda_t\, c_t.$$

The consumption path will follow the path of the marginal utilities of income. As and when the (discounted) marginal utility of income remains unchanged, consumption remains the same ($\lambda_{t+1} = \rho\, \lambda_t$ implies $c_{t+1} = c_t$), while a higher marginal utility of income reflects a situation where the farmer has to reduce future consumption ($\lambda_{t+1} > \rho\, \lambda_t$ implies $c_{t+1} < c_t$). For example, when a more dramatic drop of consumption after a crop failure is unavoidable, this will be reflected in a higher marginal utility of income. For example, when income in the next period appears twice as valuable, consumption is only half ($\lambda_{t+1} = 2\, \lambda_t$ implies $c_{t+1} = 0.5\, \rho\, c_t$). By the same token, as and when the marginal utility of income in the current period is higher than in the future, consumption today could be well below consumption tomorrow.

FOC for optimal fertilizer application:

$$\lambda_t\, p^F F_t \;= \lambda_{t+1}\, \alpha\, p\, q_t.$$

Fertilizer application too follows the path of the marginal utilities of income. As and when the marginal income in the next period remains the same, fertilizer cost in the current period will absorb its share of the crop revenues that become available in the next period ($\lambda_{t+1} = \lambda_t$ implies $p^F F_t \;= \alpha\, p\, q_t$), while a higher marginal utility of income reflects a situation that the fertilizer cost exceeds its proper share. For example, a low crop income after a crop failure

[38] Mathematically, model (5) is a convex program for which the first-order-conditions are both necessary and sufficient conditions to characterize the solution (Rockafellar, 1970).

could make income twice as valuable and fertilizer twice as costly ($\lambda_{t+1} = 2\,\lambda_t$ implies $p^F F_t = 2\,\alpha\,p\,q_t$).

FOC for optimal on-farm and off-farm work:

$$\mu_t\, l_t = \lambda_{t+1}\,(1-\alpha)\,p\,q_t,$$

$$(\mu_t - \lambda_t\, w^o)\, l_t^0 \;=\; 0.$$

The second condition says that, whenever the farmer opts for off-farm work, the marginal utility of family labor must be equal to the opportunity cost in terms of working off-farm ($l_t^0 > 0$ implies $\mu_t = \lambda_t\, w^o$). In that case, the first FOC regarding on-farm work is similar to the FOC for fertilizer application, namely $\lambda_t\, w^o\, l_t = \lambda_{t+1}\,(1-\alpha)\,p\,q_t$. In other words, when $l_t^0 > 0$, the off-farm wages determine on-farm wages, $\lambda_{t+1}\, w_t = \lambda_t\, w^o$, where $w_t > 0$ is the on-farm wage, defined as $w_t = \frac{(1-\alpha)\,p\,q_t}{l_t}$. It also happens that it is wise for the farmer to employ all family workers on the farm and set $l_t \;=\; \bar{l}$ and $l_t^0 \;=\; 0$ accordingly. This occurs in situations where agricultural productivity may be expected to be relatively high as compared to off-farm (ganyu) wages. In such cases, on-farm family wages $w_t\,\bar{l} = (1-\alpha)\,p\,q_t$ in the next period are more important than off-farm wages $w^o\,\bar{l}$ in the current period ($l_t^0 \;=\; 0$ imples $\lambda_{t+1}\, w_t > \lambda_t\, w^o$).

FOC for optimal end-of-season stocks:

$$(\lambda_t - \lambda_{t+1})\, s_{t+1} \;=\; 0.$$

Whenever the farmer opts for positive end-of-period stocks, the marginal utility of income in the current and the next period will coincide ($s_{t+1} > 0$ implies $\lambda_t = \lambda_{t+1}$). However, as and when household income is particularly low, for example after a crop failure, the household may opt to consume up to the point that all stock are depleted. In that case, het marginal utility of income in the current period is higher than the marginal utility in the next period ($s_{t+1} = 0$ implies $\lambda_t > \lambda_{t+1}$). In the final period, stocks will be null $s_{T+1} = 0$. The farmer will opt for $l_T = F_T = 0$ and off-farm work $l_T^0 \;= \bar{l}$. and consume the entire harvest from the penultimate season plus the off-farm wages and plus initial stocks s_T: $p\, c_T = p\, q_{T-1} + w^o\, \bar{l} + s_T$.

Using IHS household survey data for description and estimation

To supply empirical evidence we make use household survey data of Malawi: three cross-sections (IHS3, IHS4 and IHS5) and a panel data set (IHPS). Each cross-section covers at least two reference seasons (IHS3: 2008-2009 and 2009-2010; IHS4: 2014-2015 and 2015-2016; IHS5: 2017-2018 and 2018-2019). 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. We distinguish five major groups of crops: maize, groundnuts, tobacco, rice and other crops (mainly vegetables like pigeon peas, nkhwani and cow peas). Note that the crop balance is in quantities. Additionally, values for market sales (and production in IHS5) are recorded. Crop production in quantities 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. 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. 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. 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.

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[39]. Crop area that is not cultivated for several reasons (left fallow, rented out and given out for free) is cleaned from the data if necessary. 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 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 way 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

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

(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. To reduce arbitrariness we also run estimations with an alternative measures of the share of cash crop area.

The core explanatory variables in the household survey based estimations are start-of-season maize storage, start-of-season livestock and start-of-season cash savings. 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. 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. Livestock is the number of tropical livestock units, where the sub-Sahara specific weights for different types of livestock are obtained from FAO (2011). As a 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?'). Many households lack both types of savings (IHS-3: 26.8%; IHS-4: 41.0%; IHS-5: 30.0%). Start-of-season cash savings is unfortunately not recorded: however, we do know if outlays on inputs are funded through own savings. This recorded information is assumed to offer a good indicator of cash savings available at the start of the season. It is, however, not possible to approximate the amount of savings with the size of the outlays: these questions are not filled in!

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 possibly blurs the relationship because their role may be different[40]. Around 20%-42% of households earned no income from off-farm employment (IHS-3: 41.7%; IHS-4: 26.7%; IHS-5: 19.2%).

[40] 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.

Table A1 Combinations of start-of-season savings versus ganyu labour (IHS 3, 4, 5)

maize stocks – livestock – cash savings	IHS-3		IHS-4		IHS-5	
	0809	0910	1415	1516	1718	1819
0 – 0 – 0	0.670	0.648	0.735	0.763	0.826	0.806
	(0.026)	(0.014)	(0.017)	(0.011)	(0.022)	(0.016)
1 – 0 – 0	0.437	0.415	0.426	0.529	0.563	0.632
	(0.048)	(0.016)	(0.043)	(0.031)	(0.046)	(0.037)
0 – 1 – 0	0.651	0.625	0.720	0.757	0.805	0.801
	(0.031)	(0.017)	(0.026)	(0.014)	(0.026)	(0.022)
0 – 0 – 1	0.570	0.612	0.666	0.751	0.860	0.853
	(0.047)	(0.022)	(0.028)	(0.017)	(0.015)	(0.010)
1 – 1 – 0	0.355	0.374	0.361	0.477	0.561	0.495
	(0.035)	(0.016)	(0.040)	(0.030)	(0.044)	(0.037)
1 – 0 – 1	0.340	0.251	0.307	0.384	0.514	0.540
	(0.052)	(0.017)	(0.038)	(0.029)	(0.039)	(0.023)
0 – 1 – 1	0.593	0.494	0.634	0.669	0.825	0.795
	(0.041)	(0.022)	(0.025)	(0.017)	(0.016)	(0.013)
1 – 1 – 1	0.320	0.284	0.349	0.363	0.441	0.472
	(0.042)	(0.014)	(0.035)	(0.024)	(0.031)	(0.021)

Note: The table shows the share of households with earnings from ganyu labour for different combinations of start-of-season savings. Robust standard errors clustered by enumeration area are in brackets.

Table A2 Start-of-season savings versus ganyu labour (IHPS)

maize stocks – livestock – cash savings	2010	2013	2016
0 – 0 – 0	0.536 (0.037)	0.403 (0.029)	0.489 (0.034)
1 – 0 – 0	0.319 (0.034)	0.137 (0.030)	0.246 (0.042)
0 – 1 – 0	0.514 (0.041)	0.486 (0.037)	0.497 (0.033)
0 – 0 – 1	0.540 (0.059)	0.221 (0.051)	0.429 (0.053)
1 – 1 – 0	0.283 (0.037)	0.266 (0.028)	0.283 (0.058)
1 – 0 – 1	0.213 (0.044)	0.099 (0.037)	0.152 (0.044)
0 – 1 – 1	0.390 (0.069)	0.480 (0.057)	0.597 (0.043)
1 – 1 – 1	0.170 (0.041)	0.091(0.035)	0.240 (0.056)

Note: The table shows the share of households with earnings from ganyu labour for different combinations of start-of-season savings. Robust standard errors clustered by household are in brackets.

Table A3 Ganyu earnings vis-à-vis start-of-season savings (IHS 3,4&5, pooled&IHPS)

	(2)	(4)
Dependent variable:	household earnings from ganyu labour, per household member	
maize stocks (0/1)	-0.047*** (0.012)	-0.016*** (0.005)
livestock (0/1)	-0.013***(0.003)	0.010** (0.004)
cash savings (0/1)	-0.011*** (0.004)	-0.013* (0.007)
d(district x year)	yes	No
d(hh)	no	Yes
d(sy)	no	Yes
pseudo R^2	0.2454	-1.7211
Observations	28030	3379

Note: Column (1) is based on pooled IHS3, 4 and 5 data, while column (2) is based on IHPS panel data. ***, ** and * indicate statistical significance at the 1%, 5% and 10% level respectively.

Robustness Checks: tobacco and groundnut area in total crop area

Table A4 Market participation versus start-of-season savings (IHS3,4&5 pooled&IHPS)

	(1)	(2)
Dependent variable:	tobacco and groundnut area share	
maize stocks (0/1)	0.018** (0.008)	0.038* (0.020)
livestock (0/1)	0.129*** (0.007)	0.036* (0.020)
cash savings (0/1)	0.083*** (0.008)	-0.002 (0.021)
d(district x year)	yes	no
d(hh)	no	Yes
d(sy)	no	Yes
pseudo R^2	0.2027	0.9265
observations	28020	3326

Note: The cash crop area share used in this table is the share of tobacco and groundnut area in total crop area. Column (1) and (2) are based on pooled IHS3, 4 and 5 data, while column (3) and (4) are based on IHPS panel data. Robust standard errors in brackets are clustered by enumeration area (IHS-3 to IHS-5) and by household (IHPS). ***, ** and * indicate statistical significance at the 1%, 5% and 10% level respectively.

Robustness Checks: leaving out data from an entire survey year

Table A5a Fertilizer use vis-à-vis start-of-season savings (IHS 3, 4 & 5, pooled)

	(2)	(4)
Dependent variable:	fertilizer use	fertilizer use*
maize stocks (0/1)	30.2*** (2.0)	25.6*** (1.6)
livestock (0/1)	20.0*** (1.9)	11.8*** (1.5)
cash savings (0/1)	55.7*** (2.3)	42.0*** (1.8)
d(district x year)	yes	yes
pseudo R^2	0.0432	0.0433
Observations	17992	18411
Table A5b Fertilizer use vis-à-vis start-of-season savings (IHPS, panel)		
maize stocks (0/1)	16.1** (8.1)	14.4** (5.7)
livestock (0/1)	13.0* (7.6)	8.3 (5.4)
cash savings (0/1)	22.1*** (8.2)	14.4** (5.6)
d(household)	yes	yes
d(survey year)	yes	yes
pseudo R^2	0.1737	0.1812
Observations	2347	2380

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. *Maize stocks*, *livestock* and *cash savings* are start-of-season informal savings. (0/1) are indicator variables: 1 if informal savings are >0, and zero elsewhere. 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, with a lower limit [0]. Robust standard errors in brackets are clustered by enumeration area (IHS-3 to IHS-5) and by household (IHPS). We omit survey year 2014/15-2015/16 in IHS-3, 4 and 5, and 2013 in IHPS. ***, ** and * indicate statistical significance at the 1%, 5% and 10% level respectively.

Table A6a Market participation vis-à-vis start-of-season savings (IHS 3, 4 & 5, pooled)

	(1)	(2)
Dependent variable:	market sales share	cash crop area share
maize stocks (0/1)	0.050*** (0.009)	-0.018*** (0.005)
livestock (0/1)	0.128*** 0.009)	0.062*** (0.004)
cash savings (0/1)	0.139*** (0.010)	0.042*** (0.006)
d(district x year)	yes	yes
pseudo R^2	0.1495	0.3047
observations	18376	18604
Table A6b Market participation vis-à-vis start-of-season savings (IHPS, panel)		
maize stocks (0/1)	0.085** (0.040)	0.029 (0.022)
livestock (0/1)	0.031 (0.037)	0.044** (0.019)
cash savings (0/1)	0.077** (0.039)	0.045** (0.020)
d(household)	yes	yes
d(survey year)	yes	yes
pseudo R^2	0.8966	
observations	2089	2332

Note: *Market sales share* is the share of markets sales of all crops in the total value of the harvested crop. *Cash crop area share* is the share of the household crop area that is not cultivated with maize and not left fallow. *Maize stocks*, *livestock* and *cash savings* are start-of-season informal savings. (0/1) are indicator variables: 1 if informal savings are >0, and 0 elsewhere. 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, with a lower and an upper limit [0, 1]. Robust standard errors in brackets are clustered by enumeration area (pooled estimation, IHS-3 to IHS-5 in upper panel) and by household (IHPS in lower panel). We omit survey year 2014/15-2015/16 in IHS-3, 4 and 5, and 2013 in IHPS. ***, ** and * indicate statistical significance at the 1%, 5% and 10% level respectively.

Robustness Checks: only households that have not used credit

Table A7a Fertilizer use vis-à-vis start-of-season savings (IHS 3, 4 & 5, pooled)

	(2)	(4)
Dependent variable:	fertilizer use	fertilizer use*
maize stocks (0/1)	27.2*** (1.7)	23.9*** (1.4)
livestock (0/1)	16.5*** (1.5)	10.9*** (1.2)
cash savings (0/1)	62.1*** (1.9)	49.2*** (1.5)
d(district x year)	yes	yes
pseudo R^2	0.0456	0.0463
observations	21186	21583
Table A7b Fertilizer use vis-à-vis start-of-season savings (IHPS, panel)		
maize stocks (0/1)	22.0*** (6.9)	19.2*** (5.7)
livestock (0/1)	15.3** (6.6)	13.4*** (5.0)
cash savings (0/1)	28.4*** (7.1)	24.6*** (5.2)
d(household)	yes	yes
d(survey year)	yes	yes
pseudo R^2	0.1639	0.1660
Observations	2792	2808

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. *Maize stocks*, *livestock* and *cash savings* are start-of-season informal savings. (0/1) are indicator variables: 1 if informal savings are >0, and zero elsewhere. 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, with a lower limit [0]. Robust standard errors in brackets are clustered by enumeration area

(IHS-3 to IHS-5) and by household (IHPS). ***, ** and * indicate statistical significance at the 1%, 5% and 10% level respectively.

Table A8a Market participation vis-à-vis start-of-season savings (IHS 3, 4 & 5, pooled)

	(1)	(2)
Dependent variable:	market sales share	cash crop area share
maize stocks (0/1)	0.063*** (0.009)	-0.012** (0.005)
livestock (0/1)	0.125*** 0.008)	0.068*** (0.004)
cash savings (0/1)	0.155*** (0.009)	0.035*** (0.005)
d(district x year)	yes	yes
pseudo R^2	0.1484	0.2799
observations	21616	21834

Table A8b Market participation vis-à-vis start-of-season savings (IHPS, panel)

	(1)	(2)
maize stocks (0/1)	0.038 (0.028)	0.029* (0.017)
livestock (0/1)	0.060** (0.027)	0.036** (0.016)
cash savings (0/1)	0.030 (0.032)	0.045** (0.018)
d(household)	yes	yes
d(survey year)	yes	yes
pseudo R^2	0.7850	1.125
observations	2549	2756

Note: *Market sales share* is the share of markets sales of all crops in the total value of the harvested crop. *Cash crop area share i*s the share of the household crop area that is not cultivated with maize and not left fallow. *Maize stocks*, *livestock* and *cash savings* are start-of-season informal savings. (0/1) are indicator variables: 1 if informal savings are >0, and 0 elsewhere. 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, with a lower and an upper limit [0, 1]. Robust standard errors in brackets are clustered by enumeration area (pooled estimation, IHS-3 to IHS-5 in upper panel) and by household (IHPS in lower panel). ***, ** and * indicate statistical significance at the 1%, 5% and 10% level respectively.

Instrumental Variable Estimations

Table A9a Fertilizer use vis-à-vis start-of-season savings (IHS 3, 4 & 5, pooled)

	(1)	(1)
Dependent variable:	fertilizer use	fertilizer use*
maize stocks (0/1)	43.54*** (7.628)	39.41*** (5.865)
livestock (0/1)	21.71*** (7.241)	10.96* (5.653)
cash savings (0/1)	109.4*** (20.16)	64.23*** (15.99)
d(district x year)	yes	yes
Wald test (model)	(5289<0.001)	(5816<0.001)
Wald test of exogeneity	(23.6<0.001)	(16.7<0.001)
Observations	27133	27698

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. *Maize stocks*, *livestock* and *cash savings* are start-of-season informal savings. (0/1) are indicator variables: 1 if informal savings are >0, and zero elsewhere. 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 two-step tobit with endogenous regressors (start-of-season livestock, start-of-season maize stocks, start-of-season cash savings, Stata command: ivtobit), with a lower limit [0]. Standard errors are in brackets. The Wald test reports the chi2 statistic and its associated p-value in brackets. ***, ** and * indicate statistical significance at the 1%, 5% and 10% level respectively.

Instrumental Variable Estimations

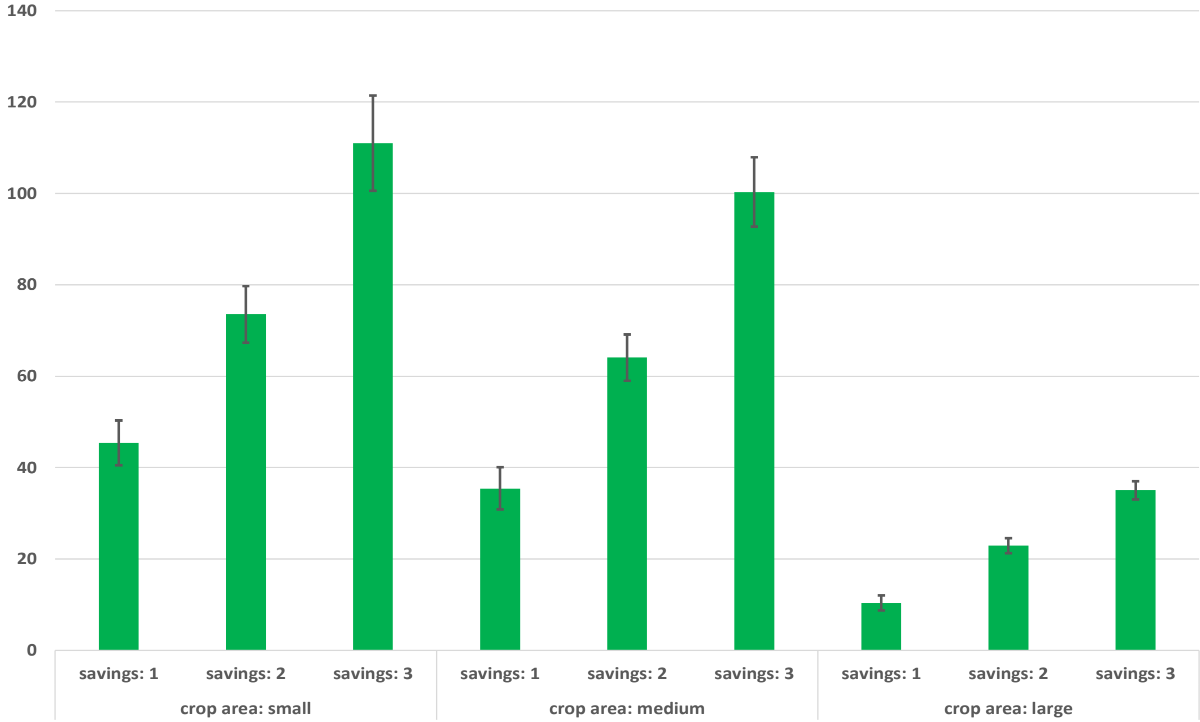
Table A9b Market participation vis-à-vis start-of-season savings (IHS 3, 4 & 5, pooled)

Dependent variable:	(1) market sales share	(2) cash crop area share
maize stocks (0/1)	0.221*** (0.054)	-0.102*** (0.029)
livestock (0/1)	0.028 (0.052)	0.081*** (0.018)
cash savings (0/1)	1.273*** (0.151)	0.370*** (0.069)
d(district x year)	yes	Yes
Wald test (model)	(2386<0.001)	(5071<0.001)
Wald test of exogeneity	(183.6<0.001)	(86.5<0.001)
Observations	27692	28020

Note: *Market sales share* is the share of markets sales of all crops in the total value of the harvested crop. *Cash crop area share* is the share of the household crop area that is not cultivated with maize and not left fallow. *Maize stocks*, *livestock* and *cash savings* are start-of-season informal savings. (0/1) are indicator variables: 1 if informal savings are >0, and 0 elsewhere. 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 two-step tobit with endogenous regressors (start-of-season livestock, start-of-season maize stocks and start-of-season cash savings; Stata command: ivtobit), with a lower and an upper limit [0, 1]. Standard errors are in brackets. The Wald test reports the chi2 statistic and its associated p-value in brackets. ***, ** and * indicate statistical significance at the 1%, 5% and 10% level respectively.

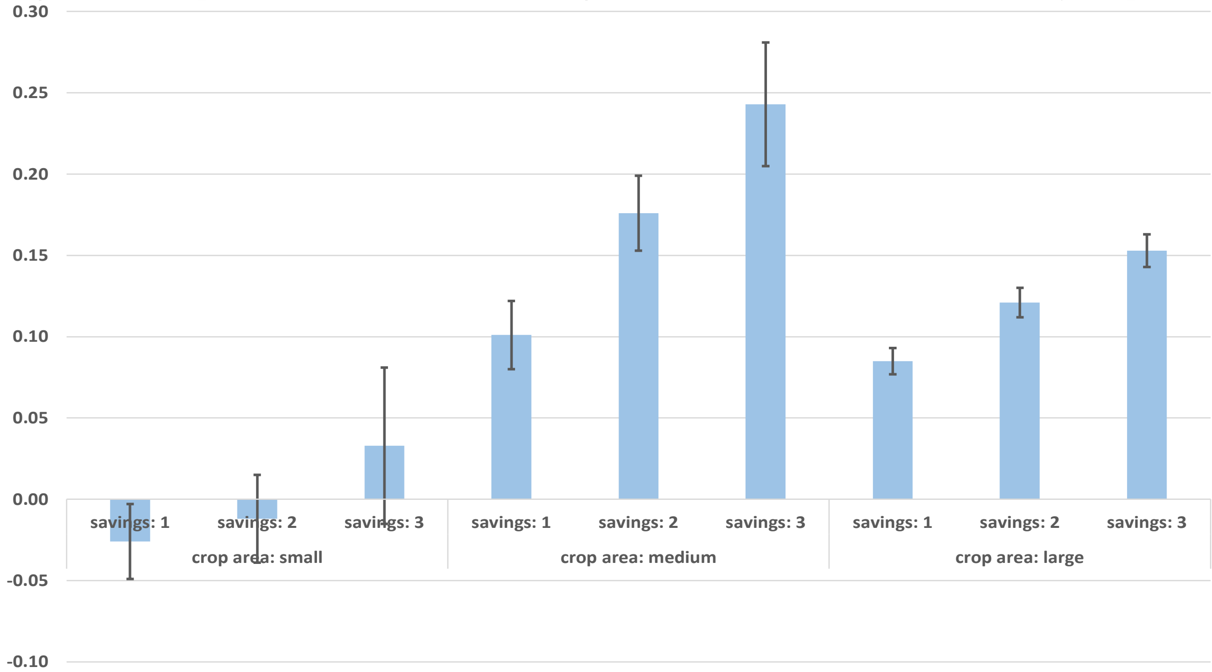
Heterogeneity of impact using panel and pooled data, different combinations of savings

Figure A1 Impact of start-of-season savings on fertilizer use by crop area



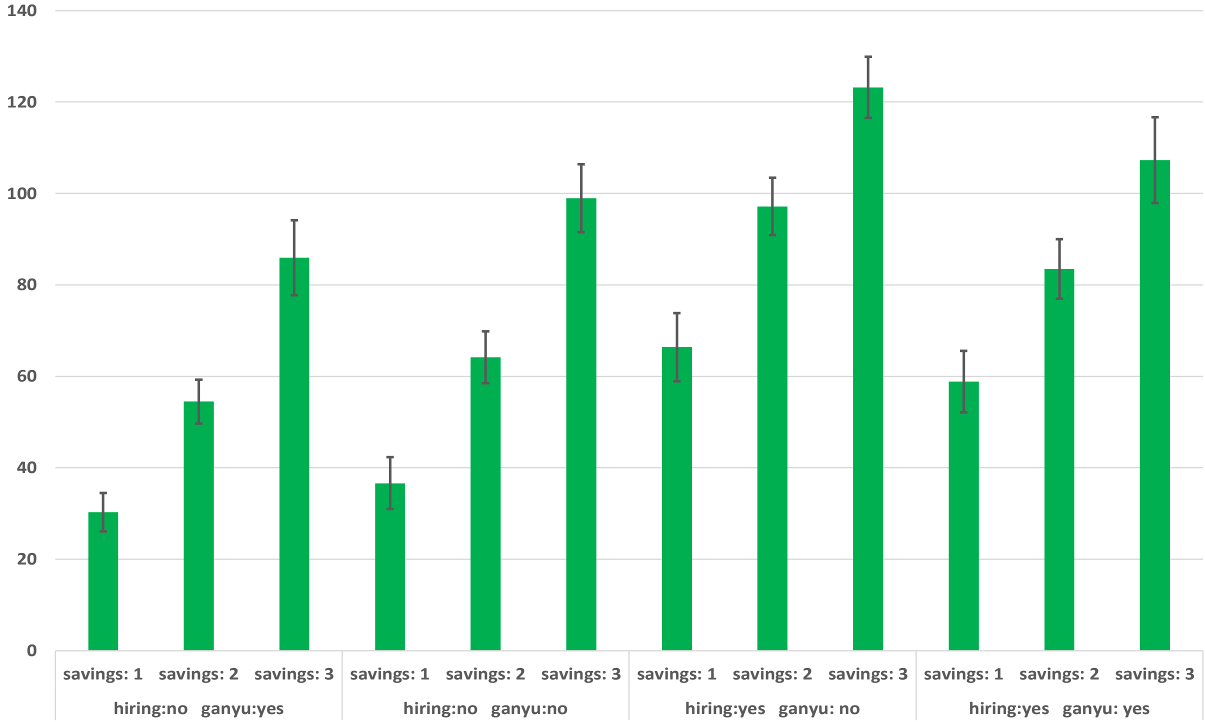
Note: see Figure below

Figure A2 Impact of start-of-season savings on the commercial sales' share by crop area



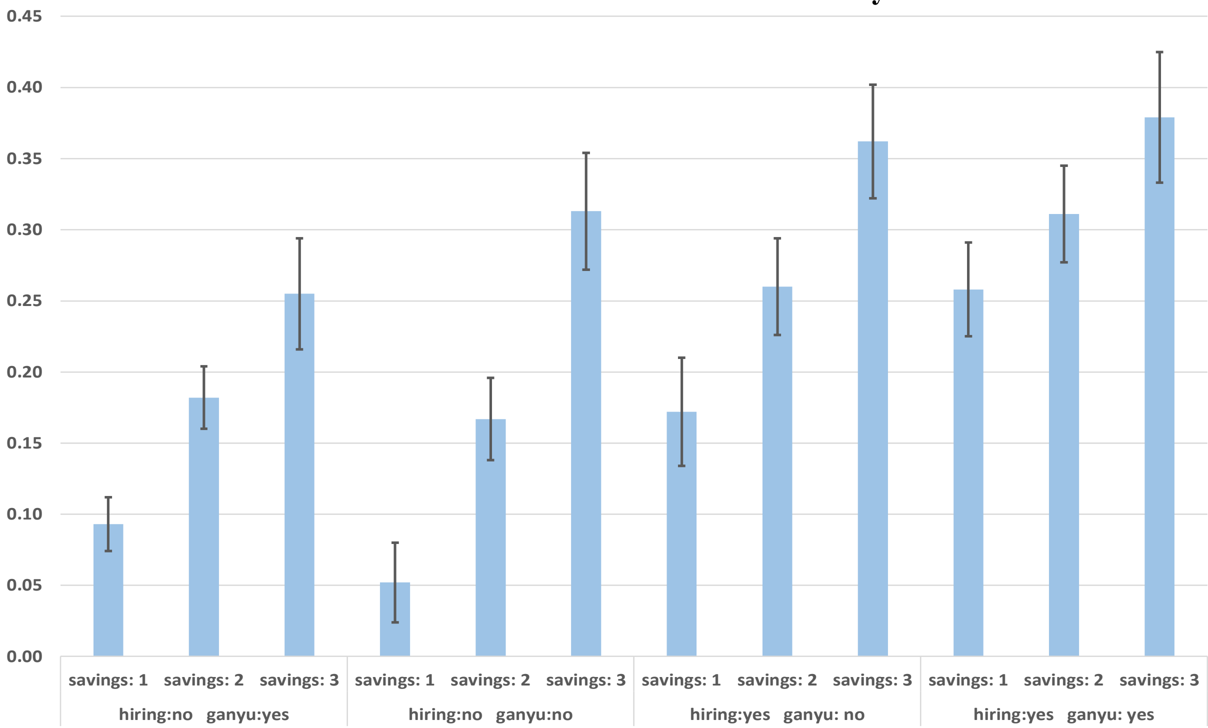
Note: Estimations are based on IHS3, IHS4 and IHS5 (pooled data: 2010, 2016, 2019); Savings: 1, 2 or 3 denote resp. 1, 2 or all 3 types of start-of-season savings (maize stocks, livestock and cash). No start-of-season savings is the omitted category (all crop area). Crop area: small 0-0.9 acres; medium 0.9-1.8 acres and large >1.8 acres.

Figure A3 Impact of start-of-season savings on fertilizer use by labour market status



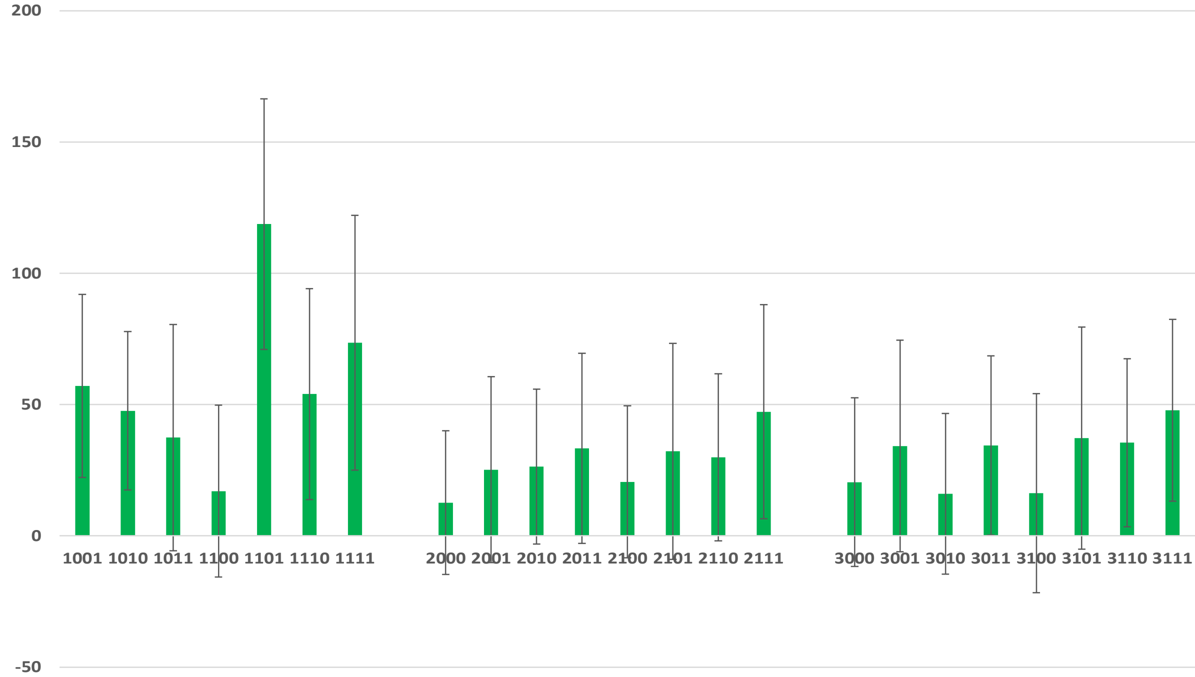
Note: see Figure below

Figure A4 Impact of start-of-season savings on the commercial sales' share by labour market status



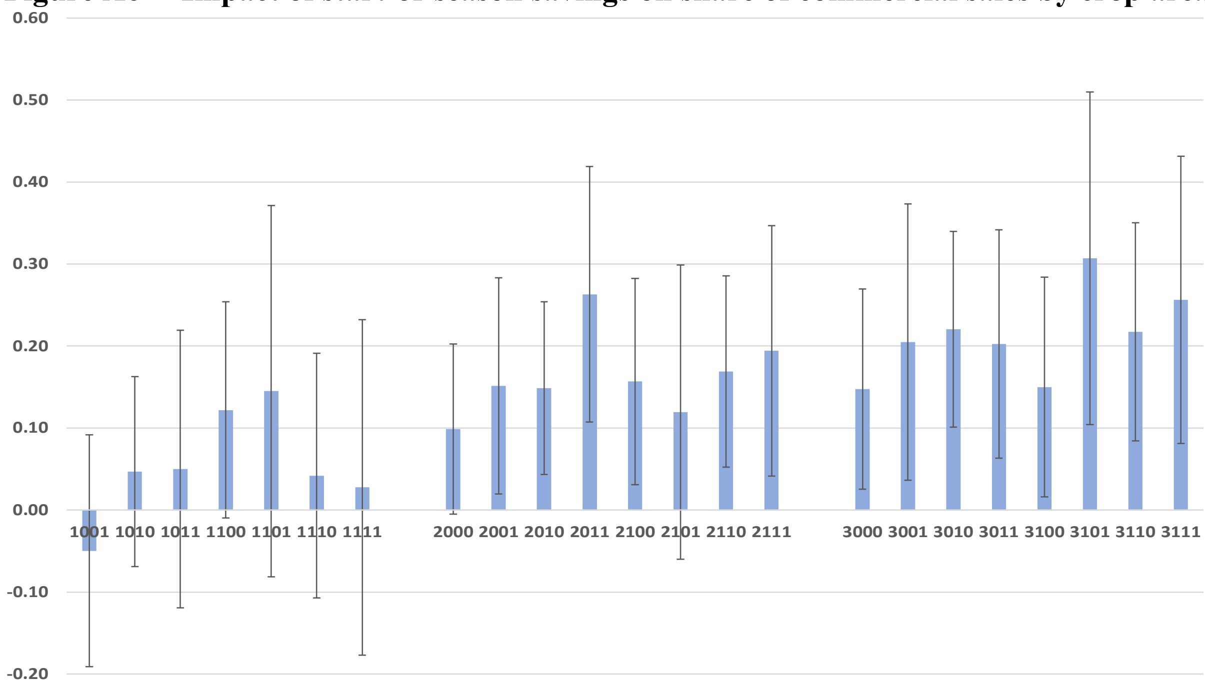
Note: Estimations are based on IHS3, IHS4 and IHS5 (pooled data: 2010, 2016, 2019); Savings: 1, 2 or 3 denote resp. 1, 2 or all 3 types of start-of-season savings (maize stocks, livestock and cash). No start-of-season savings is the omitted category (all labour status). Labour market status: 1. hired labour = 0, ganyu labour > 0; 2. hired labour = 0, ganyu labour = 0; 3. hired labour > 0, ganyu labour = 0; 4. hired labour > 0, ganyu labour > 0.

Figure A5 Impact of start-of-season savings on fertilizer use by crop area



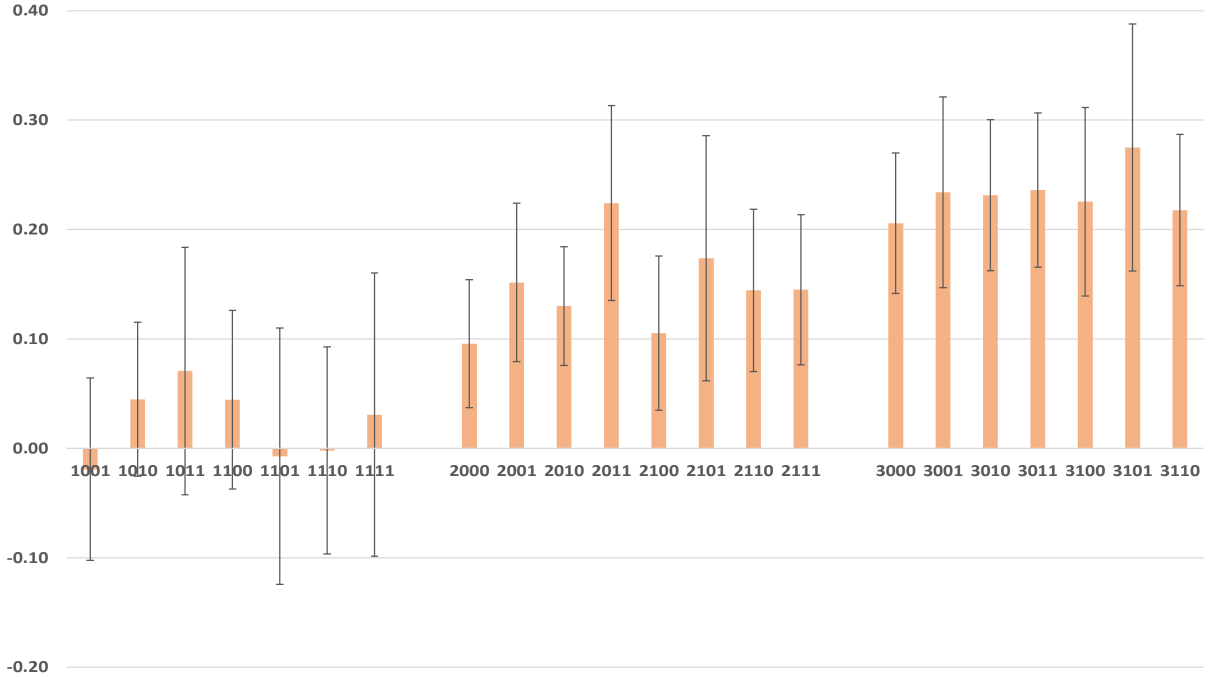
Note: See Figure below.

Figure A6 Impact of start-of-season savings on share of commercial sales by crop area



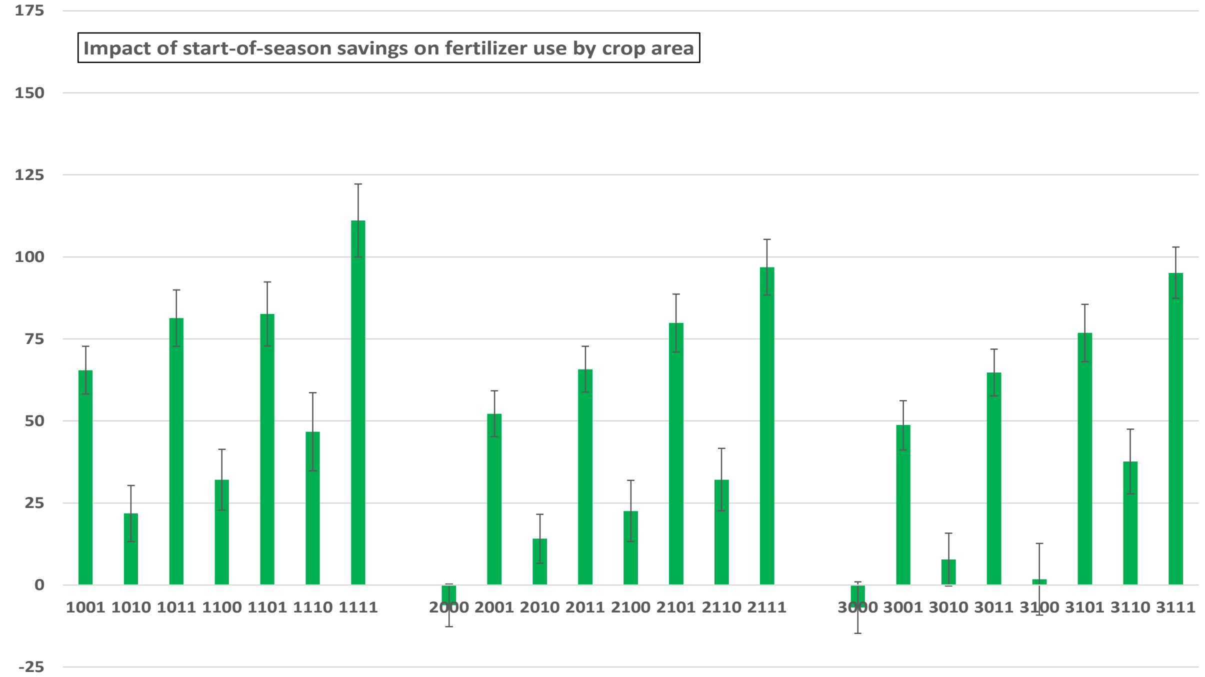
Note: Estimations based on IHPS (panel: 2010, 2013, 2016); positions of the axis number (xxxx=1234): 1 = crop area tercile; 2 = start-of-season maize stocks (0/1), 3 = start-of-season livestock (0/1), and 4 = start-of-season cash savings (0/1). Crop area: small 0-0.9 acres; medium 0.9-1.8 acres and large >1.8 acres.

Figure A7 Impact of start-of-season savings on share of cash crop area by crop area



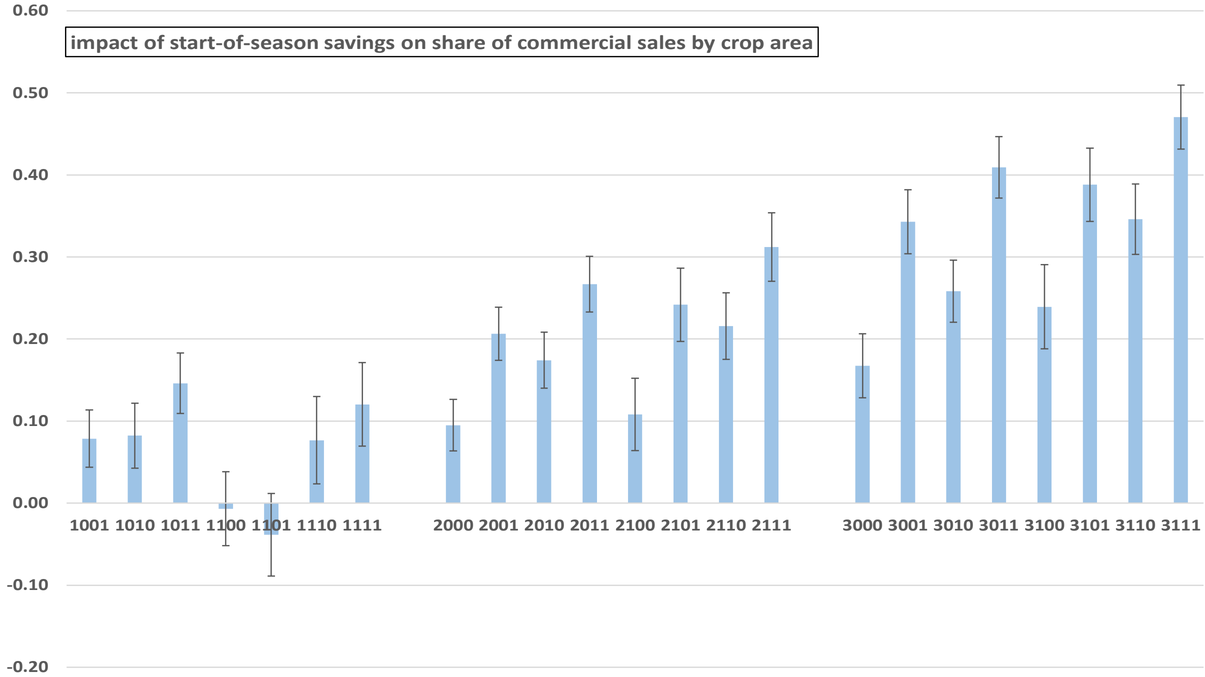
Note: Estimations based on IHPS (panel: 2010, 2013, 2016); positions of the axis number (xxxx=1234): 1 = crop area tercile; 2 = start-of-season maize stocks (0/1), 3 = start-of-season livestock (0/1), and 4 = start-of-season cash savings (0/1). Crop area: small 0-0.9 acres; medium 0.9-1.8 acres and large >1.8 acres.

Figure A8 Impact of start-of-season savings on fertilizer use by crop area



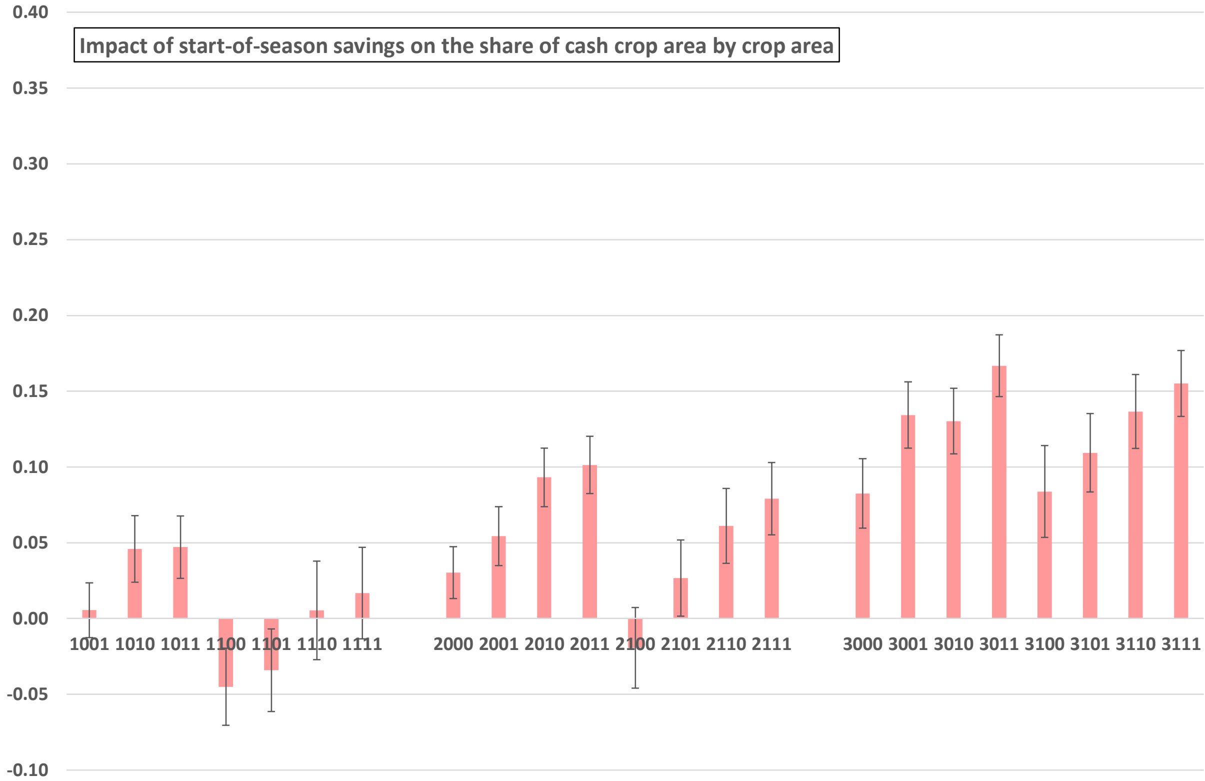
Note: Estimations based on IHS3, IHS4 and IHS5 (pooled data: 2010, 2016, 2019); positions of the axis number (xxxx=1234): 1 = crop area tercile; 2 = start-of-season maize stocks (0/1), 3 = start-of-season livestock (0/1), and 4 = start-of-season cash savings (0/1).

Figure A9 Impact of start-of-season savings on share of commercial sales by crop area



Note: See Figure below.

Figure A10 Impact of start-of-season savings on share of cash crop area by crop area



Note: Estimations based on IHS3, IHS4 and IHS5 (pooled data: 2010, 2016, 2019); positions of the axis number (xxxx=1234): 1 = crop area tercile; 2 = start-of-season maize stocks (0/1), 3 = start-of-season livestock (0/1), and 4 = start-of-season cash savings (0/1).