The Impact of Incomplete Financial Markets on Crop-Choice, Agricultural Productivity, and Welfare

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I study the aggregate implications of completing financial markets in agriculture. Using the Ugandan National Panel Survey, I document that farmers face a trade-off between crop yields and risk and low-yield crops represent the main share of output for poor farmers. Theoretically, I build an incomplete markets model with a crop-portfolio choice. Poor households optimally sacrifice profitability to reduce risk exposure by under-investing in intermediates and shifting investment to low-yield crops. Quantitatively, completing markets increases agricultural productivity by 21.75 percent, with half of the gain from reallocating inputs across farmers and crops, and the welfare gain equals 28.4 percent.

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Across poor economies, households live under a lot of risk with little access to formal financial markets or government safety nets. Many of these households heavily depend on agriculture, a sector that features high-income risk and particularly low productivity in developing countries—Caselli (2005), Restuccia et al. (2008), and Gollin et al. (2014). In this article, I quantify the gains in agricultural productivity and welfare of completing financial markets in rural Uganda.

Complete markets tests in developing countries typically show a high degree of consumption insurance, Townsend (1994), and other works.[1] Yet informal insurance mechanisms are imperfect and costly. When farmers in developing countries are offered insurance products, they tend to take riskier and more productive decisions, as increasing fertilizer usage, Karlan et al. (2014a), or shifting to more productive crops, Mobarak and Rosenzweig (2013) and Cai (2016). Lack of per-

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[1] Townsend (1994) finds that household consumption responds little to idiosyncratic income shocks in rural India. Similarly, Paxson (1993) finds little evidence that consumption tracks income seasonality in Thailand. More recent studies include Chiappori et al. (2014) and Kinnan (2021).

fect insurance can have large aggregate impacts, albeit knowledge is more scarce on this dimension. Donovan (2021) and this paper try to fill this gap. Donovan (2021) shows how lack of insurance distorts farmers intermediates investment, and that translates, also via general equilibrium effects, to an aggregate low agricultural productivity.

In this paper, to understand the relationship between incomplete financial markets and agricultural productivity, first, I study the empirical relationship between crop productivity , crop risk, and the crop selection of heterogeneous farmers. Second, I develop an incomplete markets model with a crop-portfolio choice. Besides consumption and saving decisions, heterogeneous households decide how much to invest in intermediates in high-risk, high-returns technology—high-yield crops—and in low-risk, low-returns technology—low-yield crops. To provide the quantitative results, I calibrate the model with nationally representative micro-data from Uganda, focusing on replicating the distribution of agricultural production, total household income, liquid wealth and volatility moments on crop production and income. The numerical results suggest that completing financial markets would increase agricultural productivity by 21.75 percent, and the welfare gain would be a 28.4 percent increase in equivalent units of consumption.

This article has two main contributions. First, I show that uninsurable risk can explain part of the low agricultural productivity observed in developing countries through two channels: (1) through lowering the intermediates share and (2) through generating a misallocation of intermediates across crops and heterogeneous farmers. Second, I show that even in the context of high consumption smoothing—-which the model quantitatively accounts for—the welfare gains of completing financial markets in poor rural areas are large.

Regarding the empirical results, I use the first five waves of the Ugandan National Panel Survey (UNPS). The UNPS offers detailed agricultural data at the household and plot level. From that, I compute the yields of the main crops grown in Uganda where the yields are measured as the production value—including non-sold production valued with median local consumption prices—per land unit ($/acres). Then, I study the relationship between the average yields of the crops, the volatility of the crops, and the crop selection of Ugandan farmers.

With this analysis, I find three main empirical results. First, there is a strong positive correlation between crop yields and crop riskiness. Crops such as plantain bananas, rice, or groundnuts have relatively high yields but also more volatile yields. Crops such as beans, cassava, or sorghum have lower and less volatile yields. Second, the share of output from high-yield, high-risk crops increases along with the wealth distribution of farmers. Farmers in the lowest wealth quartile obtain most of their production from low-yield crops—mostly beans, maize, and cassava. Farmers in the top quartiles obtain most of their output from high-yield crops—mostly plantain bananas. Third, most farmers grow simultaneously high-yield crops and low-yield crops.

The model presents an economy with one type of agent—households—that ex-ante only differ in a permanent component on agricultural production. Households live infinitely and have standard preferences with a CRRA instant utility function. Households obtain income from investing in intermediates in a high-returns and high-risk technology, from investing in intermediates in a low-returns and low-risk technology, and from an exogenous non-agricultural income process. The economy presents a world with risk, with household-idiosyncratic shocks in the three sources of income. Financial markets are incomplete following the tradition of incomplete markets models as in Bewley (1986), Imrohoroğlu (1989), Huggett (1993), and Aiyagari (1994). Yet, to be consistent with the evidence of the difficulties to save in developing countries, I follow the approach in Donovan (2021) and Lagakos et al. (2023) and I assume savings are in a risk-free asset with a depreciation rate and there is a no borrowing constraint.[2] Given that most of the agricultural production in Uganda is at subsistence level, I model the economy as a small open economy where input prices are fixed.

The model exhibits two mechanisms by which households deal with risk: precautionary savings and precautionary income choices. In the first, households accumulate wealth to cope with the risk. In the second, households under invest in intermediates and shift the investment to the low-returns and safer technology (low-yield crops) to reduce risk exposure. The poorer the households the more they reduce intermediates investment and the investment is more displaced towards the low-returns technology. This makes the households on expectation poorer in the next period, generating a negative circle between income choices and wealth.[3]

I discipline the model to the region with the Ugandan National Panel Survey (UNPS), a survey that is part of the ISA-LSMS project. Measuring living standards and, in particular, household income is a daunting task in developing countries.Two references to better understand measuring poverty and using household survey data in developing countries are Deaton (2005) and Deaton (2019). The ISA-LSMS project implements a set of laborious questionnaires that allows us to construct an accurate measures of agriculture, consumption, income, wealth, and other variables for households in Sub-Saharan Africa. Such extensive information allows me to virtually recover the entire household budget constraint in the model from this single dataset.

With the calibrated model in hand, I investigate the capacity of the model to replicate critical moments in the data that are not directly targeted in the calibration. First, I show that the model generates an endogenous relationship between crop output and the wealth distribution that is close to the relationship

[2]Although risk-sharing schemes are an essential source of insurance in developing countries, e.g., Udry (1994), Besley (1995), Ligon et al. (2002), Fafchamps and Lund (2003), for tractability purposes, here insurance is modelled only through a self-insurance mechanism. Yet, the quantitative exercise is able to capture both mechanisms since the model can account for the insurance observed in the data.

[3]The dynamics of poverty traps in this model differ from the standard poverty traps in two aspects. First, poverty is not an absorbent state, households might experience a continuation of good shocks and move out of the trap. Second, once-a-time big-push policies will not be effective at moving households to the high-returns technology.

observed in the data. Second, I show that the model is able to approximate well the observed inequality in rural Uganda. The framework of incomplete markets provides a theory for consumption, income, and wealth inequality because the distributions are endogenous to the model. Thus, one of the main objectives of this literature has been to account for these distributions and their trends mainly for the United States and other rich economies—e.g. Aiyagari (1994), Quadrini et al. (1997), Castaneda et al. (2003), Krueger and Perri (2006), or Krueger et al. (2016). Nevertheless, the consumption, income, and wealth distributions and their dynamics are less known for low-income countries. De Magalhães and Santaeulàlia-Llopis (2018) provide a detailed description of such distributions for some of the poorest countries in Sub-Saharan Africa. Here, I bring a quantitative theory on inequality in Uganda—which, as far as my knowledge goes, this is a new exercise for a country in Sub-Saharan Africa. On this line, by calibrating the dispersion of agricultural production, the model approximates well the observed income distribution and it does less so for the distribution of liquid wealth. More interestingly, without targeting, the calibrated model accurately replicates the consumption distribution. Hence, the model captures the transmission of income inequality to consumption inequality in Uganda. Third, I show that by targeting the level of income volatility, the model is able to generate a level of consumption volatility that is very close to the one observed in the data.

Capturing the transmission of income volatility to consumption volatility is key to discipline the quantitative evaluation of the impact of incomplete markets. The benchmark model needs to capture relatively well the standing levels of insurance in the economy. Similarly, the benchmark model by also capturing the transmission of income inequality to consumption inequality, provides a framework to carefully perform a welfare evaluation.

To obtain the main results of this paper, I develop a planner's problem that replicates the competitive equilibrium allocations of intermediates and consumption under complete markets in agriculture. In this case, intermediates' allocations are such that households maximize discounted expected profits. By comparing the calibrated benchmark model with this counterfactual world, I obtain the main results of the paper.

Completing financial markets in agriculture increases agricultural output and agricultural productivity by 21.38 percent. In this work labor and land size are fixed. Thus, agricultural productivity, both in per worker terms or in per land unit, is equivalent to agricultural production. The productivity increase comes from (1) a higher investment in intermediates, which increases by 44 percent, (2) and from an efficient reallocation of the intermediates across crops and farmers. To quantify these efficiency gains, I restrict the complete markets solution to the case where the intermediates share is equal as in the benchmark economy. With this counterfactual, I find that the efficiency gains account for half of the total increase in agricultural output.

When financial markets in agriculture are complete, demand for precautionary savings falls. Given that in this economy saving is costly at a depreciation rate, the impact on aggregate consumption is larger than on income; consumption increases by 25 percent.

In this model, completing markets has non-obvious effects on the cross-sectional distributions of consumption. Completing markets has an egalitarian effect: consumption allocations no longer depend on the good or bad realizations of the agricultural shocks. Nevertheless, in this exercise, completing markets has two inequality-enhancing effects that outweigh the previous egalitarian force. First, households with high permanent components experience the most significant increase in output. In the stationary equilibrium, these households are not uniformly distributed, but they are typically concentrated in the middle and top of the distribution. Second, completing markets decreases costly savings, which are highly concentrated at the top. With the three effects together, the consumption Gini index after completing markets increases by 3.7 percent.

All these effects have important effects on welfare which I measure with an ex-ante welfare measure in terms of consumption equivalent variation. Households would need to experience 28.4 percent in their lifetime consumption to be indifferent between being born in the status-quo world with incomplete markets and the world with complete markets in agriculture.

A. Related Literature

The most related paper to this work is Donovan (2021). In a dynamic general equilibrium model including agricultural and industrial sectors, the author shows how completing financial markets increases agricultural productivity in India and reduces the observed cross-countries agricultural productivity gap. I contribute to his work in three aspects. First, I show that uninsurable risk reduces intermediates investment but also misallocates the intermediates across agricultural technologies and farmers with different permanent components. Second, I provide the welfare gains of completing financial markets in agriculture. An important insight from the welfare analysis is that the gains on consumption are substantially larger than in income. Third, I complement the general validity of the insights in Donovan (2021). Uganda is a much poorer economy with little industrialization and based on subsistence agriculture. I show that even without general equilibrium effects through workers' reallocation, different model assumptions, and a different country/data, the same insights remain.[4] Uninsurable risk can have a large impact on agricultural productivity.

This paper also relates to other works documenting the impact of uninsurable risk in agricultural decisions. In rural India, and exploiting variation on delays in the monsoon rains, Rosenzweig and Binswanger (1992) show that the impact

[4]In this paper, labor supply is fixed. In Donovan's model, households decide how much to work on the farm—after the shocks' realizations—and in the industry. Other important different assumptions are that I do not include a subsistence requirement while I also include household permanent components in agricultural production.

of risk in agricultural investment depends on the wealth of the farmers, with poor farmers experiencing significant distortions while wealthy farmers taking decisions close to profit maximization. This work obtains the same result but with the distribution of wealth being endogenous to the model. Thus, it provides the equilibrium effect of agricultural decisions and wealth inequality.

By studying the impact of risk and crop choice under large but imperfect insurance, this work strongly relates to Kurosaki and Fafchamps (2002). Using detailed data for villages in the Pakistan Punjab, The authors show both empirically and theoretically that ex-ante crop choices depend on price and yield risk even when accounting for risk-sharing village mechanisms. Here, I present an aggregate quantification of the cost of agricultural risk on crop choices while being able to quantitatively capture the existing levels of consumption insurance in rural Uganda. In Ethiopia, Dercon and Christiaensen (2011) find that fertilizer usage drops when farmers face the risk of harvest failure. This paper and Donovan (2021) also account for the impact of uninsurable risk on intermediate inputs usage, and show its impact on the aggregate economy.

The paper builds on the literature of the low agricultural productivity in developing economies—Restuccia et al. (2008), Yang and Zhu (2013), Lagakos and Waugh (2013), Adamopoulos and Restuccia (2014), and Chen (2017)—and mainly, to those studies focusing on Sub-Saharan Africa—Gollin and Rogerson (2014), Gottlieb and Grobovšek (2019), and Chen et al. (2023). Adamopoulos and Restuccia (2022) show that geographic factors cannot explain the agricultural productivity gap between poor and rich countries. The authors also point out that there would be large productivity gains—a one-fifth reduction in the gap—if there was an efficient distribution of crops within poor countries. This paper shows that part of the inefficient allocation of crops can result from uninsurable risk.

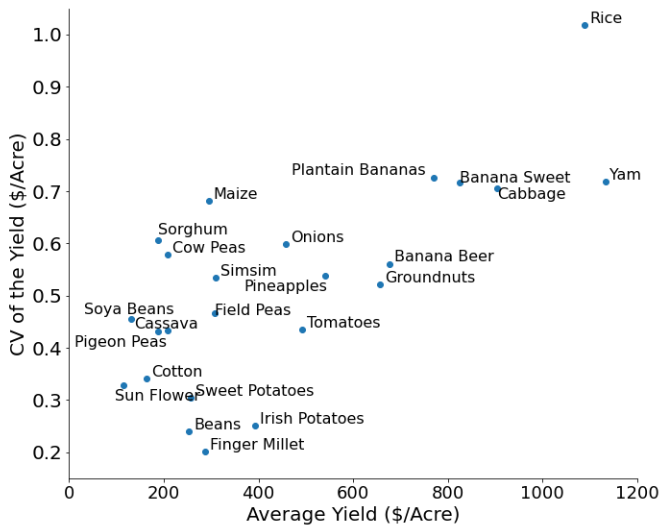
By studying the welfare effects of incomplete markets in rural Uganda, this paper relates to the literature above on insurance in development. This paper finds that even in the context of high consumption smoothing, the welfare impact of incomplete markets is large. The distortions on income and savings choices to smooth consumption imply a big loss in economic growth. These results go in line with other works documenting a trade-off between insurance and growth including Rosenzweig and Wolpin (1993), Kurosaki and Fafchamps (2002), Munshi and Rosenzweig (2016) and, Santaeulalia-Llopis and Zheng (2018).

I. Empirical Findings

This section explores the relationships between agricultural yields, risk, and farmers' usage across the main crops grown in Uganda. With this analysis, I document three main empirical results: (1) there is a strong and robust positive correlation between yields and risk across crops, (2) low-risk, low-yield crops represent the main share of output for poor farmers, and (3) most farmers grow simultaneously low-risk low-yield crops and high-risk high-yield crops.

To document these results, I use the first five waves of the Ugandan National

Panel Survey (UNPS) and I compute the yields of the crops harvested in Uganda. Yields are the value of production per land unit ($/acres), also known as agricultural productivity or land productivity. The value of production is the sum of the household reported value on sales on the crop plus the non-sold production valued with district-level median consumption prices.[5] The unit of land is the reported number of acres devoted to cultivating the crop. For the interested reader, a deeper explanation on how the variables are computed is provided in the data section (section III).



Note: Yield observations ($/acres) are at the wave level. All crops with span of time between planting and harvest below 2 years.
Source: UNPS: 09/10–15/16.

Figure 1. : Crop Yield and Crop Risk in Uganda

Figure 1 plots the average yield against the Coefficient of Variation (CV) of the yield across the main crops cultivated in Uganda. Crops that have higher yields have higher volatility and the differences are large in magnitude. For example, the yield of plantain bananas, a major staple crop in Uganda and locally known as matooke, have an average yield of around $769 per acre and a CV of 0.73. In comparison, the yield of beans is $253 per acre and a CV of 0.24. The positive relationship between average yields and the CV of the yields is strong, with a correlation of 0.81.

For robusteness, Table 1 computes the correlation between yields and risk across crops using three different measures of risk, the Standard Deviation (SD), the

[5]Given that a significant fraction of the agricultural production in Uganda is not sold, assigning an adequate value to the unsold production is key. To do so, first, I convert all reported production into standard units (kgs), and then I use median consumption prices at the district level to capture the shadow value of not selling the crop. See section III for a discussion on how variables are construced.

Coefficient of Variation (CV), and the Gini Index; 6 methods of grouping the data; and 2 samples of crops, all crops and no long-term crops—crops that the period between planting and harvesting is not longer than two years. Long-term crops present a problem with yield measures since the crop might be at different stages of production across waves, artificially increasing dispersion. Moreover, long term-crops imply large fixed costs while this work focuses on risk distortions.

From Table 1, we observe that for all the different computations, the correlation between yields and risk is positive and typically above 0.6. The strong correlation between crop yields and risk is observed across the three volatility measures; it is observed across pooling crop yield observations at the household-wave level or at the wave level; across each of the four main regions of Uganda; and across no long-term crops and all the crops.

Table 1—: Correlation Average Yields and Risk Measures among Crops

Risk Measure	Correlation Coefficient ($r \in [-1, 1]$)					
	Grouping Data by:					
	Hhs-Waves	Nationwide	Central	Eastern	Northern	Western
	(1)	(2)	(3)	(4)	(5)	(6)
Excluding long-term crops:						
SD	0.63	0.92	0.99	0.84	0.98	0.91
CV	0.45	0.81	0.83	0.47	0.69	0.27
Gini	0.63	0.83	0.82	0.75	0.81	0.58
All crops:						
SD	0.97	0.99	0.99	0.94	0.98	0.84
CV	0.93	0.61	0.76	0.69	0.69	0.29
Gini	0.54	0.57	0.79	0.78	0.81	0.74

Note: Grouping observations by pooling household and waves (1), by aggregating at the wave level (2) and, aggregating at the four main regions in Uganda (3)-(4)-(5)-(6).
Source: UNPS: 09/10–15/16.

Next, I study the crop portfolio along with the wealth distribution of Ugandan farmers. Rosenzweig and Binswanger (1992) show that, in India, poor farmers switch from profitability to risk by choosing less profitable and less risky capital investments in the farm. Here I study whether poor farmers in Uganda choose less profitable, less risky crops. To do so, from the non-long-term crops, I group those crops above the median yield as high-yield crops while those below it as low-yield crops. The high-yield crops are bananas (for beer), plantain bananas, sweet bananas, cabbage, eggplants, groundnuts, Irish potatoes, onions, pineapples, pumpkins, rice, sugarcane, tomatoes, and yam. The low-yield crops are beans, cassava, cotton, dodo, cowpeas, field peas, finger millet, maize, pigeon peas, simsim, sorghum, soya beans, sunflower, and sweet potatoes.

Figure 2 plots the shares of high-yield and low-yield crops on total household agricultural production along the wealth distribution.

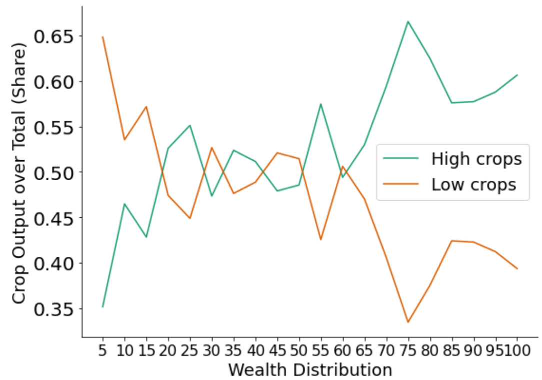
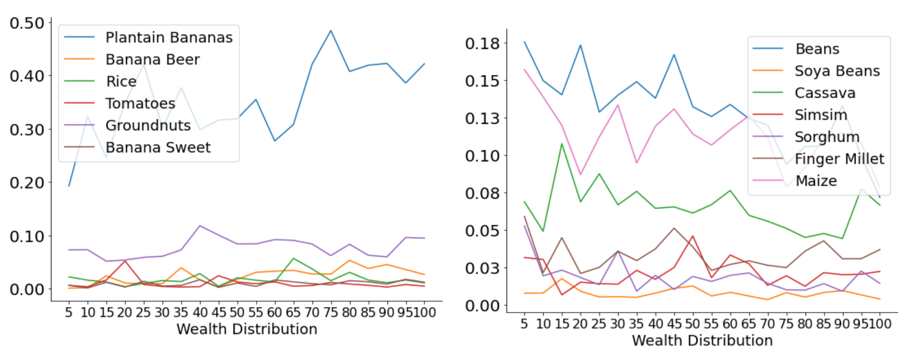


Figure 2. : High Crops vs Low Crops along the Wealth Distribution

Note: the list of high-yield crops and low-yield crops can be found in the text. Farmers' wealth includes estimated land value, household assets, livestock, and farming capital.
Source: UNPS: 09/10–15/16.



(a) High-yield Crops

(b) Low-yield Crops

Figure 3. : Crops Production along the Wealth Distribution

Notes: a) plots the six most grown high-yield crops, while b) plots the seven most grown low-yield crops.
Source: UNPS: 09/10–15/16.

For the farmers at the bottom of the wealth distribution, 0–5 and 5–10 percent bins, low-yield crops account for around 60 percent of their agricultural production. As farmers become richer, the share of low-yield crops in total production decreases. For farmers in the middle of the distribution, production comes roughly equal from low-yield crops and high-yield crops. For farmers at the top of the wealth distribution, 80–85 to 95–100 bins, around 60 percent of their agricultural production comes from high-yield crops.

Sub-plot (3a) shows the shares of the six most cultivated high-yield crops, while (3b) the seven most cultivated low-yield crops along the wealth distribution. For the high-yield crops, we observe that the increase in the shares of production along the wealth distribution is driven mainly by plantain bananas. From low-yield crops like beans, maize, and cassava, we observe a steady decrease in the shares of total production—roughly from 16 to 10 percent.

Figure A1 in the appendix provides the same plots as in Figure 2 and Figure 3 but across the income distribution. The trend of the higher economic level, the higher the share of high-yield crops on total output is also observed—and more strongly—along the income distribution. Those households below 50 percent of the income distribution obtain most of their agricultural output from low-yield crops, with those in the bottom 25 percent obtaining around 70 percent of their output from the low-yield crops. The top 10 percent in the income distribution obtain around 65 percent of their output from high-yield crops, with more than 40 percent coming only from plantain bananas.[6]

Table 2—: Share of Farmers Cultivating Crops

	High-yield Crops (%)	Low-yield Crops (%)	Both Crops (%)
2009–10	61.99	93.29	60.75
2010–11	68.34	97.25	66.87
2011–12	68.68	97.39	66.92
2013–14	61.19	96.26	59.28
2015–16	64.83	97.01	62.08
Mean	65.01	96.24	63.18
Some	76.13	98.64	75.26

Note: Proportion of farmers that cultivated high-yield crops (1), low-yield crops (2), and both types of crops (3). Some denotes at some point during the 5 waves.
Source: UNPS: 09/10–15/16.

Interestingly, most farmers in Uganda grow both low-return crops and high-return crops. Table 2 shows the proportion of households that grew low-return crops (column 1), high-return crops (column 2), and both types of crops (column 3) across the waves of the data. In the average wave, 63 percent of households grew high-yield crops, while 96 percent grew low-yield crops. For the entire period of the surveys, 99 percent of farmers grew low-yield crops, 76 percent grew high-

[6]Table A1 in the appendix provides the estimates of the elasticity of the proportion of output from high-yield crops over output from low-yield crops with respect to household consumption, income, wealth, and land size. All the elasticities are significantly positive and large.

yield crops, and 75 percent grew both low-yield and high-yield crops.

Motivated by these empirical results, in the next section, I propose an incomplete markets model with endogenous agricultural income from two technologies that differ in risk and productivity.

II. Model

A. *Primaries of the Model*

The model presents an economy with one type of agent, households, who are ex-ante equal except in a permanent component in agriculture. A continuum of them populates the economy with measure one.

Preferences. Households live infinitely and maximize expected utility

$$E_0\left[\sum_{t=0}^{\infty}\beta^t u(c_t)\right] \qquad u(c)=\frac{c^{1-\rho}}{1-\rho}$$

where $\beta \in (0,1)$ is a discount factor, E_0 is the expectation at time 0. The utility flow at time t has ρ consumption curvature.

Agricultural Production. Households obtain agriculture income from investing in intermediates in two technologies: one high-returns and high-risk technology—high-yield crops—and one low-returns low-risk technology—low-yield crops. Both technologies have decreasing returns to scale, and production is subject to household idiosyncratic shocks. The production functions take the following form

$$\begin{aligned} y_{it}^h &= \theta_{it} z_i A(m_{h,it-1})^\alpha \\ y_{it}^l &= \varepsilon_{it} z_i B(m_{l,it-1})^\gamma \end{aligned}$$

in which $m_{h,it-1}$ is household i at period $t-1$ intermediates investment in high-yield crops—$m_{l,i-1t}$ in low-yield crops—z_i is the household-specific permanent component. γ and α represent the elasticity of intermediates investment on output and A, B are the technology-neutral productivity factors in each technology. θ_{it} and ε_{it} represent the crop-specific idiosyncratic shocks while y_{it}^h is the output in the high-yield crops and y_{it}^l the output on the low-yield crops. The permanent component z captures household permanent characteristics in agricultural production.[7] The shocks θ_{it} and ε_{it} are independent across households i and time t

[7]The permanent component z Includes differences in productivity, but also other factors such as location or land size. In Sub-Saharan Africa, farming land tends to be in fixed supply since customary rights constrain it—see, for example, Chen et al. (2023) or Gottlieb and Grobovšek (2019). Yet, land markets are not perfectly imperfect, and the interaction with financial markets is important, Manysheva (2022); thus, the quantitative results here should be seen as a lower bound.

and identically distributed from a multivariate log-normal distribution

$$ln\theta_{it}, ln\varepsilon_{it} \sim MN\left(\begin{bmatrix}0\\0\end{bmatrix}, \begin{bmatrix}\sigma_\theta^2 & \sigma_{\theta\varepsilon}\\ \sigma_{\theta\varepsilon} & \sigma_\varepsilon^2\end{bmatrix}\right)$$

. Note that shocks take only positive values, and they are normalized to one.

Non-agricultural earnings. To match the model to aggregate variables, households also obtain non-agricultural earnings from an exogenous stochastic process, $y_{na,it}$, defined by the following AR(1) process

$$lny_{it+1}^{na} = b + \rho_{na} lny_{it}^{na} + u_{it} \qquad\qquad u_{it} \sim N(0, \sigma_{y_{na}}^2)$$

In which ρ_{na} represents the autocorrelation coefficient and u_{it} the withe noise on the log of the non-agricultural earnings process.

Financial market. Households in low-income countries are able to smooth consumption relatively well through informal manners. Households participate in risk-sharing networks. Households also use self-insurance mechanisms as crop storage, Fafchamps et al. (1998), Kazianga and Udry (2006) or livestock holdings, Rosenzweig and Wolpin (1993), both examples of precautionary savings. To incorporate this in the model, I assume households can save in a risk-free asset a at a depreciation rate δ. Thus the model exhibits a no-borrowing constraint and incorporates the finding that saving in poor countries is costly. This financial market assumption is consistent with other macro-development papers, Donovan (2021) or Lagakos et al. (2023).

B. *The household's Problem*

Consider the household's problem of the previous economy under stationarity. Households maximize lifetime wellbeing by choosing consumption, savings, and intermediates investment in the two technologies in each period. The Bellman equation defines the household's problem in recursive form. I define the state space of the economy in three state variables: x, z, y_{na}. Variable x is a type of "cash on hand" variable, which is equal to the sum of agricultural income and the depreciated risk-free asset holdings. z is the household–specific permanent component in agriculture, while y_{na} is the current realization of the non-agricultural income process. Let $V(x, z, y_{na})$ be the value function at state (x, z, y_{na}), then, the Bellman equation is

$$V(x, z, y_{na}) = \underset{a', c, m_h', m_l'}{\text{Max}} u(c) + \beta E\left[V(x', z, y_{na}')\right] \tag{1}$$

subject to

$$a' \geq \underline{a} \tag{2}$$

$$c(x,z,y_{na}) + a'(x,z,y_{na}) + pm'_h(x,z,y_{na}) + pm'_l(x,z,y_{na}) = x + y_{na} \tag{3}$$

$$x' = \theta' z A \left(m'_h(x,z,y_{na})\right)^{\alpha} + \varepsilon' z B \left(m'_l(x,z,y_{na})\right)^{\gamma} + (1-\delta)a'(x,z,y_{na}) \tag{4}$$

$$ln\theta', ln\varepsilon' \sim MN(0,\Sigma) \tag{5}$$

$$lny'_{na} = b + \rho_y lny_{na} + u, \qquad u_t \sim N(0,\sigma_z^2) \tag{6}$$

in which c, a', m'_h, m'_l are the policy functions that solve the household problem in state (x, z, y_{na}). To reduce notation, current period variables x do not carry subscript t, while the apostrophe sign, x' denote next period variables. Given that policy functions maximize the value function, the derivatives of $c, a', m'_h m'_l$ with respect to V evaluated at the policy function value are equal to zero. Combining this envelope condition, Benveniste and Scheinkman (1979), with the first-order conditions of the problem imply

$$u_c\left(c(x,z,y_{na})\right) \geq \beta(1-\delta)E\left[u_c\left(c(x',z,y'_{na})\right)\right] \tag{7}$$

$$pu_c\left(c(x,z,y'_{na})\right) = \beta E\left[u_c\left(c(x',z,y'_{na})\right)\theta' z A\alpha\left(m'_h(x,z,y_{na})\right)^{\alpha-1}\right] \tag{8}$$

$$pu_c\left(c(x,z,y_{na})\right) = \beta E\left[u_c\left(c(x',z,y'_{na})\right)\varepsilon' z B\gamma\left(m'_l(x,z,y_{na})\right)^{\gamma-1}\right] \tag{9}$$

and the budget constraint is

$$c(x,z,y_{na}) = x + y_{na} - a'(x,z,y_{na}) - pm'_h(x,z,y_{na}) - pm'_l(x,z,y_{na}) \tag{10}$$

. The solution to the household problem is the set of policy functions that solve the system of equations (7)–(8)–(9)–(10).

To see the implications of risk in household choices, first note that equations (8) and (9) can be rewritten as

$$p = \frac{E\left[u_c\left(c(x',z,y'_{na})\right)\theta'\right]}{u_c\left(c(x,z,y_{na})\right)}\beta z A\alpha\left(m'_h(x,z,y_{na})\right)^{\alpha-1} \tag{11}$$

$$p = \frac{E\left[u_c\left(c(x',z,y'_{na})\right)\varepsilon'\right]}{u_c\left(c(x,z,y_{na})\right)}\beta z B\gamma\left(m'_l(x,z,y_{na})\right)^{\gamma-1} \tag{12}$$

where p is the marginal cost and $zA\alpha(m'_h(x,z,y_{na}))^{\alpha-1}$ and $zB\gamma\left(m'_l(x,z,y_{na})\right)^{\gamma-1}$ are the marginal products of using m_h and m_l, respectively. Suppose households can perfectly smooth consumption across states. then, the ratio of marginal utilities is equal to one, and optimal m_h and m_l, are such that the discounted expected marginal returns equalx the price. That is the expected profit maximization scenario.[8] If households cannot perfectly smooth consumption across states, the ratio of marginal utilities is different from one, so their choices depart from profit maximization. In concrete, whenever the marginal utility of current consumption is larger than the expected marginal utility of the next period weighted by the shocks, the ratio of marginal utilities is smaller than one. Therefore, the marginal products need to be above marginal cost. Since the production functions have decreasing returns to scale, a higher marginal product implies a lower intermediates investment, m_h, m_l.

The presence of risk not only distorts the intermediates level but it also shifts the intermediates investment towards the low-risk, low-returns technology. Dividing (11) by (12) household's optimal conditions of inputs can be rewritten as

$$B\gamma \left(m_l'(x,z,y_{na})\right)^{\gamma-1} = \frac{E\left[\theta' u_c\left(c(x',z,y_{na}')\right)\right]}{E\left[\varepsilon' u_c\left(c(x',z,y_{na}')\right)\right]} A\alpha \left(m_h'(x,z,y_{na})\right)^{\alpha-1} \tag{15}$$

From equation (15), first, notice that the marginal utility is decreasing on consumption, and consumption is increasing on shocks' realizations. Since the shocks in the high-technology have more dispersion than in the low technology, $\sigma_\theta > \sigma_\varepsilon$, the low realizations of ε are larger than the low realizations of θ. And the high realizations of ε are smaller than the high realizations of θ. Precisely, since the marginal utility is decreasing on the shock realizations, the expectation in the denominator is higher than the expectation in the nominator. Thus, marginal returns in the high technology are higher than in the low technology whenever consumption is not flat across states.

Figure 4 plots the value function and the policy functions that solve the household problem under the parameter values from the quantitative exercise. The x-axis represents the level of cash-on-hand (x), the primary colors represent the permanent agricultural component (z), and the different tones within the primary colors represent the realization of the non-agricultural earnings. For the same level of cash-on-hand (x), households with high permanent components (red lines) accumulate less risk-free assets, (4b), and consume more, (4c), than households with low permanent components (purple lines). Similarly, households with high realization of non-agricultural earnings save less and consume more than households with low realizations.

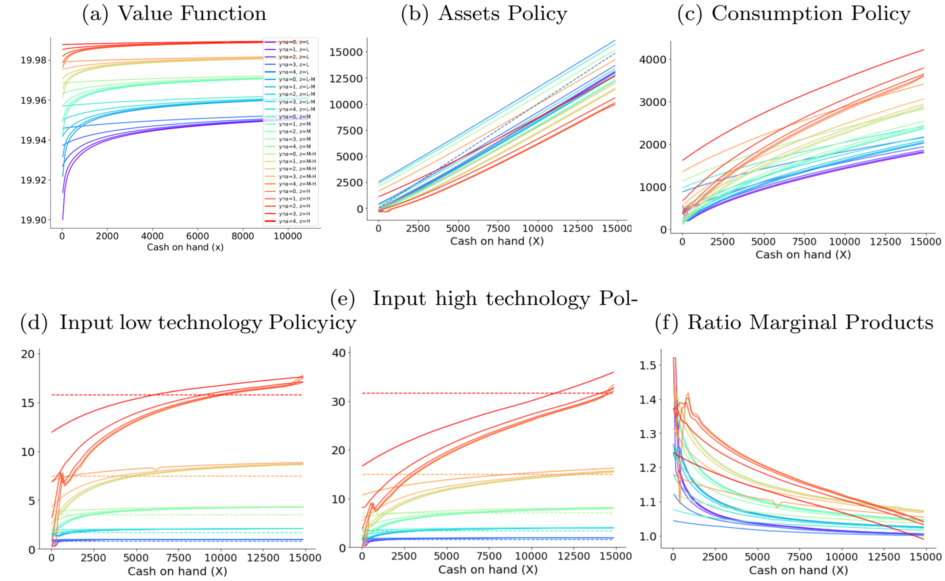
Sub-plot (4d) shows the policy function in $m_l'(x,z,y_{na})$, and (4e) in $m_h'(x,z,y_{na})$. The dotted lines represent the intermediates under discounted expected profits maximization. From (4d) and (4e) we observe the following. First, poor households—low cash-on-hand, x—under-invest in intermediates for both high

[8] Expected profit maximization implies marginal cost equalizes expected discounted marginal return:

$$p = \beta E_\theta \left[\theta' z A\alpha m_h^{\alpha-1}\right] = \beta z A\alpha m_h^{\alpha-1} \tag{13}$$

$$p = \beta E_\varepsilon \left[\varepsilon' z B\gamma m_l^{\gamma-1}\right] = \beta z B\gamma m_l^{\gamma-1} \tag{14}$$

Figure 4. : household's Optimality: Policy Functions



(a) Value Function (b) Assets Policy (c) Consumption Policy

(d) Input low technology Policyicy (e) Input high technology Pol- (f) Ratio Marginal Products

Notes: (b)–(e) plot the policy functions of the household problem, and (a) the value function associated with it. These functions depend on the state cash-on-hand x—x-axis—the permanent component z—the primary colors—and the non-agricultural earnings y^{na}—the tones within the primary colors. The dotted lines represent expected profit maximization allocations.

and low technologies. Second, As households get richer, they increase intermediates and get closer to profit maximization allocations. Third, since saving on the risk-free asset is costly in this economy, households at the top of the distribution over-invest in intermediates especially in the low-productive technology.

Sub-plot (4f) plots the ratio of the expected marginal products along the state variables. As stated in equation (15), if households can perfectly smooth consumption, then this ratio should be equal to one. Nevertheless, we observe that the poorer the households and the higher their permanent component, the higher the ratio of marginal products with respect to one. This implies that the poorer the households the more they under-invest in the high technology with respect to the low technology. In line with the results of Rosenzweig and Binswanger (1992), in this economy, the production choices of poor farmers are more distorted by the presence of risk. The model shows that even in the absence of fixed costs, the poor might not invest enough and move to more productive technologies, given their limited ability to cope with risk. Thus, poverty traps might exist even in the absence of fixed costs—Dercon and Christiaensen (2011) take a similar conclusion.

C. Equilibria

Rural Uganda is an economy based on subsistence farming. Consequently, I model the economy as an open economy with exogenous input and output prices. For completeness and brevity, the definition of the equilibria is presented in the appendix A.A1.

III. Data: Uganda National Panel Survey

This study uses the first five waves of the Ugandan National Panel Survey, a household survey carried out by the Ugandan National Statistics and part of the World Bank LSMS-ISA project.[9] The UNPS interviews approximately 3,200 households per wave. The first wave started in 2009–10 and its initial sample was visited for two consecutive years: 2010–11 and 2011–12. In the fourth wave, 2013–14, one-third of the initial sample was refreshed. The fifth wave, 2015–16, uses the sample from 2013–14. The survey is conducted annually, spanning from September to August. It involves two visits spaced approximately six months apart to effectively capture the agricultural outcomes associated with the two harvesting seasons.

From a macroeconomics perspective, The UNPS has two main strengths. First, it is a nationally representative panel household data from one of the poorest economies in the world. Second, with this single dataset, we can recover the consumption, income, and wealth dynamics of the households—practically, their entire budget constraint. In particular, the survey allows us to quantify agricultural production and inputs which is the main economic activity for most families in Sub-Saharan Africa. Yet, measuring these variables in this context is complex. In the subsequent subsections, I describe the computation process of consumption, income (including agricultural revenues), and wealth.

A. Consumption

The UNPS includes three sections for household consumption: food consumption (over the last seven days), non-food and non-durables consumption (over the last month), and durables consumption (over the last year). I compute the consumption value for each good or service by summing the value across consumption from purchases, from home production, and from in-kind and gift transfers.[10] Then, I compute the household aggregate consumption as the sum of food and non-durable item consumption, excluding non-durable goods. To maintain data

[9] Uganda National Panel Survey, the World Bank. The Living Standards Measurement Survey, LSMS, follows the standardized survey implemented by the World Bank to assess living standards across countries. The Integrated Survey on Agriculture, ISA, is a survey specifically designed to capture the agricultural production, inputs, and expenditures in the context of Sub-Saharan Africa.

[10] In the survey, households are asked to report the approximate monetary value of the goods and services consumed from home production and received from transfers.

integrity, outliers are trimmed by excluding the bottom and top one percent of total household consumption for each wave.

B. Income

Measuring household income in developing countries is particularly difficult; see Deaton (2019) for a discussion. Firstly, a significant portion of the economy operates within the informal sector, leading to irregular periods of work and frequent in-kind payments. Secondly, most households work as self-employed, making it challenging for them both in terms of conceptual understanding and practical implementation to report their earnings accurately. Thirdly, many of these self-employed individuals are farmers, which presents further data measurement issues, mainly when many of the farmers operate in subsistence farming. To overcome these challenges, in the LSMS-ISA surveys, households are queried about earnings derived from formal and informal labor services, non-agricultural business and trade operations revenues, and costs (LSMS section). Moreover, the LSMS-ISA surveys incorporate an exceptionally detailed agriculture questionnaire (ISA section).

Agricultural Income. — With the agriculture questionnaire, I compute the agricultural revenues for each household and each crop as the sum of earnings from sales plus the value of non-sold production using district-level median consumption prices per crop kilogram.

From the production side, households are questioned on the total production of the crop, but also the production of the crop devoted to the market, to own consumption, gifted to other households, stored, and for feeding animals. Common to other surveys in developing countries, households can report crop production in a large variety of units, including non-standard units such as baskets, pales, bunches, and others. Moreover, conversion rates can vary across crops and seasons. A basket of maize might not weigh the same as a basket of coffee, nor a basket of maize in a good season might weigh the same as a basket of maize in a bad season. To carefully convert crop production into kilograms, I use the median of the conversion rates to kilograms reported by the households for each wave, season, crop, and unit combination.

Subsistence farming is widespread in Uganda. From the UNPS data, only between 24 to 29 percent of the agricultural production is devoted to the market. For the interested reader, Table A2 in the appendix presents the share of production devoted to the market and non-market activities and the proportion of farmers that did devote a part of their production to these usages. Thus, to understand Ugandan household's livelihood and measure agricultural yields, it is vital to account for the non-sold agricultural production correctly. Nevertheless, as Deaton (2019) argues, setting prices to evaluate non-sold production in monetary terms is, in general, a difficult choice. Prices at the gate (selling prices) are commonly used in the literature to value non-sold production. Yet, as De Magalhães and Santaeulàlia-Llopis (2018) argue, prices at the gate might underestimate non-sold production. First, the sold items might only be a part of the harvested crops. Second, prices at the gate are measured in the period after the harvest when supply is relatively abundant, and prices are likely to be the lowest of the entire year.

Taking advantage of the household questionnaire that captures food consumption in quantity and value, I follow the approach in De Magalhães and Santaeulàlia-Llopis (2018), and I use median consumption prices at the district level to evaluate unsold agricultural production. Using this set of prices allows us to capture better the shadow value of not selling the crop: the cost if that particular household did not produce the crop and had to buy it in the local market.[11] For the crops that do not have a consumption price, as is the case for sorghum, groundnuts, and other crops, I use district-level median prices at the gate. Agricultural revenues for each season and each wave are trimmed at 2 percent of the top of the distribution.

Intermediates. — Agricultural intermediates expenditure is computed as the sum of the costs of chemical and organic fertilizer, pesticides, herbicides, seeds, hired labor, and transport. Since in the data, the use of intermediates is reported at the plot level, for multi-crops plots, I assume that the intermediates were distributed uniformly across the plot. For the case of chemical fertilizer, organic fertilizer, pesticides, and herbicides, the costs include total expenditure plus the value of the non-bought quantities using median prices recovered from the survey.

Agriculture in Uganda relies on a very low usage of intermediates. Table A3 in the appendix presents the share of farmers using intermediates and their average expenditure across the five waves of the UNPS. Farmers, on average, only spend \$60.69 per year on intermediates. Decomposing across crops, the average intermediates expenditure in high-yield, high-risk crops is \$41.14, while in the low-yield low-yield crops is \$38.53. The use of modern agricultural intermediates in Uganda is extremely low. Only 4% of farmers use chemical fertilizer, and only 10% use pesticides.

Non-Agricultural Earnings. — Non-agricultural earnings include business profits, formal and informal labor income, and livestock earnings.

The household questionnaire collects on each non-farming business of the household data on operative months, gross revenues, wage expenditures, raw materials costs, and other expenditures. Business profits are the difference between monthly gross revenues and costs multiplied by the number of months the business operated. Labor earnings aggregate yearly payments for a primary job and potential

[11] There are 135 districts in Uganda. For those crops that a price at the district level cannot be computed in a particular wave, I use the price at the regional level, and if this price is also absent, I use the nationwide price.

secondary job for each household member regardless the job is of a formal or informal nature.[12] Livestock profits are determined by summing net animal sales, meat, milk, and egg sales minus associated costs. The value of unsold production is estimated from the consumption of self-produced livestock products reported in the consumption section of the household questionnaire.

To ensure consistency with the model, household total income is calculated as the sum of agricultural revenues, business profits, labor payments, and livestock profits after trimming extreme values at 2.5 percent in both tails.

C. Wealth

The data equivalent of assets in the model is the liquid wealth which includes stored crops, livestock, household assets, rents and transfers.[13] The value of stored crops is measured with district-level consumption prices. In contrast, the values of livestock and household assets are the self-reported value if the household were to sell the asset at the current moment.

For the empirical motivation part, wealth considers all the assets that the household owns, including livestock and household assets, but also farm capital and land value. In Sub-Saharan Africa, land ownership is usually not well defined, with a large proportion of land subject to customary systems of tenure—Gottlieb and Grobovšek (2019). In the UNPS 2009–10 and 2010–11, households were asked for the value of their farming land, which allowed me to compute per-acre land prices grouped by counties and plot characteristics. Then, for the rest of the waves, the value of land is estimated by using the per-acre prices from 2010–11 matched with the location and characteristics of the plots of the successive waves times the reported size of the plot.

D. Summary of the Data

Table 3 presents the average and the Gini index of the consumption, income, and wealth at the household level for rural Uganda (columns 2 to 4) and for the whole country (columns 5 to 7).

Two critical insights are revealed from Table 3.

First, income and consumption estimates closely align in the dataset, indicating robust measurement. Typically, income estimates from surveys in developing countries lag behind consumption estimates Deaton (2019). The average household income in rural Uganda is approximately $1,500, rising to $1,800 nationwide. Per capita, this amounts to $300 (rural) and $360 (nationwide) yearly. Second,

[12]Information on labor supply and remuneration is collected for all household members aged five and above. This includes details on the last cash payment and estimated cash value of in-kind payments, allowing us to derive weekly salaries and compute annual labor income based on reported weeks and months worked.

[13]household assets include housing and other buildings, non-agricultural land, furniture, household appliances, electronic devices, jewelry, vehicles, and other assets. Rents and transfers include property income, dividends, interests from current accounts or bonds, remittances, inheritance, and alimony.

Table 3—: household Consumption, Income, and Wealth in Uganda

	Rural			National		
	Cons ($) ([0, 1])	Income ($) ([0, 1])	Wealth ($) ([0, 1])	Cons ($) ([0, 1])	Income ($) ([0, 1])	Wealth ($) ([0, 1])
2009-2010	1,471.21	1,197.46	3,854.07	1,717.00	1,234.82	4,318.13
	(0.35)	(0.6)	(0.61)	(0.38)	(0.61)	(0.66)
2010-2011	1,429.59	1,314.92	4,169.74	1,698.62	1,569.33	6,029.18
	(0.36)	(0.56)	(0.64)	(0.39)	(0.58)	(0.74)
2011-2012	1,585.70	1,544.95	4,512.11	1,800.72	1,710.25	5,254.73
	(0.34)	(0.56)	(0.62)	(0.36)	(0.56)	(0.67)
2013-2014	1,541.70	1,519.79	4,319.46	1,738.55	1,718.25	5,006.59
	(0.3)	(0.57)	(0.61)	(0.32)	(0.56)	(0.66)
2015-2016	1,475.38	1,725.42	3,763.02	1,705.91	2,078.29	4,477.14
	(0.31)	(0.58)	(0.6)	(0.33)	(0.58)	(0.64)
Average	1,500.72	1,460.51	4,123.68	1,732.16	1,662.19	5,017.15
	(0.33)	(0.57)	(0.62)	(0.36)	(0.58)	(0.67)

Note: Household average (in 2013$) and Gini index within parenthesis. the measurement of consumption, income, and wealth is provided in the text.
Source: UNPS: 09/10–15/16.

income and wealth inequalities are pronounced. While the consumption Gini index is around 0.33, the income Gini index is around 0.56, and the wealth Gini index is 0.61.

Table A5 in the appendix provides the composition of consumption, income, and wealth among rural Ugandan households.

Food constitutes the majority of consumption expenditures, accounting for 66% to 71% of total consumption.

Agriculture is the primary income source, with nearly 90% of households engaged in crop production, contributing to 50% to 56% of total income. Yet most households are also engaged in business activities or salaried work. Approximately 40% to 45% of households earn income from enterprises, representing 20% to 25% of total household income. Wage labor contributes 15% to 20% of total income, with 30% to 40% of households having at least one member employed in salaried work.

Wealth composition among rural Ugandan households predominantly consists of farming land holdings, averaging around \$3,000 per household, and household assets valued at approximately \$1,600.

IV. Calibration

To quantitatively study the impact of incomplete financial markets in agriculture, I calibrate the baseline model to rural Uganda using the UNPS data. A set of parameters is chosen directly from the literature: preference parameters and the intermediate input shares. The rest of the parameters are calibrated to match key moments in rural Uganda economy: agricultural production, the two types of crop output and volatility, the cross-sectional dispersion on agricultural output, aggregate household income and wealth levels, and income volatility. In the following sub-section, I describe the values and calibration of the parameter values.

Preferences. The values of preference parameters are chosen directly from the literature. I set the curvature of consumption, ρ, equal to 2, a value commonly used in the macroeconomics literature—e.g., Kaplan and Violante (2010), Lagakos et al. (2023)—and within the range of commonly micro-estimated values. For the discount factor, β, I set its value equal to 0.96—Aiyagari (1994), Donovan (2021) and other authors.

Technology parameters and inputs price. I set the intermediates shares α, γ equal to 0.4, the agriculture intermediate share in the US—from Restuccia et al. (2008), and commonly used in macroeconomic exercises in agriculture, Donovan (2021). Second, I calibrate the inputs price p, and the constant factors in each technology, A, B, to match the household average high-yield crop output, household average low-yield crop output, and reduce the distance between the model and the data of the inputs expenditure.[14]

[14]Due to intermediates inputs expenditure is minimal in Uganda, the only way the model could repli-

Table 4—: Parameter Values for the Benchmark Economy

	Parameter	Value	Source
Curvature of consumption	ρ	2	Literature
Discount factor	β	0.96	Literature
High technology inputs elasticity	α	0.4	Literature
Low technology inputs elasticity	γ	0.4	Literature
intermediates price	p	30.7	Calibration
High technology constant factor	A	288	Calibration
Low technology constant factor	B	189	Calibration
SD high shock	σ_θ	1.0352	Calibration
SD low shock	σ_ε	0.853	Calibration
Covariance high and low shocks	$\sigma_{\theta,\varepsilon}$	0.105	Calibration
Persistence non-agric earnings	$\rho_{y_{na}}$	0.39	UNPS estimate
SD non-agricultural eanings	σ_u	1.47	Calibration
SD permanent productivity	σ_z	0.259	Calibration
Depreciation rate	δ	0.0865	Calibration

Note: Notes: ρ value from Kaplan and Violante (2010) and other works; β from Aiyagari (1994) and other works; α, γ value from Restuccia et al. (2008). p, A, B, σ_z, δ are calibrated targeting cross-sectional moments for which I use average values across the five waves. Risk parameters—σ^2_θ,σ^2_ε $\sigma_{\theta,\varepsilon}$,$\sigma_u$—are calibrated targeting volatility measures of residuals in crop production and income.

Agricultural shocks. A key aspect of the quantification of the model is to capture the agricultural risk across the two types of crops. While in the model, production fluctuations are only driven by household shocks and changes in intermediates input usage, in the data, production fluctuations are also driven by other factors. To factor out the factors in the data but not in the model from the quantification of the model, I calibrate the covariance matrix of the agricultural shocks following the two-step procedure in Kaboski and Townsend (2011).

First, I run an OLS regression on output and factors not in the model that can lead to output variation for the high-yield crops, equation (16), and for the low-yield crops, equation (17).

$$ln(y_{it}^h) = \phi ln(Z_{it}^h) + \beta X_{it} + \gamma F_i + \psi T_t + ln\theta_{it} \tag{16}$$

$$ln(y_{it}^l) = \phi ln(Z_{it}^l) + \beta X_{it} + \gamma F_i + \psi T_t + ln\varepsilon_{it} \tag{17}$$

In which y_{it} represents crop output for a household i in wave t. Z_{it} represents a vector of household-crop-specific variables, in this case, land size and labor hours. X_{it} represents a vector of household characteristics that might change over time: household size and the gender, education, age, and age squared of the household head. F_i represents household fixed effects while T_t represents wave fixed effects. Factoring out time effects is particularly relevant since the model does not feature aggregate shocks. For the high-yield crops, the R^2 of the OLS regression in (16) is 0.18 while for the low-yield crops, equation (17), the R^2 is 0.14.

Second, using the estimated residuals of the regressions, I set the crop risk parameters, σ_θ, σ_ε and $\sigma_{\theta\varepsilon}$, such that the model in stationarity replicates the volatility of the estimated residuals.[15] The parameter values are: $\sigma_\theta = 1.0352$, $\sigma_\varepsilon = 0.853$ and $\sigma_{\theta\varepsilon} = 0.105$.

Non-agricultural income process. For the non-agricultural income process, The OLS regression on $lny_{i,t}^{na} = b + \rho_y lny_{i,t-1}^{na} + u_{i,t}$ delivers the estimates of $\hat{\rho}_{y_{na}} = 0.39$ and $\hat{\sigma}_u = 1.34$. This non-agricultural income process generates a lower household income volatility than the one observed in the data. Since the income volatility moment is key for this study, I set the parameter value of σ_u such that the model generates the level of income volatility observed in the data. The value is equal to 1.47 where again, to measure the income volatility in the data, I follow the same procedure with the crop volatility, and I compute the volatility as the average time-variance of the residuals in log income. Given the parameter values $\rho_{y_{na}} = 0.398$, $\sigma_u = 1.47$, I discretize this AR(1) process into a five-state Markov chain using the Rouwenhorst procedure.

Permanent component. To calibrate the permanent component in agricultural

cate both the agricultural output and intermediates usage is by setting a very low exponent, inconsistent with any previous work on agriculture.

[15] The volatility of the estimated residuals are $\overline{var_i(ln\hat{\theta}_{it})} = 1.049$, $\overline{var_i(ln\hat{\varepsilon}_{it})} = 0.719$, $cov(ln\hat{\theta}_{it}, ln\hat{\varepsilon}_{it}) = 0.1247$. Volatility is measured as the average of the individual time-variance of output (model) or output residuals (data).

production, I follow the procedure in Huggett and Parra (2010) and I approximate z_i with five equally log-spaced points in the interval $[-3\sigma_z, +3\sigma_z]$ with equal mass of agents in each point. Then, I set σ_z to match the Gini level of agricultural production. Given that σ_z is calibrated after the agricultural shocks, σ_z captures the dispersion in agricultural production that is not explained by risk.

Depreciation rate. The depreciation rate is set such that the aggregate savings in the economy match the average holdings in liquid wealth. Liquid wealth includes crop storage, livestock holdings, household assets, and other holdings—remittances, alimony, royalties, and other transfers. The calibrated value is $\delta = 0.0865$.This high value is consistent with the significant costs to save in developing countries, for a summary, see Karlan et al. (2014b), and consistent with calibrated values in the macro-development literature—e.g., Donovan (2021), Lagakos et al. (2023).

A. Model vs. Data

Next, I evaluate the capacity of the model to replicate the data. First, I present the results of the targeted moments. Then, I focus on the capacity of the model to replicate a set of key moments that are mostly not directly targeted in the calibration: (1) the endogenous relationship between crop production and wealth, (2) the consumption, income, and wealth cross-sectional distributions (3) and the transmission of income volatility into consumption volatility.

Table 5 presents the data-targeted moments and the model counterparts. Regarding agricultural moments, the calibration targets the average high-yield crop and low-yield crop output and their volatilities with a very high precision. To capture the entire agricultural production distribution, the model also targets the Gini of agricultural production with a model value of 0.02 Gini points lower than the data counterpart.

To be able to discuss the effects on aggregates, the model also targets the average income, and the average liquid wealth, and the model is able to get close but not fully replicate the level of income volatility.

Given these targeted moments, I next present the prediction of the model in terms of primarily untargeted moments.

Crop-Choice. Figure 5 plots the share of agricultural output coming from high-yield crops and low-yield crops along the wealth distribution in the data vs. the model. The solid lines represent the crop shares in the data. The shares are computed along the wealth distribution, averaging household observations across waves. The dotted lines represent the share of output coming from the two technologies in the model along the state variable X, cash-on-hand.

The model generates a higher share in high-yield crops along the wealth distribution than the share observed in the data. While in the data the bottom 20 % have a share of high-yield crops on total output of around 47%, the model generates a share of 56%—and a similar distance is observed up to the 60% point of the wealth distribution. Yet, the model approximates very well the trend of

Table 5—: Benchmark Economy Targeted Moments

Description	Model Value	Data Target
Avg high-yield crops output *	654.96	649.9
Avg low-yield crops output *	354	352.86
Avg Income *	1,466.74	1460.51
Avg Liquid Wealth *	1925.34	1938
high-yield crops volatility **	1.04	1.04
low-yield crops volatility **	0.72	0.72
High-low-yield crops correlation across time **	0.115	0.11
Income volatility **	0.62	0.63
Gini agricultural output *	0.60	0.62

**:* Averages and Gini index moments are computed from the average of the moments across the five waves. [**] Volatility moments are computed on the estimated residuals of regressions $ln(y_{it}) = \beta X_{it} + \gamma F_i + \psi T_t + u_{it}$. In which y is the variable for the volatility, X represents household characteristics, and F_i T_t represents fixed and time effects.
Source: UNPS: 09/10–15/16.

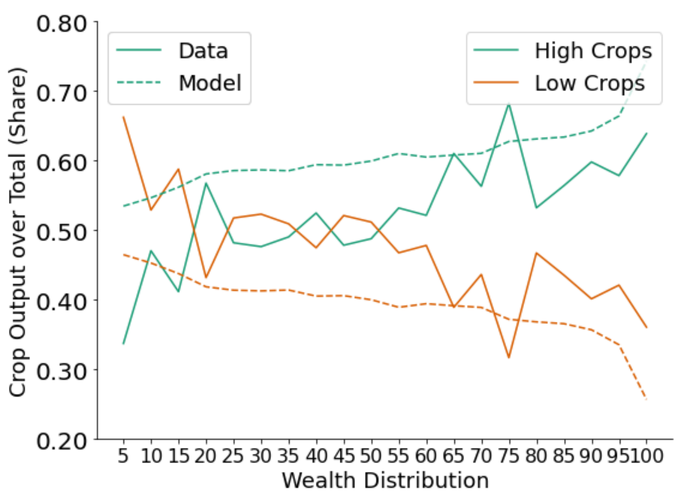


Figure 5. : Crop Production along the Wealth distribution: Model vs. Data

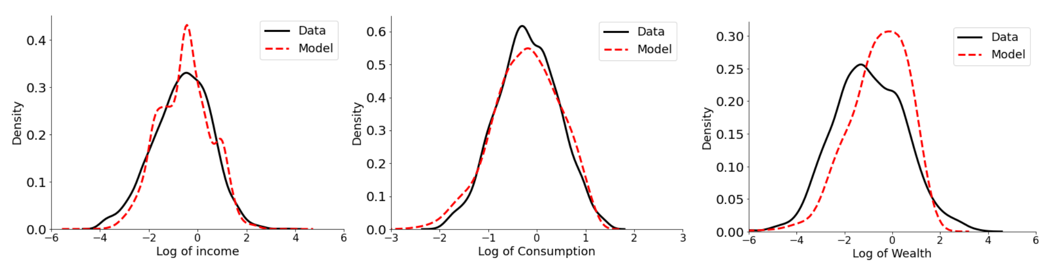
Notes: Dotted lines represent the share of output coming from the two technologies in the model along the state variable X. Solid lines represent the data counterpart.
Source: UNPS: 09/10–15/16.

crop shares along the wealth distribution; it predicts an increase in the share of high crops of 14%—from a share of 56% to a share of 70%—while in the data, the increase is of 13%—from 47% to 60%.

Consumption, income and wealth distributions. Here, I study how much the model can account for the consumption, income, and liquid wealth distributions in rural Uganda. This exercise is relevant because a common objective with heterogeneous-agents models is to account for the data distributions of these key endogenous variables. Nevertheless, for African countries, this exercise has been missing. Moreover, this is a necessary exercise in this work since having a proper approximation of the consumption distribution is key to disciplining the welfare analysis.

The calibration of the model targets the Gini of agricultural production (0.63) with no additional targets on cross-sectional distributional moments. With this in mind, the model approximates well the inequality levels observed in Rural Uganda.

Figure 6 presents the distributions of the log of income (6a), log of consumption (6b), and log of liquid wealth (6c) generated by the model in stationarity and the equivalent distributions in the 2011-2012 UNPS wave. Note that the model generates an income distribution relatively close to the data (6a). Nevertheless, since the model discretizes the permanent component in 5-states, we observe multiple peaks in the model distribution that are nonexistent in the data.



(a) Income (b) Consumption (c) Wealth

Figure 6. : the Income, Consumption, and Wealth distributions. Model vs. Data

Notes: Solid black line presents the distributions in the UNPS 2011-12 wave. Red dotted line represents the model–simulated distributions. Wealth is in terms of liquid assets.
Source: UNPS: 09/10–15/16.

To my surprise, the model generates a consumption distribution that is very close to the data counterpart (6b). Notice that the calibration does not have any value targetting consumption moments; rather, it takes assumptions and parameterized preferences standard the literature. Namely, rational agents with identical preference under a CRRA utility function with coefficient $\rho = 2$, and a discount factor $\beta = 0.96$, and a no-borrowing constraint. Yet, the model generates a liquid wealth distribution (6c) that is much less unequal than in the data.

To be more precise on the cross-sectional distributions, Table 6 compares the percentiles shares of the income, liquid wealth, and consumption distributions generated by the model with the data counterparts for the 2011–12 wave.

The model does well at approximating the shares of income across the distribution. The model prediction of the top 50% share of income is 84.93%, in the data is 86%. In the case of the extremes of the distribution, for the bottom 1, 5, and 10%, the approximation is still reasonably accurate. Nevertheless, the model underpredicts the shares of the top households in the income distribution. For example, the share of income from those in the top 5% in data is 28.08%, while in the model, it is 23.93%.

In terms of wealth, the model under-predicts inequality. The top 50% in rural Uganda hold 92.32% of the total liquid wealth, while in the model, that share is 85.93%. In the top extremes, the model predicts that the top 10% holds 32% of the total liquid wealth, while in the data, it is 51%.

In terms of consumption, the model replicates almost exactly the shares of the bottom and top and even for the extremes of the distribution. The share of the top 50% in the model is 74.67%, while in the data, the share is 73.7%. The top 1% holds 3.4% of consumption in the data; in the model is 3.82. The bottom 1% and 10 hold 0.15% and 2.80% of total consumption in the data—in the model, the shares are 0.12% and 2.32%.

Table 6—: Income, Wealth, and Consumption Inequality. Model vs. Data

	Bottom					Top				
	1	**5**	**10** (%)	**25**	**50**	**50**	**25**	**10** (%)	**5**	**1**
Data										
Income	0.02	0.22	0.68	3.29	13.12	86.88	65.58	41.16	28.08	10.77
L. Wealth	0.01	0.11	0.32	1.57	6.68	93.32	78.87	57.38	43.31	18.31
Consumption	0.17	1.15	2.80	9.53	26.35	73.65	48.06	24.99	14.54	3.82
Model										
Income	0.04	0.37	1.02	4.08	15.07	84.93	64.14	37.94	23.93	8.36
L. Wealth	0.00	0.17	0.59	3.23	14.07	85.93	61.34	33.59	19.94	5.25
Consumption	0.12	0.89	2.32	8.66	25.06	74.94	48.85	24.58	13.77	3.22

Note: Shares of the bottom percentiles groups, columns (1) to (5), and the top percentiles groups, columns (6) to (10) of the income, liquid wealth, and consumption distributions in the data and in the model.
Source: UNPS: 09/10–15/16.

Income volatility and consumption volatility. The model targets the level of income volatility in the data (0.63), and it approximates the value sufficiently, generating an income volatility of 0.62. More interestingly, although the calibration does not target any moment on consumption or insurance, the model predicts a level of consumption volatility (0.11) that is very close to its data counterpart (0.12). This result is crucial for two reasons.

First, the result shows that incomplete markets with standard assumptions on borrowing limits and household preferences might match well the consumption insurance observed in the data.[16] Albeit in developing countries a large part of insurance arises from risk-sharing schemes, here, a self-insurance model can quantitatively capture well the consumption insurance in the economy. Thus, incomplete markets models can also provide a suitable framework to study issues and policies in the developing world.

Second, a major objective of this work is to provide a welfare evaluation of the cost of agricultural risk. The fact that the model can reproduce the level of consumption volatility in the data is a fundamental aspect of carefully performing such welfare evaluation.

In short, the model captures well important moments in agricultural risk and crop decisions, the income and cross-sectional distributions, and, especially, the consumption volatility and inequality observed in the data. With that, the following section proposes the counterfactual scenario with complete markets in agriculture, and then section VI provides the quantitative results.

V. Complete Markets in Agriculture: the Planner's Problem

I obtain the main quantitative results of this paper by comparing the previous benchmark economy vs. an economy where financial markets on agriculture are complete. To solve this counterfactual world, I develop a social planner's problem that provides full insurance for the agricultural output, but the planner cannot observe the realizations of the non-agricultural earnings.

The planner is able to allocate intermediates and consumption allocations from the total agricultural production. To formulate the problem, I follow the approach in Maliar and Maliar (2003), and I represent the planner's problem in the form of two sub-problems. The first sub-problem is to distribute aggregate consumption across heterogeneous agents, which delivers the social period utility

$$U(C_t) = \operatorname*{Max}_{c_{i,t}} \int_i \omega_i u(c_{i,t}) di \tag{18}$$

$$\text{subject to} \qquad \int_i c_{t,i} di = C_t \tag{19}$$

where ω_i is the Pareto weight on individual i. The second sub-problem is to solve

[16]Namely, the assumptions of an incomplete financial market with a no-borrowing constraint, CRRA utility, and standard preferences values capture well the transmission of income volatility to consumption volatility.

for the aggregate consumption that maximizes the social preferences

(20)
$$\underset{\{m^h_{i,t},m^l_{i,t}\}^\infty_{t=0}}{\text{Max}} E_0 \sum_{t=0}^{\infty} \beta^t U(C_t)$$

(21)
$$\text{subject to} \quad C_t = \int_i \left[\theta_{it} z_i A {m^h_{i,t-1}}^{\alpha} + \varepsilon_{it} z_i B {m^l_{i,t-1}}^{\gamma}\right] di - p \int_i \left[m^h_{i,t}(s^t) + m^l_{i,t}(s^t)\right] di$$

(22)
$$C_t = Y_t - pM_t$$

in which the planner at time t does not observe the shocks realizations $\theta_{it+1}, \varepsilon_{it+1}$, but it knows the underlying distributions. The first-order conditions of the second problem per each individual and each period are

$$\left[m^h_{it}\right] : E\left[\beta^{t+1} U_c(C_{t+1}) \alpha \theta_{i,t+1} z_i A {m^h_{it}}^{\alpha-1}\right] = E\left[\beta^t u_c(C_t) p\right] \tag{23}$$

$$\left[m^l_{it}\right] : E\left[\beta^{t+1} U_c(C_{t+1}) \gamma \varepsilon_{i,t+1} z_i B {m^l_{it}}^{\gamma-1}\right] = E\left[\beta^t u_c(C_t) p\right]. \tag{24}$$

. Given that $\theta_{i,t+1}$ and $\varepsilon_{i,t+1}$ are independently distributed across time and unobservable by the planner, planner intermediates allocations $m^h_{i,t}, m^l_{i,t}$ are also independent of the idiosyncratic shocks realizations $\theta_{i,t+1}$ and $\varepsilon_{i,t+1}$. Also, note that in this economy, there are no aggregate shocks, and households have preferences for a smoothed consumption profile, so aggregate consumption growth needs to be constant. Thus, the expectations on the first-order conditions simplify to

$$\left[m^h_{it}\right] : E\left[\theta_{i,t+1}\right] \beta U_c(C_{t+1}) \alpha z_i A (m^h_{it})^{\alpha-1} = u_c(C_t) p \tag{25}$$

$$\left[m^l_{it}\right] : E\left[\varepsilon_{i,t+1}\right] \beta U_c(C_{t+1}) \gamma z_i B (m^l_{it})^{\gamma-1} = u_c(C_t) p \tag{26}$$

in which $E\left[\theta_{it+1}\right] = 1$ and $E\left[\varepsilon_{i,t+1}\right] = 1$. Given that in the benchmark economy, aggregate consumption is stationary; I set the aggregate consumption from the planner solution to also be stationary, $C_t = C_{t+1}$. Thus, the first-order conditions become

$$\beta \alpha z_i A (m^h_{it})^{\alpha-1} = p \tag{27}$$

$$\beta \gamma z_i A (m^l_{it})^{\gamma-1} = p \tag{28}$$

. For optimality, the planner equalizes the discounted expected marginal product of each individual i on both crops h, l to the marginal cost, the price. In other words, under complete markets in agriculture, input allocations are equal to expected discounted profit maximization. Isolating the input allocations from previous equations, we get

$$m^*_{h,i} = \left(\frac{p}{\beta\alpha A z_i}\right)^{\frac{1}{\alpha-1}} \text{ and } m^*_{l,i} = \left(\frac{p}{\beta\gamma B z_i}\right)^{\frac{1}{\gamma-1}} \tag{29}$$

To solve the first sub-problem, I set the distribution of welfare weights in the planner's problem to replicate the competitive equilibrium under complete markets. In this regard, I set the Pareto weights such that each agent consumes according to its permanent component. That is, the shares of consumption across agents are equal to the expected shares of production. Thus, the consumption of an agent with productivity z_i is

$$c^*(z_i) = c_{it}(z_i) = z_i(Am^*_{h,i})^\alpha + z_i B(m^*_{l,i})^\gamma - p\left(m^*_{h,i} + m^*_{l,i}\right). \tag{30}$$

From the first sub-problem, note that the planner optimal consumption allocations will be such that the Pareto-weighted marginal utilities of consumption across agents equalize. As a consequence, the Pareto weights for agents i, j are set such that

$$\int_i \omega_i = 1 \qquad \frac{\omega_i}{\omega_j} = \frac{u^{-1}\left(c^*(z_j)\right)}{u^{-1}\left(c^*(z_i)\right)}. \tag{31}$$

The set of allocations from the planner provides the allocations of agricultural inputs and the consumption coming from its production under complete markets on agriculture. Given these allocations, households decide how much to consume and save out of the non-agricultural income process under the financial market of the benchmark economy.[17]

VI. Quantitative Results

In this section, I present the numerical results of completing financial markets in agriculture I present the results in two sections. The first section presents the gains in agricultural productivity and the risk-induced misallocation of inputs. The second section shows the gains related to welfare: average consumption, the cross-sectional distribution of consumption, and an aggregate ex-ante welfare measure.

A. Agricultural Productivity

Completing financial markets increases agricultural output—and, equivalently, agricultural productivity—by 21.75 percent. Table 7 provides the gains in agricultural output and input usage on aggregate and separately for the two types

[17]The appendix A.A2 states the household problem under complete financial markets in agriculture and provides the solution of the stationary equilibrium under this economy.

of crops. Completing markets increases intermediate inputs expenditure by 43.66 percent. In Sub-Saharan Africa the use of intermediate inputs is extremely low, which is a main force driving the observed low agricultural productivity, Restuccia et al. (2008). Uninsurable risk can explain part of the low investment in intermediates in the region.

Uninsurable risk also distorts the investment across the two types of crops. In Table 7, we observe that the two types of crops do not contribute equally to the increase in agricultural productivity. For the high-yield crops, intermediates investment increases by 53.86 percent and output by 25.33 percent. For the low-yield crops, intermediates expenditure increases by 26.70 percent and output by 15.10 percent.

Table 7—: Gains Agricultural Output and Intermediates Usage

	Aggregate (%)	Low-yield Crops (%)	High-yield Crops (%)
Output	21.75	15.10	25.33
Intermediates Inputs	43.66	26.70	53.86

Note: Changes in agricultural output and intermediates from the benchmark economy in stationarity to the economy with complete financial markets in agriculture.

Under incomplete markets, household investment depends on their permanent component but also on their realizations of income and the wealth that they currently hold.

Table 8—: Agricultural gains across Farmer's Permanent Component

	Input Usage			Output		
	Total	High-Crops	Low-Crops	Total	High-Crops	Low-Crops
Average	43.66	53.86	26.70	21.75	25.33	15.10
Permanent Component (z_i)						
Low	8.50	13.79	-0.80	3.97	6.17	-0.23
Middle-Low	18.81	26.11	6.39	8.23	11.07	2.90
Middle	28.28	38.35	11.86	12.06	15.83	5.11
Middle-High	36.35	46.99	18.98	14.40	17.80	8.08
High	40.45	50.03	24.41	15.95	19.37	9.63

Note: Each value represents the proportional variation from the allocations in the incomplete markets economy to the allocations in the complete markets economy.

If markets are complete, household investment depends only on the permanent component. Thus, completing markets generates efficiency gains from transferring resources from wealth-rich households to wealth-poor households and from households with low permanent components to those with high permanent components.

Table 8 shows the increase in input usage and agricultural output across the permanent component of the households. While for the households with the lowest component, the increase in inputs usage is 8.5 percent—a 13.8 percent increase in high-yield crops and a decrease of 0.8 percent in low-yield crops—for the households with the highest permanent component, the increase is 40.45 percent—50 percent on high-yield crops and 24.4 percent on low-yield crops.

In this work, we observe that risk and incomplete financial markets decrease agriculture productivity through two channels: (1) by decreasing intermediate inputs investment and (2) by generating a misallocation of the intermediate inputs across the join distribution of crops and heterogeneous farmers. Next, I disentangle the effects of the two channels by quantifying the impact of the misallocation channel.

Efficiency gains and the risk-induced misallocation cost. — To compute the efficiency gains of the reallocation of inputs across farmers and across crops, I restrict the complete markets solution to the case that the intermediates share is the same as in the benchmark economy. This implies finding the social planner solution with an intermediate price that is a 10 percent increase in the intermediate price (from p =30.10 to p = 33.10). In this counterfactual economy, I find that the efficiency gains account for 65 percent of the total increase in agricultural productivity.

B. Consumption and Welfare

Aggregate Consumption. — The gains in aggregate consumption from completing financial markets are larger than the gains in agricultural production due to completing financial markets having a large effect on reducing costly precautionary savings.

Table 9 compares the aggregates of agricultural output, income, assets, and consumption between the benchmark economy and the complete markets economy. Agricultural output increases household income by 15 percent. Completing markets dramatically cuts costly unproductive asset accumulation by 63 percent. As a consequence, the increase in consumption is more prominent than in income: consumption increases by 25 percent.

Interestingly, completing agricultural financial markets reduces consumption volatility by a small amount: a 2.73 percent decrease. In the absence of complete markets, households smooth their income to avoid consumption fluctuations. According to this calibration, income smoothing reduces the volatility of agricultural profits by 43.05 percent. Thus, the changes in consumption volatility in the benchmark economy to the complete market scenario are small. Under this context,

Table 9—: Aggregate Gains Completing Markets

	Benchmark ($)	Complete Markets ($)	$\triangle_{CM}$ ($)	$\triangle_{CM}$ (%)
Agric. Output	1,008.32	1,227.58	219.26	21.75
Income	1,466.74	1,686.63	219.89	14.99
L. Wealth	1,925.34	713.34	-1,212.00	-62.95
Consumption	908.96	1,133.74	224.79	24.73

Note: The aggregate resource constraint is: $C = Y_a - pM + Y_{na} - \delta A$, where Y_a represents total agricultural output, M total input usage. C represents consumption, Y_{na} non-agricultural income, and A total assets holdings in the economy.

The potential gains of insurance products or safety net policies can be greater in terms of productivity than in terms of reducing consumption fluctuations.

The Distributional Effects of Completing Markets. — Table 10 shows the distributional effects of completing markets on agricultural output, income, and consumption. Column (1) presents the percentual change in the Gini index of the distributions. Columns (2–6) present the percentage change for the individuals in the bottom of the distribution (1, 5, 10, 25, 50 percent bottom) while columns (7–11) presents the percentage changes fot the same percentile groups in the top of the distribution.

There are several mechanisms at play regarding the distributional effects. In this work, the underlying sources of inequality are risk—under three different income sources—and permanent differences in agricultural production. In the benchmark economy, the poor are a combination of households with low permanent components and a continuation of bad shocks realizations. The rich will be the opposite. In the complete markets world, agricultural production and income inequality slightly increase. The lack of income smoothing makes households experiment a more volatile income, therefore translating to larger differences in the cross-sectional distribution.

Under complete markets, consumption allocations are independent of shocks realizations. Conditional on the permanent component, households experiencing a sequence of good or bad agricultural shocks will experience the same consumption. Thus, this mechanism notably reduces consumption inequality; it shuts down all consumption inequality coming from agricultural risk. Nevertheless, in this exercise, completing markets has two inequality-enhancing effects that outweigh the previous egalitarian force. First, households with high permanent components z_i experience the most significant increase in output. In the stationary equilibrium, these households are not uniformly distributed, but they are typically concentrated in the middle and top of the distribution. thus, we also observe large income increases for the households in the top of the income distribution.

Second, completing markets decreases costly savings, by 63 percent. The savings are heavily concentrated in the top of the distribution, so for these households the effect of the reduction on costly savings into consumption is much larger. In proportional terms, households in the top 5 percent of the distribution increase their consumption by 25.68 percent; households in the bottom distribution by 30.31 percent. Across the other percentile groups one observe relatively close percentual increases. Consequently, the consumption levels of the rich households increase more than of the poor households. This translates to an increase of the consumption Gini index after completing markets of 3.7 percent.

Table 10—: Distributional Gains Completing Markets

	Gini (%)	Bottom (%)					Top (%)				
		1	**5**	**10**	**25**	**50**	**50**	**25**	**10**	**5**	**1**
Agric Outp	1.16	19.48	15.17	9.00	12.62	19.04	19.04	22.68	25.90	21.26	24.94
Income	1.01	14.12	13.60	8.87	10.06	11.23	11.23	14.35	14.97	14.28	15.05
Consumption	3.70	32.70	30.31	21.44	17.19	18.09	18.09	21.58	25.47	25.68	24.66

Note: Column (1) presents the proportional change in the Gini index after completing financial markets. The rest of columns present the proportional change in agricultural output (row 1), income (row 2), and consumption (row 3) holdings of the bottom percentile groups (columns 2 to 6) and the top percentile groups (columns 7 to 11) after completing markets.

Computing the Welfare Gains. — Consider the ex-ante welfare comparison of the benchmark economy with the complete market economy. The average welfare gain, in terms of consumption-equivalent changes (CEV), that results from completing risk markets is defined as the percentage increase in consumption, g, constant across time and agents that equalizes the utilitarian welfare to the value associated under complete markets

$$\int E_0 \left[\sum_{t=0}^{\infty} \beta^t u((1+g)c_{i,t}^{IM}) \right] d\lambda^* = \int E_0 \left[\sum_{t=0}^{\infty} \beta^t u(c_{i,t}^{CM}) \right] d\lambda^* \tag{32}$$

I find that, on average, these gains are equivalent to a 28.4 percent increase in consumption. Note that the gains are larger than the average increase in consumption even if inequality is increasing. This is due to the welfare gain associated to lower consumption fluctuations.

VII. Conclusion

In this paper, I argue that uninsurable risk can notably affect crop choice and intermediate investment in farmers and, therefore, reduce output and welfare in poor agrarian-based economies. The paper has two main findings to generate the argument.

First, the results suggest that incomplete financial markets reduce agricultural productivity and create a misallocation of resources. In the absence of complete markets, intermediate input usage is small. At the same time, the risk-induced misallocation across crops and farmers is large, with a 16 percent gain in agricultural production directly coming from the reallocation of inputs. Second, the quantitative results suggest that despite high insurance levels in rural Uganda, completing financial markets in agricultural risk can have significant welfare effects.

Are the quantitative results large? It depends. If we consider the magnitude of the experiment, the results might not be surprisingly large. An increase of 25 percent in consumption in rural Uganda implies that they are still one of the poorest areas in the world. In the absence of other reforms, see, for example, Manysheva (2022), it is difficult to argue—and therefore to model—that completing financial markets in poor agrarian-based areas will alone lead to a large process of structural transformation.[18] Yet, the results also show that despite high levels of informal insurance in rural developing areas, the gains of formal insurance schemes, especially in terms of increasing income and consumption levels, can be substantial. Thus, well-functioning markets and policies that provide better insurance on consumption risk—from index-based insurance, cash transfers, pension systems, etc.—can help to promote growth and increase welfare in the poorest areas of the world.

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[18]Note that this exercise does not take into account any scenario where completing markets would in the long term affect structural change. This is different from the results in Donovan (2021), where structural change is a crucial mechanism of the gains.

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Appendix

A1. Stationary Recursive Competitive Equilibria

Stationary Recursive Competitive Equilibria. The stationary RCE is defined by a stationary distribution $\lambda(x, z, y_{na}) = \lambda^*(x, z, y_{na})$, a transition function $Q((x', z, y'_{na}), (x, z, y_{na}))$, a value function $V(x, z, y_{na})$, a set of policy functions $g(x, z, y_{na})\{c(x, z, y_{na}),\ a'(x, z, y_{na}),\ m'_h(x, z, y_{na}),\ m'_l(x, z, y_{na})\}$ such that:

1) Policy functions $g(x, z, y_{na})$ solve the household problem and $V(x, z, y_{na})$ is the associated value function.

2) Given policy functions, $g(x, z, y_{na})$ the production market clears

$$\begin{aligned}\int_{\mathcal{S}} c(x, z, y_{na}) d\lambda^*(x, z, y_{na}) = & \int_{\mathcal{S}} \left[\theta z A(m'_h(x, z, y_{na}))^{\alpha} + \varepsilon z B\left(m'_l(x, z, y_{na})\right)^{\gamma}\right] d\lambda^*(x, z, y_{na}) - \\ & - \int_{\mathcal{S}} \left[p m'_h(x, z, y_{na}) + p m'_l(x, z, y_{na})\right] d\lambda^*(x, z, y_{na}) + \\ & + \int_{\mathcal{S}} y_{na} d\lambda^*(x, z, y_{na})\end{aligned}$$

3) The stationary distribution $\lambda^*(x, z, y_{na})$ associated with $g(x, z, y_{na})$ satisfies the law of motion

$$\lambda^*(x', z', y_{na}) = \int_{\mathcal{S}} Q((x', z, y'_{na}), (x, z, y_{na})) d\lambda^*(x, z, y_{na})$$

. [19]

[19] Where $\lambda_t(x, z, y_{na})$ is the proportion of agents at time t in state (x, z, y_{na}), $x \in \mathcal{X}$, where $\mathcal{X} \equiv [0, +\infty)$, $z \in \mathcal{Z} \equiv \{z_l, z_{lm} z_m, z_{mh}, z_h\}$ where $z_j \in R_{++}$, and $y_{na} \in \mathcal{Y}_{na} \equiv R_{++}$. Also, $\mathcal{S}\mathcal{X} \times \mathcal{Z} \times \mathcal{Y}_{na}$.

A2. The Stationary Equilibria under Complete Financial Markets in Agriculture

The set of pareto optima allocations—in section V—provides the allocations of agricultural inputs and the consumption coming from its production under complete markets on agriculture. Each agent i produces in agricultural outputs and receives the consumption from this production according to their ex-ante permanent component (z_i).

$$m^*_{h,i} = \left(\frac{p}{\beta\alpha A z_i}\right)^{\frac{1}{\alpha-1}} \text{ and } m^*_{l,i} = \left(\frac{p}{\beta\gamma B z_i}\right)^{\frac{1}{\gamma-1}} \tag{A1}$$

$$c^*(z_i) = c_{it}(z_i) = z_i(Am^*_{h,i})^{\alpha} + z_i B(m^*_{l,i})^{\gamma} - p\left(m^*_{h,i} + m^*_{l,i}\right). \tag{A2}$$

Given these allocations, households decide how much to consume and save out of the non-agricultural income process under the financial markets of the benchmark economy. That is they solve the following problem in stationarity

$$V(a, z, y_{na}) = \underset{a',c}{\text{Max}} \quad u\left(c^*(z_i) + c\right) + \beta E\left[V(a', z, y'_{na})\right] \tag{A3}$$

$$\text{subject to} \qquad a' \geq \underline{a} \tag{A4}$$

$$c(a, z, y_{na}) + a'(a, z, y_{na}) = (1-\delta)a + y_{na} \tag{A5}$$

$$lny'_{na} = b + \rho_y lny_{na} + u, \qquad u \sim N(0, \sigma^2_u). \tag{A6}$$

.Finally, the definition of the stationary equilibria in the economy under complete markets on agriculture is analogous to the definition in section II with: the optimal allocations given by $m^*_h(z_i)$, $m^*_l(z_i)$, $c = c^*(z_i) + c(a, z, y_{na})$, $a'(a, z, y_{na})$; the transition function defined as $Q\left((a', z, y'_{na}), (a', z, y'_{na})\right)$; the stationary distribution as $\lambda^*(a, z, y_{na})$; Under the space $\mathcal{S} := \mathcal{A} \times \mathcal{Z} \times \mathcal{Y}_{na}$ where $\mathcal{A} = [\underline{a}, \infty]$.

A3. Tables and Figures

Table A1—: Relationship Household Economic Level and Crop Portfolio

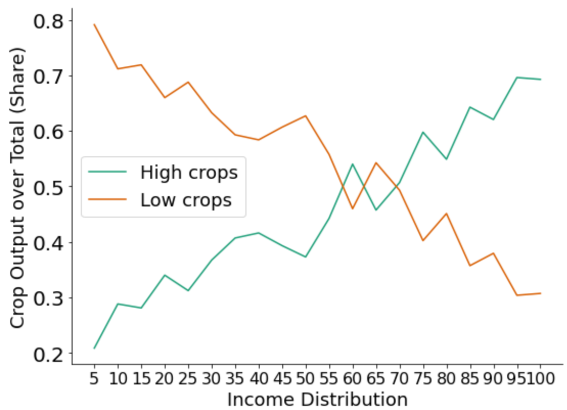
Log\Log	Output High-Yield Crops over total Output			
	($\hat{\beta}$)	($\hat{\beta}$)	($\hat{\beta}$)	($\hat{\beta}$)
Consumption		0.9945		
		(0.0456)		
Income	0.9004			
	(0.0197)			
Wealth			0.4246	
			(0.0195)	
Land Area				0.4524
				(0.0163)
Intercept	-0.9653	-1.9508	2.0325	5.0663
	(0.1403)	(0.3380)	(0.1563)	(0.0219)
N	5960	5960	5957	7038
R2	0.26	0.07	0.07	0.10

Notes: Coefficients and their standard errors of running the following OLS regressions: $logy^h_{it} - logy_{it} = \beta_0 + \beta_1 logx_i + u_{it}$. Where y^h_{it} is the household's agricultural production in high-yield crops, y^l_{it} in low-yield crops, and x_i is the household's time-average consumption, income, wealth, or land area.

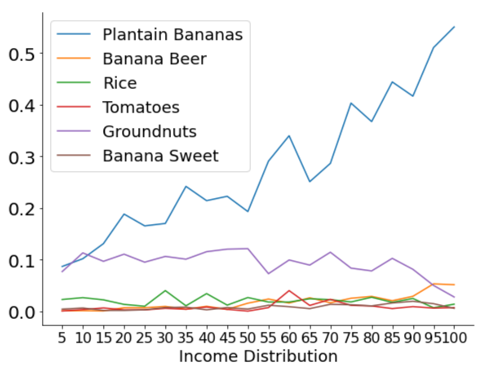
Table A2—: Agricultural Production Allocations in Uganda

Wave	Share Production to: (%)				Proportion Farmers did: (%)			
	Sell	Cons	Stored	gift	Sell	Cons	Stored	gift
2009	24.98	57.01	4.38	5.80	72.74	93.16	35.00	57.57
2010	23.94	59.66	4.58	6.41	77.73	97.68	34.27	62.51
2011	24.75	59.17	4.61	6.30	78.62	98.38	33.08	63.91
2013	28.63	54.48	6.41	6.25	74.64	96.30	40.13	59.11
2015	29.37	55.70	6.80	5.19	77.05	98.76	44.31	57.41

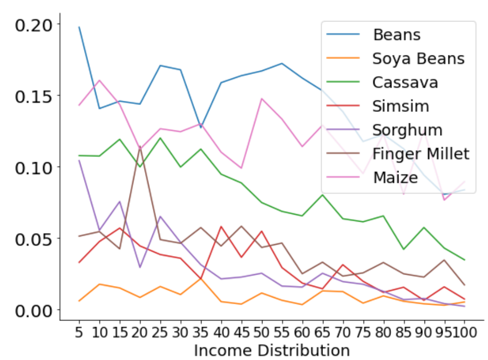
Note: Notes: Columns (1) to (4) show the share of agricultural production devoted to the market (1), to own consumption (2), stored (3), and gifted to other households(4). Columns (5) to (8) show the proportion of farmers that sold (5), own consumed (6), stored (7), and gifted (8) some part part of their agricultural production. Data: UNPS first 5 waves.



(a) High-yield vs. Low-yield Crops



(b) High-yield Crops



(c) Low-yield Crops

Figure A1. : Crop Production along the Income Distribution

Note: Farmer's observations on crop production and wealth are computed as the average across the five waves. Data: UNPS first five waves.

Table A3—: intermediates Summary

A. Intermediates Expenditure across Types of Crops			
	Total (m) ($)	High-Yield Crops (m_h) ($)	Low-Yield Crops (m_l) ($)
Avg	59.41	41.24	38.50

B. Decomposition of Intermediates Inputs Usage and Expenditure						
	Chem. fert. (%) ($)	Org. Fert. (%) ($)	Pesticides (%) ($)	Seeds (%) ($)	transport (%) ($)	Wages (%) ($)
Usage	3.92	9.17	10.24	57.44	13.08	
Expend	48.74	51.97	34.43	19.58	15.34	

Note: Notes: Panel A shows the average expenditure in intermediates, Avg ($), in all crops (column 1), in the high-yield crops (column 2), and in the low-yield crops (column 3). Panel B shows the proportion of farmers, usafe (%), and average expenditure, Expend ($), across intermediates: chemical fertilizer, organic fertilizer, pesticides, seeds, transport costs, and hired labor costs (columns 2 to 6).

Table A4—: Per Capita Consumption, Income, and Wealth in Uganda

	Rural				National			
	Cons ($) ([0, 1])	Income ($) ([0, 1])	Wealth ($) ([0, 1])	Hh Size (N)	Cons ($) ([0, 1])	Income ($) ([0, 1])	Wealth ($) ([0, 1])	Hh Size (N)
2009-2010	264.58	214.69	696.93	6.56	320.65	234.87	737.41	6.41
	(0.36)	(0.61)	(0.61)		(0.4)	(0.63)	(0.65)	
2010-2011	236.15	225.21	656.54	7.19	276.29	256.18	954.64	7.15
	(0.38)	(0.59)	(0.64)		(0.41)	(0.6)	(0.75)	
2011-2012	257.97	251.48	685.22	7.54	290.40	277.02	738.39	7.50
	(0.38)	(0.59)	(0.63)		(0.41)	(0.59)	(0.66)	
2013-2014	320.14	321.76	830.56	5.82	376.92	385.86	962.33	5.67
	(0.33)	(0.59)	(0.6)		(0.37)	(0.6)	(0.65)	
2015-2016	326.20	401.91	834.68	5.65	395.63	494.61	937.29	5.53
	(0.35)	(0.6)	(0.61)		(0.4)	(0.63)	(0.65)	
Average	281.01	283.01	740.79	6.55	331.98	329.71	866.01	6.45
Average	(0.36)	(0.6)	(0.62)		(0.4)	(0.61)	(0.67)	

Note: Notes: Values in 2013 US dolars. Data controlled for inflation. Gini index within parenthesis. Consumption includes food and non-durables consumption. Income includes crops revenues computed with median district crop consumption prices and selling prices when missing. Livestock profits, salary labor earnings, business profits and other sources of income. Wealth includes housing, household assets, land, livestock holdings, and farm capital. Data: UNPS first five waves.

Table A5—: Composition Consumption, Income, and Wealth: Rural Uganda

Wave	Consumption ($) ([0,1])		Income ($) [(0,1])				Wealth ($) ([0,1])			
	Food ($) (N)	Nofood ($) (N)	Agric ($) (N)	business ($) (N)	Lvsk ($) (N)	Labor ($) (N)	Assets ($) (N)	Land ($) (N)	Lvstk ($) (N)	farmK ($) (N)
09–10	1,499.19		1,497.88				4,066.35			
	(0.33)		(0.57)				(0.61)			
	967.95	578.60	854.84	625.06	287.85	766.82	1,495.03	3,249.30	1,016.39	NaN
	[2008]	[1920]	[1888]	[931]	[480]	[849]	[2003]	[1584]	[495]	[0]
10–11	1,419.42		1,383.18				3921.16			
	(0.36)		(0.55)				(0.63)			
	1,001.54	473.09	780.93	683.12	232.47	783.15	1,775.54	3,145.06	940.08	24.73
	[1923]	[1917]	[1775]	[843]	[467]	[746]	[1919]	[1495]	[482]	[1776]
11–12	1,582.88		1,620.54				4,182.69			
	(0.34)		(0.55)				(0.61)			
	1,129.07	503.11	1,014.51	918.86	353.22	867.47	1,382.18	3,659.23	979.42	18.63
	[2087]	[2081]	[1847]	[848]	[478]	[624]	[2042]	[1690]	[473]	[1817]
13–14	1,539.26		1,502.92				4,391.47			
	(0.30)		(0.57)				(0.61)			
	1,054.45	519.81	889.76	932.59	238.40	831.97	1,709.23	2,792.61	963.85	83.43
	[1895]	[1894]	[1764]	[768]	[503]	[579]	[1895]	[1616]	[519]	[1791]
15–16	1,466.62		1,733.13				3,731.18			
	(0.31)		(0.58)				(0.60)			
	1,002.87	511.90	1,052.81	886.58	274.15	429.07	1,458.82	2,634.23	1,074.73	18.11
	[1899]	[1896]	[1724]	[788]	[479]	[1899]	[1898]	[1624]	[502]	[1791]

Note: Values in 2013 US dollars. Data controlled for inflation. (Gini), [observations]. C-*nofood* consists of non-durable goods. Non-agriculture business; I-*livestock* net income from livestock; I-*labor* income from salary labor. W-*hh* value of household assets; W-*farm* value of farming capital and livestock, Land not included in.

Table A6—: High-yield and Low-yield Crops at Household Level

Wave	y_h (\$)	y_l (\$)	A_h (acres)	A_l (acres)	m_h (\$)	m_l (\$)
09–10	674.73	328.91	0.88	2.22	32.23	41.96
10–11	402.86	354.04	1.31	1.76	21.69	18.30
11–12	554.84	406.39	1.75	2.89	56.93	44.24
13–14	728.01	344.21	1.63	2.84	55.52	41.04
15–16	889.07	330.75	1.33	2.32	37.43	36.76
Avg	649.90	352.86	1.38	2.41	40.76	36.46

Note: Where y represents output in \$, A represents land size in acres, m represents intermediates expenditure in \$. h denotes variables for high-yield crops, l for low-yield crops. Last row presents the targeted moments for high-yield crops output and input usage and low-yield crops.