Incomplete Markets, Crop Portfolios, and Agricultural Productivity

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Using the Uganda National Panel Survey, I document that farmers face a trade-off between crop yields and risk, with poorer households concentrating on low-yield, low-risk crops. I develop an incomplete markets model with a crop-portfolio choice, in which households trade off income returns against consumption smoothing. In the model, wealth-poor households optimally under-invest in intermediates and shift toward safer crops. Crop portfolios, intermediate input use, and the wealth distribution are jointly determined in equilibrium. Calibrated to rural Uganda, the model implies that completing markets raises agricultural productivity by 12.2%, with about half of the gain coming from input reallocation across farmers and crops. Consumption rises by 17.2%, while inequality increases slightly.

Keywords: Agriculture, Risk, Incomplete markets, Crop choice.

JEL Classification: O11, 013, E21.

Households in low-income countries live with high levels of risk while having limited access to formal financial markets or public safety nets. Many of these households rely heavily on agriculture, a sector characterized by both high income risk and particularly low productivity in developing countries (Caselli 2005, Restuccia, Yang, and Zhu 2008, and Gollin, Lagakos, and Waugh 2014). In this article, I study how risk distorts agricultural decisions among heterogeneous farmers to then quantify the aggregate impact of completing financial markets in agriculture in Uganda.

Complete markets tests in developing countries typically show a high degree of consumption insurance (Townsend 1994).[1] Yet informal insurance mechanisms are often imperfect and

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[1] Townsend (1994) finds that household consumption responds little to idiosyncratic income shocks in rural India. Similarly, Paxson (1993) finds limited evidence that consumption tracks income seasonality in Thailand. More

costly. When farmers in developing countries are offered insurance products, they tend to take riskier and more productive decisions, such as increasing fertilizer usage (Karlan, Osei, et al. 2014) or shifting to more productive crops (Mobarak and Rosenzweig 2013 and Cai 2016). The absence of perfect insurance can have significant aggregate impacts, though knowledge on this dimension is still limited. Donovan (2021) shows how uninsurable risk reduces the intermediate share and in equilibrium creates a large agricultural productivity gap.

To better understand the relationship between incomplete financial markets and agricultural productivity, I first examine the empirical relationship between crop productivity, crop risk, and the crop selection of heterogeneous farmers. Second, I develop an incomplete markets model with the novelty of introducing a crop-portfolio choice. In addition to making consumption and saving decisions, heterogeneous households optimize in their crop-portfolio investment modelled via two types of technologies: high-risk, high-return technologies (high-yield crops) and in low-risk, low-return technologies (low-yield crops).[2]

To provide the quantitative results, I calibrate the model using 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. The numerical results suggest that completing financial markets increases agricultural productivity by 12.20% and consumption by 17.18%. Additionally, the welfare gain is 15.20% in consumption equivalent units.

I use data from the Uganda National Panel Survey (UNPS), a dataset that provides detailed agricultural information at the household-plot level. I compute the yields of the main crops grown in Uganda, measuring yields as the production value—including non-sold production valued with local median consumption prices—per land unit ($/acres). Then, exploring the relationship between crop yields and risk, and the crop selection of farmers, I find three main empirical results. First, there is a strong positive correlation between crop yields and risk. Crops such as plantain bananas, rice, or groundnuts offer high but also more volatile yields. Crops such as beans, cassava, or sorghum offer lower and less volatile yields. Second, the share of output resulting 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—mainly beans, maize, and cassava. Farmers in the top quartiles obtain most of their output from high-yield crops—mainly plantain bananas. Third, most farmers cultivate high-yield crops and low-yield crops simultaneously.

Motivated by these results, I develop an incomplete markets model with a crop-portfolio choice. The model depicts an agrarian economy with one type of agent—households with farms—that differ ex-ante only in a permanent component on agricultural production. These households live infinitely, and have standard preferences with a CRRA instant utility function.

recent studies with results along the same lines include Chiappori et al. (2014), De Magalhães and Santaeulàlia-Llopis (2018), and Kinnan (2021).

[2] Adamopoulos and Restuccia (2020) also model crop selection as a choice between two technologies, where the key trade-off is higher productivity versus lower fixed costs: a "cash-crop" technology and a "food-crop" technology.

Income is endogenous to farming decisions. Household farms (or simply households) choose intermediate inputs for both high-return, high-risk technologies and for low-return, low-risk technologies. Additionally, households receive non-agricultural earnings from an exogenous and stochastic process. Financial markets are incomplete, following the tradition of incomplete markets models, as in Bewley (1986), Imrohoroğlu (1989), Huggett (1993), and Aiyagari (1994). Yet, to capture the hardships of saving in developing countries, and in line with Donovan (2021) and Lagakos, Mobarak, and Waugh (2023), I assume savings occur through a risk-free asset with a depreciation rate, and that households face a no-borrowing constraint.[3] Given that most of the agricultural production in Uganda is at subsistence level, I model the economy as a small open economy with fixed input prices.

The model exhibits two interlinked mechanisms through which households manage risk: precautionary savings and precautionary income choices.

Regarding the latter, when choosing intermediate inputs, households must weigh the trade-off between higher agricultural returns and less consumption smoothing in their decision-making process. To resolve this tension, the model includes two adjustment margins within household farming. The first margin involves the total amount of intermediate usage (as described in Donovan (2021)). By holding a constant portfolio choice, households can increase agricultural returns by increasing the total amount of intermediate use. Crucially, if only this margin is in operation, there exists a monotonic relationship between total intermediate use, agricultural returns, and risk.

The second margin of adjustment involves the portfolio choice across production technologies, which is a new mechanism I introduce. The introduction of this margin opens up the possibility of increasing agricultural returns by shifting production from low-return, low-risk technologies to high-return, high-risk technologies, without necessarily increasing total intermediate input use. Formally, this new trade-off is reflected in the first-order (Euler) conditions for intermediate input use, where a risk-induced wedge varies by production technology. In other words, portfolio choice introduces an additional allocation problem within the household farm, where the distribution of risk across production technologies could potentially lead to misallocation. This distinct feature of my work microfounds, in a straightforward yet powerful manner, the aggregate risk-induced wedge that would arise in an intermediate use problem if portfolio choice were not considered.

I calibrate the model to rural Uganda using data from the Uganda National Panel Survey (UNPS), a survey part of the ISA-LSMS project. Measuring living standards, particularly household income, is challenging in developing countries. The ISA-LSMS project employs a comprehensive set of questionnaires that enables the accurate measurement of agriculture,

[3] Although risk-sharing schemes are a critical source of insurance in developing countries (e.g., Udry 1994, Ligon 1998, Ligon, Thomas, and Worrall 2002, Fafchamps and Lund 2003) for tractability, insurance in this model is limited to a self-insurance mechanism. Yet, quantitatively, the model captures well the aggregate levels of insurance in the data—measured with the transmission of income to consumption volatility. Karaivanov and Townsend (2014) find that in rural Thailand incomplete markets with saving-only and borrowing regimes provide a better fit to the data than endogenous incomplete (risk-sharing) models.

consumption, income, wealth, and other variables for households in Sub-Saharan Africa. This extensive data allows me to effectively reconstruct the entire household budget constraint in the model from this single dataset.

With the calibrated model, I investigate its ability to replicate key moments in the data that were not directly targeted during calibration. First, I compare the endogenous relationship between the crop portfolio and the wealth distribution generated by the model with the relationship observed in the data. Second, I demonstrate that the model reasonably approximates the observed inequality in rural Uganda, particularly in terms of income and consumption. Third, I show that the model also captures the transmission of income volatility to consumption volatility relatively well.[4]

The framework of incomplete markets offers a theory for consumption, income, and wealth inequality because these distributions are endogenous to the model. Consequently, a key objective of this literature has been to account for these distributions and their trends, primarily for the United States and other high-income economies—e.g., Aiyagari (1994), Quadrini and Ríos-Rull (1997), Castaneda, Diaz-Gimenez, and Rios-Rull (2003), and Krueger and Perri (2006). However, this approach has been lacking for African countries.[5] In this paper, by calibrating the dispersion of agricultural production, I demonstrate that the model closely approximates the observed income distribution, although it underpredicts inequality levels in liquid wealth. More notably, without specific targeting, the model accurately replicates the consumption distribution using standard assumptions and preference values.[6]

Next, I develop a planner's problem to replicate the competitive equilibrium allocations of intermediates and consumption under complete markets in agriculture. In this scenario, allocations are such that households maximize discounted expected profits through their crop-portfolio investment choices. By comparing the calibrated benchmark model with this counterfactual framework, I derive the main results of the paper.

Completing financial markets in agriculture increases agricultural productivity by 12.20%. Since labor and land size are fixed in the model, agricultural productivity (both per worker and per land unit) is equivalent to agricultural production. This increase in productivity results from two main channels: (1) a 26.65% rise in the average amount of intermediates used, and (2) a more efficient allocation of intermediates across the crop portfolio of heterogeneous farmers. To quantify the efficiency gains from (2), I compare the complete markets solution with a counterfactual where the level of intermediate inputs is fixed at the benchmark economy's level. This analysis shows that the efficiency gains from reallocating intermediates across crops and farmers account for 46.54% of the total increase in agricultural production.

[4]Capturing how income volatility translates into consumption volatility is essential for assessing the effects of incomplete markets. The benchmark model should capture the degree of consumption insurance, as this shapes both the size of risk-induced distortions and their distributional consequences for welfare and farm choices.

[5]See De Magalhães and Santaeulàlia-Llopis (2018) for an in-depth empirical analysis of consumption, income, and wealth distributions in Malawi, Uganda, and Tanzania.

[6]Specifically, rational agents with identical preferences under a CRRA utility function with a coefficient $\rho = 2$, a discount factor $\beta = 0.96$, and a no-borrowing constraint on risk-free assets with a depreciation rate.

When financial markets in agriculture are complete, the demand for costly precautionary savings decreases. This reduction, combined with the increase in agricultural productivity, leads to an aggregate consumption increase of 17.18%.

In this model, the effects of completing markets on consumption inequality are theoretically ambiguous. On the one hand, completing markets has an egalitarian effect: consumption allocations no longer depend on the realizations of agricultural shocks. On the other hand, two inequality-enhancing effects in this exercise outweigh the egalitarian force. First, households with high permanent components experience the most significant increases in output. In the stationary equilibrium, these households are concentrated in the middle and upper parts of the distribution. Second, completing markets reduces costly savings, which are concentrated among households at the top of the distribution. Although both poor and rich households benefit from completing markets, the gains are slightly greater for richer households, with the Gini index for consumption increasing by 0.56%.[7]

All these effects have important consequences for welfare which I measure with an ex-ante welfare measure in terms of consumption equivalent variation. With the baseline calibration, households would need to experience a 15.20% increase 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.

Related Literature

The paper most closely related to this work is Donovan (2021), who shows how, in equilibrium, completing financial markets raises agricultural productivity and narrows the cross-country agricultural productivity gap.[8] This paper contributes to his work in three main ways. First, I show that uninsurable risk distorts the use of intermediates across households but also across agricultural technologies (crops). This joint risk-induced distortion leads to a greater misallocation effect. Second, I quantify the welfare gains from completing financial markets in agriculture. The welfare analysis has two important insights: the gains in aggregate consumption are substantially larger than in income while the distributional effects are complex. Third, by studying a different economy and with different model assumptions, I find that the core insights in Donovan (2021) remain consistent.[9] Uninsurable risk significantly impacts agricultural productivity.

[7]Households with low permanent components, such as limited agricultural skills, small landholdings, or residing in remote and unproductive areas, might not experience substantial gains from insurance products.

[8]To show that, Donovan (2021) focuses on India and builds a two-sector model (agriculture and riskless industry) with three key mechanisms in which completing financial markets raises agricultural productivity: higher intermediate share, eliminating misallocation of intermediates across farmers that differ in shocks' histories, and labor reallocation to industry. This work omits the third mechanism, which relies on a viable industrial sector absorbing post-shock agricultural labor. In rural Uganda, such sectoral labor shifts are hard to argue.

[9]by studying Rural Uganda, a much poorer and subsistence-based economy, and by showing that even with absent general equilibrium effects from labor reallocation across sectors and differences in model assumptions, such as including household permanent components in agricultural production and excluding a subsistence requirement.

More broadly, this paper contributes to the literature on the determinants of low agricultural productivity in developing economies, including Restuccia, Yang, and Zhu (2008), Yang and Zhu (2013), Lagakos and Waugh (2013), Gollin, Lagakos, and Waugh (2014), or Adamopoulos and Restuccia (2014). Gollin and Rogerson (2014) show that in low-income countries high transport costs drive subsistence farming and thereby entrenching persistently low productivity. Another major explanation is land misallocation, especially in Africa, where land markets are often absent due to traditional communal tenure systems (Chen 2017; Adamopoulos and Restuccia 2020; Gottlieb and Grobovšek 2019; Chen, Restuccia, and Santaeulàlia-Llopis 2023). Le (2020) demonstrates that crop-specific policy distortions also contribute to misallocation, while Manysheva (2022) emphasizes the importance of jointly quantifying the costs of incomplete land and financial markets. Geography alone cannot account for the agricultural productivity gap between poor and rich countries (Adamopoulos and Restuccia 2022). The authors also highlight the potential for substantial productivity gains through more efficient crop allocation. This paper contributes by showing that part of the inefficient crop allocation observed in poor countries stems from uninsurable risk.

This paper builds on the micro-literature examining the role of risk in agricultural decisions. Dercon (1996) shows that risk affects crop choices, Rosenzweig and Binswanger (1993) demonstrate that wealth conditions the impact of risk on investment, and Dercon and Christiaensen (2011) find that fertilizer use in Ethiopia declines when farmers face harvest risk. Similarly, Kurosaki and Fafchamps (2002) provide evidence that crop choices respond to price and yield risk even when accounting for village-level insurance mechanisms. The contribution of this paper is twofold: it develops a framework that incorporates these micro-level mechanisms into an equilibrium setting with an endogenous wealth distribution, and it quantifies the aggregate consequences of risk for agricultural productivity and inequality.

By examining the welfare effects of incomplete markets in rural Uganda, this article contributes to the literature on insurance in development (Deaton 1992; Townsend 1994; Kinnan and Townsend 2012; Karaivanov and Townsend 2014; De Magalhães and Santaeulàlia-Llopis 2018). The findings indicate that even in the presence of substantial smoothing of consumption, the welfare impact of incomplete markets is significant. The distortions in income and savings choices to smooth consumption result in considerable losses in economic growth. These quantitative results contribute to other studies documenting a trade-off between consumption smoothing and growth, both at the micro-level (Rosenzweig and Wolpin 1993; Morduch 1995; Kurosaki and Fafchamps 2002) and at the macro-level (Munshi and Rosenzweig 2016; Santaeulalia-Llopis and Zheng 2018; Donovan 2021).

1 Empirical Findings

This section explores the relationships between agricultural yields, risk, and farmers' usage across the main crops grown in Uganda. I document three main empirical results from this analysis: (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 simultaneously grow low-risk, low-yield crops and high-risk, high-yield crops.

To document these results, I use the first five waves of the Uganda National Panel Survey (UNPS) and I compute the yields of the crops harvested in Uganda. Yields are defined as the value of production per land unit ($/acre), also known as agricultural productivity or land productivity. The value of production is the sum of the household-reported value of crop sales plus the non-sold production, valued at district-level median consumption prices. The unit of land is the reported number of acres devoted to cultivating the crop.

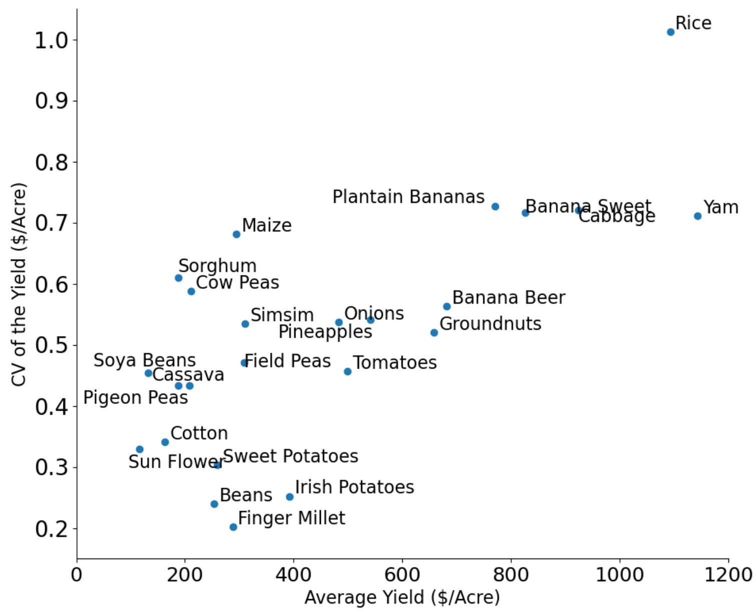


Figure 1: Crop Yield and Crop Risk in Uganda
Notes: Yield observations ($/acres) at the wave level. Crops with a span of time between planting and harvest below 2 years. *Source:* UNPS 2009/10–2015/16.

Figure 1 plots the average yield against the Coefficient of Variation (CV) of the yield for the main crops cultivated in Uganda. Observations are aggregated at the wave-seasonal level so that the dispersion is across time and not across households. Crops with higher yields exhibit greater volatility, and the differences are substantial. For example, the yield of plantain bananas, a major staple crop in Uganda locally known as matooke, has an average yield of around $770 per acre and a CV of 0.73. In comparison, the yield of beans is $253 per acre with a CV of 0.24. The positive relationship between average yields and the CV of the yields is strong, with a correlation of 0.84.

For robusteness, Table 1 presents the correlation between yields and risk across crops using three different measures of risk—the Standard Deviation (SD), the Coefficient of Variation (CV), and the Gini Index. It also considers six methods of grouping the data—variation across household and waves-seasons (1), variation across waves-seasons (2), and variation across waves-seasons per each of the 4 main regions of Uganda (3-6); and two samples of crops: all crops, and no long-term crops (those with a planting-to-harvesting period not exceeding two years).[10] Across all computations, the correlation between yields and risk is positive and typically above 0.65.[11]

Table 1: Correlation Average Yields and Risk Measures among Crops

Risk Measure	Correlation Coefficient ($r \in [-1, 1]$)					
	Grouping Data by: Hhs-Waves (1)	Nationwide (2)	Central (3)	Eastern (4)	Northern (5)	Western (6)
Excluding long-term crops:						
SD	0.63	0.95	0.94	0.76	0.96	0.94
CV	0.44	0.84	0.68	0.10	0.81	0.60
Gini	0.70	0.84	0.78	0.66	0.90	0.79
All crops:						
SD	0.97	0.98	0.97	0.92	0.89	0.93
CV	0.91	0.62	0.71	0.57	0.37	0.58
Gini	0.54	0.60	0.79	0.69	0.53	0.78

Notes: 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 2009/10–2015/16.

Next, I examine the crop portfolio along with the wealth distribution of Ugandan farmers. To do this, I group the non-long-term crops into high-yield and low-yield categories based on whether they are above or below the median yield crop. High-yield crops include bananas (for beer), plantain bananas, sweet bananas, cabbage, eggplants, groundnuts, Irish potatoes, onions, pineapples, pumpkins, rice, sugarcane, tomatoes, and yam. Low-yield crops include beans, cassava, cotton, dodo, cowpeas, field peas, finger millet, maize, pigeon peas, simsim, sorghum, soya beans, sunflower, and sweet potatoes.[12]

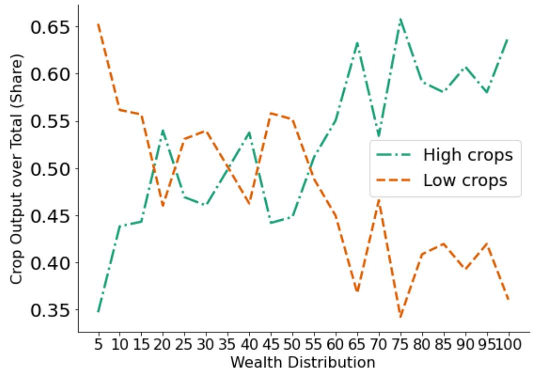
Figure 2 depicts the crop-portfolio along the wealth distribution. Sub-plot (2a) shows the shares of high-yield and low-yield crops in total agricultural production by wealth percentile groups. Among the poorest farmers (0-10th percentiles), low-yield crops dominate, making up around 60% of their production. In contrast, farmers in the middle (15th-55th percentiles) have a more balanced output, with production split roughly equally between high- and low-yield crops. At the top of the wealth distribution (60th percentile and above), high-yield crops

[10] Long-term crops pose a challenge for yield measures since they might be at different stages of production across waves, which artificially increases dispersion. Additionally, long-term crops involve significant fixed costs, while this study focuses on risk distortions.

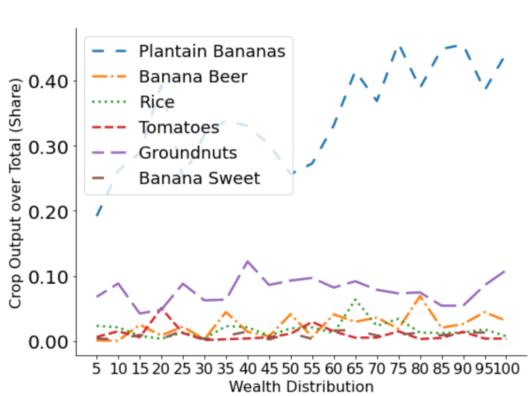
[11] The strong correlation is present across the three volatility measures, whether pooling crop yield observations at the household-wave level (column 1) or at the wave level (column 2) for the entire country; across each of the four main regions of Uganda (observations pooled at the wave level, columns 3 to 6); and whether considering all crops (rows 3 to 6) or excluding long-term crops (rows 1 to 3).

[12] Table 2 in the Online Appendix presents descriptive statistics for each crop, including the number of observations, average yield, output, land size, and intermediate expenditure at the household level, pooled across waves. It also provides the coefficient of variation for the yield of each crop. Crops are ranked from most to least cultivated.

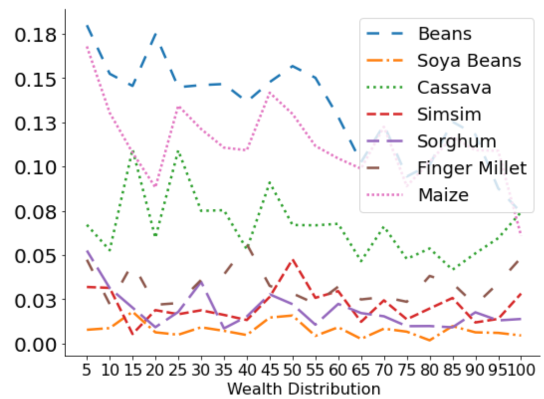
account for about 60% of total production.



(a) High-Yield vs Low-Yield Crops



(b) High-Yield Crops



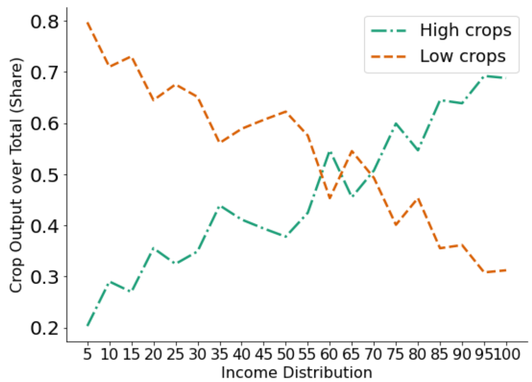
(c) Low-Yield Crops

Figure 2: Crops Production along the Wealth Distribution

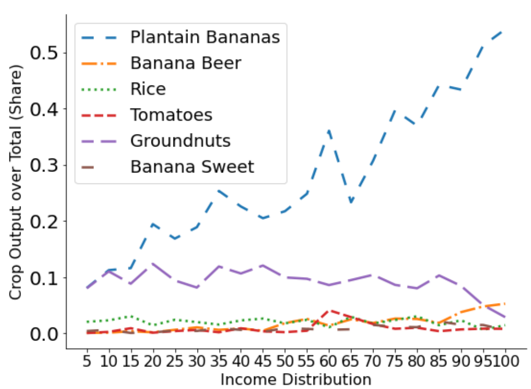
Notes: Wealth includes estimated land value, household assets, livestock, and farming capital. Farmer's crop production and wealth ranking computed from average across the five waves. *Source:* UNPS 2009/10–2015/16.

Sub-plot (2b) shows the shares of the crop output over total agricultural output for the six most cultivated high-yield crops, while sub-plot (2c) shows the shares the seven most cultivated low-yield crops. For high-yield crops, the increase in production shares along the wealth distribution is driven mainly by plantain bananas. Plantain bananas represent 33% of the total agricultural production for the farmers in the bottom 50%. For the farmers in the top 35%, plantain bananas represent 40% of the total agricultural output. Conversely, while beans and maize together represent around 30% of the total output of the poor, for the rich they represent less than 20%.

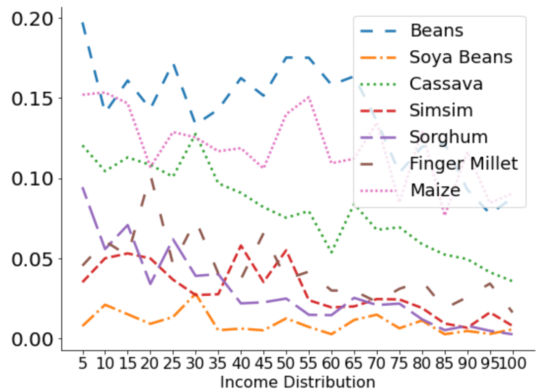
Figure 7 presents the crop-portfolio across the income distribution. Low-yield crops represent 80% of the total output for farmers in the bottom 5% percent and roughly 50% for the 55th-70th percentile. For the farmers in the top 10%, high-yield crops represent more than 70% of total output. Among the high-yield crops, plantain bananas again dominates this result, representing only 10% of total output for the bottom poor, while this single crop represents more than 50% of total output for the top 10% farmers. For low yield crops, the share of beans, maize, cassava, and sorghum go from representing, respectively, 20%, 15.3%, 12.4%, 9.5% (57.9%) of the total production for the bottom 5% of the distribution, to represent 8.3%, 9.2%, 4.6%, 0.8%, respectively, (22.9%) for the farmers in the top 5% of the distribution. [13]



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



(b) High-yield Crops



(c) Low-yield Crops

Figure 3: Crop Production along the Income Distribution

Notes: Farmer's crop production and income ranking computed from average across the five waves. *Source:* UNPS 2009/10–2015/16.

Interestingly, most farmers in Uganda grow both low-yield and high-yield 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 five waves. On average across waves, 65.01% of households grew high-yield crops, while 96.24% grew low-yield crops. Over the entire panel period, 98.64% of farmers grew low-yield crops, 76.14% grew high-yield crops, and 75.27% grew both types.

Motivated by these empirical results, the next section proposes an incomplete markets

[13]Table 3 in the Online Appendix provides the estimates of the elasticity of the proportion of output from high-yield crops relative to low-yield crops with respect to household consumption, income, wealth, and land size. All elasticities are significantly positive and large.

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
Any Wave	76.14	98.64	75.27

Notes: Mean denotes the average of wave´s averages. Any wave is the share of farmers growing the crops at least in 1 of the 5 waves. *Source:* UNPS 2009/10–2015/16.

model with endogenous agricultural income from two technologies that differ in profitability and risk. The model features an endogenous relationship between the crop-portfolio and the wealth distribution in equilibrium.

2 Model

2.1 Primaries of the Model

The model depicts an agrarian economy with one type of agent: households farms or simply households. Households are ex-ante equal except for a permanent component in agricultural production. The economy is populated by a continuum of them with a measure of one.

Preferences. Households live infinitely and maximize expected utility

$$\mathbb{E}_0 \left[\sum_{t=0}^{\infty} \beta^t u(c_t) \right] \qquad u(c) = \frac{c^{1-\rho}}{1-\rho}$$

where $\beta \in (0, 1)$ is a discount factor and $\mathbb{E}_0$ represents the expectation at time 0. The utility flow at time t has a consumption curvature equal to ρ.

Agricultural production. Households generate farming income by choosing intermediate input quantities for two types of technologies: high-return, high-risk and low-return, low-risk. Both technologies exhibit decreasing returns to scale ($\gamma, \alpha \in (0, 1)$) and are subject to household idiosyncratic shocks. The production functions take the following form

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

in which m_{it-1}^h and m_{it-1}^l are the intermediate input choices in high-return and low-return technologies, respectively for household i at period $t-1$. γ and α are the elasticities of intermediates on output, A, B are technology-neutral productivity factors, while y_{it}^h represents the output of high-return technology and y_{it}^l from low-return technology. z_i is the household-specific component which captures permanent or quasi-permanent characteristics in agricultural production including differences in productivity as well as location and land characteristics.[14] Shocks θ_{it} and ε_{it}, are correlated among technologies ($\sigma_{\theta\varepsilon} > 0$), independent across households i and time t and follow a multivariate log-normal distribution

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

Non-agricultural earnings. Households also earn non-agricultural earnings from an exogenous stochastic process, y_{it}^{na}, defined by the following AR(1) process

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

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

Financial market. Despite limited access to formal financial markets, households smooth consumption through informal risk-coping mechanisms, such as risk-sharing networks (e.g., Udry 1994; Ligon, Thomas, and Worrall 2002; Fafchamps and Lund 2003) and self-insurance mechanisms such as precautionary savings. In poor countries, households accumulate assets such as crop storage (Fafchamps, Udry, and Czukas 1998; Kazianga and Udry 2006), livestock holdings (Rosenzweig and Wolpin 1993), and other assets (Collins et al. 2009) to cope with future adversities. This model captures insurance in a tractable format by incorporating an exogenously incomplete financial market. Households can save in a risk-free asset, a, with depreciation rate δ. Households cannot borrow. The depreciation rate captures the finding that saving in poor countries is costly. Hence, the financial market in this work takes the structure as in Donovan (2021) and Lagakos, Mobarak, and Waugh (2023) and it is consistent with results documenting a better match with the data with exogenously incomplete markets in developing rural areas (Karaivanov and Townsend 2014).

[14] The model's permanent component is an uncommon but central assumption, motivated by both theoretical and quantitative considerations. Farmers in less productive regions—such as semi-arid northern Uganda—face systematically different crop choices and lower average productivity, while farmers with weaker agricultural skills tend to produce less. The model captures these and other fixed or quasi-fixed characteristics in a parsimonious way, which allows it to: (i) distinguish risk-induced from structural dispersion in agricultural output, (ii) generate a non-degenerate consumption distribution even under complete markets, and (iii) analyze heterogeneous effects of market completion. Since land allocations are not modeled explicitly, z_i also absorbs land heterogeneity. In Sub-Saharan Africa, farmland is typically in fixed supply, with rigid or nonexistent land markets. Accordingly, this paper studies financial market completion holding land allocations constant.

2.2 The Household's Problem

Consider the household's problem of the 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 by three state variables: x, z, and y_{na}. Variable x represents "cash on hand", which is 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 earnings process. Let $V(x, z, y_{na})$ be the value function at state (x, z, y_{na}), then, the Bellman equation is

$$V(x, z, y_{na}) = \underset{a', c, m'_h, m'_l}{\text{Max}} u(c) + \beta \mathbb{E}\left[V(x', z, y'_{na})\right] \tag{1}$$

subject to

$$a' \geq 0 \tag{2}$$

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

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

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

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

in which c, a', m'_h, and m'_l are the policy functions that solve the household-farm 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 the 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 implies

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

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

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

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

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

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

in which 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 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 equals the price. That is the expected profit maximization scenario.[15]

Nevertheless, lack of perfect consumption smoothing creates a risk-induced wedge between marginal cost and marginal products. Specifically, when the marginal utility of current consumption exceeds the expected marginal utility of the next period, adjusted for shocks, the ratio of marginal utilities is less than one. Consequently, marginal products must surpass marginal cost. Given the production functions' decreasing returns to scale, a higher marginal product corresponds to lower investments in intermediates (m_h, m_l). This represents the first margin of adjustment households use to mitigate risk exposure.

The second margin of adjustment considers the technology portfolio. Risk not only distorts intermediate input levels but it also distorts their allocation across the two types of technologies. Dividing (11) by (12) household's optimal intermediate input choices can be rewritten as

$$B\gamma\left(m'_l(x, z, y_{na})\right)^{\gamma-1} = \frac{\mathbb{E}\left[\theta' u_c\left(c(x', z, y'_{na})\right)\right]}{\mathbb{E}\left[\varepsilon' u_c\left(c(x', z, y'_{na})\right)\right]}A\alpha\left(m'_h(x, z, y_{na})\right)^{\alpha-1}. \tag{15}$$

The absence of perfect consumption smoothing introduces a risk-induced wedge across the marginal products of the two technologies. From equation (15), notice first that the marginal utility decreases with consumption while consumption increases on shocks' realizations. Since the shocks in the high-technology have greater 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 numerator. Hence, marginal returns in the high technology are higher than in the low technology whenever consumption is not uniform across states. This represents the second margin of adjustment in which households optimally shift investment across the technologies portfolio to mitigate risk exposure.

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

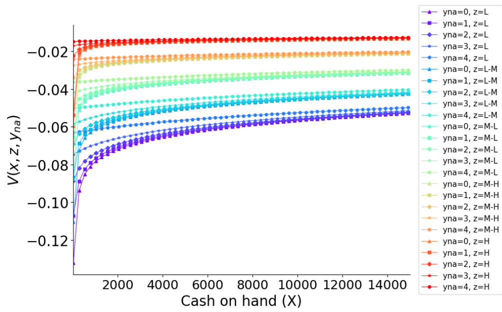
$$p = \beta\mathbb{E}_\theta\left[\theta' z A\alpha m_h^{\alpha-1}\right] = \beta z A\alpha m_h^{\alpha-1} \tag{13}$$

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

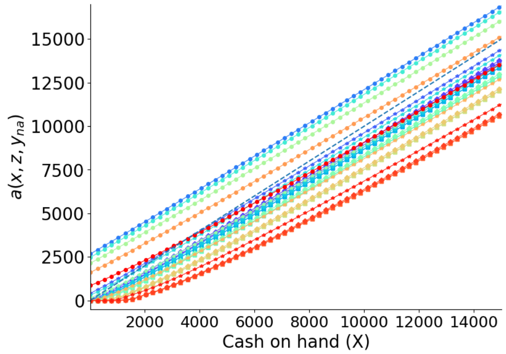
Figure 4 shows the value function and the policy functions resulting from solving the household problem (under the parameter values from the quantitative exercise). The x-axis represents the level of cash-on-hand (x), while variations in color indicate different levels of the permanent component (z), while different color shades and markers denote the realizations of non-agricultural earnings (y_{na}). For a given cash-on-hand level (x), households with high permanent components (depicted in red) accumulate fewer risk-free assets, (4b), and consume more, (4c), compared to households with lower permanent components (shown in purple). Similarly, households with higher realizations of non-agricultural (dot-marker) earnings save less and consume more than those with lower realizations (triangle-marker).

Sub-plot (4d) and (4e) illustrate the policy functions for $m_l'(x, z, y_{na})$ and $m_h'(x, z, y_{na})$, respectively, where solid lines represent the intermediates investment under discounted expected profits maximization (the complete markets allocation). Sub-plots (4d) and (4e) reveal the impact of uninsurable risk on intermediates investment across heterogeneous farmers. First, poor households, those with low cash-on-hand (x), under-invest in intermediates across both technologies. Second, as households get richer, there is a corresponding uptick in intermediate investment, aligning closer to profit maximization levels dictated by their permanent component. Lastly, due to the high cost associated with saving in the risk-free asset within this economy, households situated at the upper echelons of the distribution tend to over-invest in intermediates, particularly favoring the low-return technology.

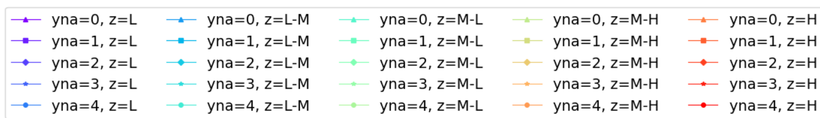
To illustrate the impact of uninsurable risk on the technologies portfolio (second margin of adjustment), sub-plot (4f) plots the ratio of the expected marginal products along the state variables of the economy. As per equation (15), if households can perfectly smooth their consumption across states, the ratio is equal to one (there is a complete separation of the household and farm decisions). Nevertheless, with incomplete markets the ratio is larger than one. In particular, the poorer the households and the higher their permanent component, the higher the ratio of marginal products with respect to one, and consequently, the higher is the under-investment in the high technology with respect to the low technology.

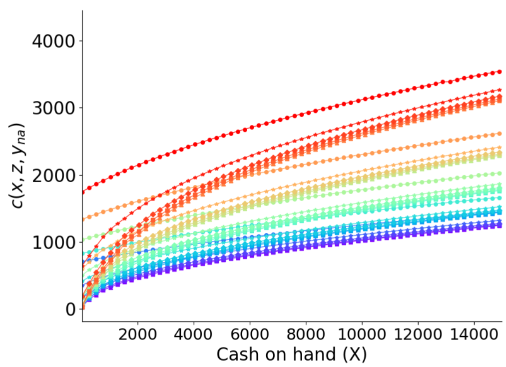


(a) Value Function (V)

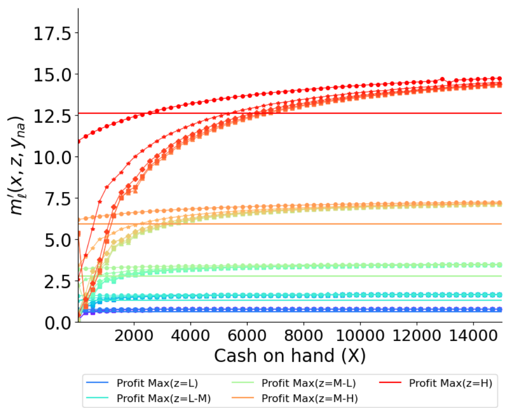


(b) Assets (a)

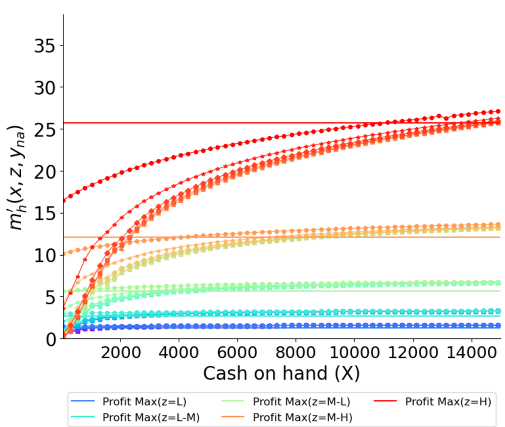




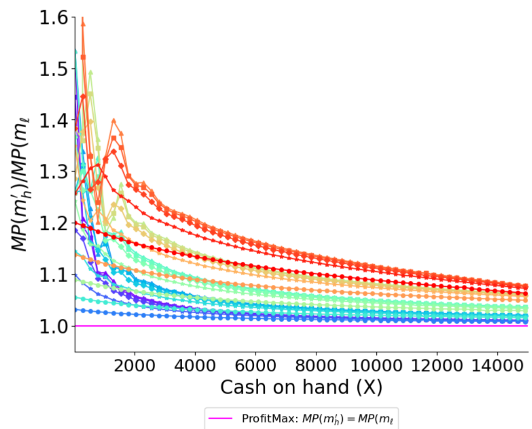
(c) Consumption (c)



(d) Input Low-Technology (m_l)



(e) Input High-Technology (m_h)



(f) Ratio Mg. Products $\left(\frac{MP(m_h)}{MP(m_l)}\right)$

Figure 4: Household's Optimality, Policy Functions

Notes: Value and policy functions depend on the state cash-on-hand x—x-axis—the permanent component z—primary colors—and realization non-agricultural earnings y^{na}—markers and tones within the primary colors. Straight-solid lines in (d), (e), and (f) represent expected profit maximization allocations.

In line with the results of Rosenzweig and Binswanger (1993), 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 to move to more productive technologies, given their limited ability to cope with risk. Thus, poverty quasi-traps might exist even in the absence of fixed costs—similar conclusion reached in Dercon and Christiaensen (2011).

2.3 Equilibria

Rural Uganda is an economy based on subsistence farming. Only 26.49% of the total agricultural production is devoted to the market (see Table 10 in the Appendix). Consequently, I model the economy as a small-open economy: the two types technologies contribute to a single consumption good (no relative prices between technologies) while intermediate input prices and the depreciation rate are exogenous.[16]

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 aggregate resource constraint holds

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

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

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

.[17] in Section A of the Online Appendix, I describe the computational approach to solve the model including the simulation and convergence to the stationary equilibrium.

[16] Given that most of the production is at subsistence level, the relevant aspect is to model completing markets in a scenario with fixed prices. Yet how prices fluctuations increase or reduce consumption risk differentiating with selling and buying prices as well as sellers versus subsistence farmers is an interesting question beyond the scope of this work. Intermediate inputs such as inorganic fertilizer or pesticides are mainly produced abroad.

[17] 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 $z_j \in \mathbb{R}_{++}$, and $y_{na} \in \mathcal{Y}_{na} \equiv \mathbb{R}_{++}$. Also, $\mathcal{S} := \mathcal{X} \times \mathcal{Z} \times \mathcal{Y}_{na}$.

3 DATA: UGANDA NATIONAL PANEL SURVEY

This study uses the first five waves of the Uganda National Panel Survey (UNPS), a household survey carried out by the Uganda Bureau of Statistics as part of the World Bank LSMS-ISA project.[18] The UNPS interviews approximately 3,000 households per wave. The first wave started in 2009-10, and its initial sample was revisited 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) used the sample from 2013-14. The survey is conducted annually from September to August, involving two visits spaced approximately six months apart to effectively capture the agricultural outcomes associated with the two harvesting seasons.

From a macroeconomic perspective, the UNPS has two main strengths. First, it provides nationally representative panel household data from one of the poorest economies in the world. Second, it allows for the recovery of the consumption, income, and wealth dynamics of households, effectively capturing their entire budget constraints. Specifically, the survey enables the quantification of agricultural production and inputs, which constitute the main economic activity for most families in Sub-Saharan Africa. However, measuring these variables in this context is complex. In the subsequent subsections, I describe the computation process for consumption, income (including agricultural revenues), and wealth.

3.1 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 values from purchases, home production, and in-kind and gift transfers. Then, I compute the household aggregate consumption as the sum of food and non-durable items consumption, excluding durable goods. To maintain data integrity, outliers are trimmed by excluding the bottom and top one percent of total household consumption for each wave.

3.2 Income

Measuring household income in developing countries is challenging; see Deaton (2005) and Deaton (2019) for useful discussions. First, a significant portion of the economy operates within the informal sector, leading to irregular periods of work and frequent in-kind payments. Second, most households are self-employed, making it challenging for them to report their earnings accurately both conceptually and practically. Third, many of these self-employed individuals are farmers, which presents further data measurement issues, especially when many farm-

[18] Uganda Bureau of Statistics. Uganda National Panel Survey (UNPS) 2009-2015. The Living Standards Measurement Study (LSMS) follows a standardized survey implemented by the World Bank to assess living standards across countries. The Integrated Survey on Agriculture (ISA) is specifically designed to capture agricultural production, wealth, inputs, and expenditures in Sub-Saharan African countries.

ers operate at the subsistence level. To overcome these challenges, the LSMS-ISA surveys query households 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).[19]

3.2.1 Agricultural Income

With the agriculture questionnaire, I compute the agricultural revenues for each household and each crop by summing the 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 about the total production of the crop, as well as the production of the crop allocated to the market, own consumption, gifts to other households, storage, and animal feed. Like many surveys in developing countries, households can report crop production in various units, including non-standard units such as baskets, pails, or bunches. Additionally, conversion rates can vary across crops and seasons. For accurate conversion of crop production into kilograms, I use the median of the conversion rates to kilograms reported by households for each wave, season, crop, and unit combination.

Subsistence farming is prevalent in Uganda. From the UNPS data, only between 24% to 29% of agricultural production is devoted to the market.[20] Thus, understanding Ugandan households' livelihoods and measuring agricultural yields requires accounting for non-sold agricultural production correctly. However, as Deaton (2019) argues, setting prices to evaluate non-sold production in monetary terms is challenging. While prices at the gate (selling prices) are commonly used in the literature, they may underestimate non-sold production. This is because the items sold may only represent a portion of the harvested crops, and prices at the gate are typically measured after the harvest when supply is abundant and prices are low.

To address this issue, I leverage the household questionnaire, which captures food consumption in quantity and value. Following the approach in De Magalhães and Santaeulàlia-Llopis (2018), I use median consumption prices at the district level to evaluate unsold agricultural production. This procedure allows for better capturing the shadow value of not selling the crop: the cost if the household did not produce the crop and had to buy it in the local market. Agricultural revenues for each season and wave are trimmed at the top 2 percent of the distribution.[21]

[19] To ensure consistency with the model, household total income is calculated as the sum of agricultural revenues, business profits, labor payments, and livestock profits, with extreme values trimmed at one percent in both tails.

[20] See Table 10 in the Appendix presenting the share of production devoted to the market and non-market activities, as well as the proportion of farmers who devoted a part of their production to these uses.

[21] Uganda has 135 districts. For crops without a district-level consumption price, such as sorghum and groundnuts, I use district-level median prices at the gate. If these prices are unavailable, I use regional-level prices, and if those are also unavailable, I resort to nationwide prices.

3.2.2 Intermediates

Agricultural intermediates expenditure is computed as the sum of the costs of chemical and organic fertilizers, pesticides, herbicides, seeds, hired labor, and transport. Since the data report the use of intermediates at the plot level, for multi-crop plots, I assume that the intermediates are distributed uniformly across the plot. For 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 is characterized by a minimal usage of intermediates. Table 11 in the Appendix presents the share of farmers using intermediates and their average expenditure across the five waves of the UNPS. On average, farmers spend only $59.4 per year on intermediates. Decomposing across crops, the average intermediates expenditure in high-yield, high-risk crops is $41.23, while for low-yield low-risk crops, it is $38.50. The use of modern agricultural intermediates in Uganda is extremely low, with only four percent of farmers using chemical fertilizer, and ten percent using pesticides.

3.2.3 Non-Agricultural Earnings

Non-agricultural earnings include business profits, formal and informal labor income, and livestock earnings. The household questionnaire collects detailed data on each non-farming business, including operative months, gross revenues, wage expenditures, raw materials costs, and other expenditures. Business profits are calculated as the difference between monthly gross revenues and costs, multiplied by the number of months the business operated. Similarly, labor earnings aggregate yearly payments for primary and potential secondary jobs for each household member, regardless of whether the job is formal or informal. Livestock profits are determined by summing net animal sales, meat, milk, and egg sales, and subtracting associated costs. The value of unsold production is estimated based on the consumption of self-produced livestock products reported in the household questionnaire's consumption section.

3.3 Wealth

The data equivalent of assets in the model is liquid wealth, which encompasses stored crops, livestock, household assets, rents, and transfers. Household assets include a wide range of items such as housing and other buildings, non-agricultural land, furniture, household appliances, electronic devices, jewelry, vehicles, and other assets. Rents and transfers consist of property income, dividends, interest from current accounts or bonds, remittances, inheritance, and alimony.

The value of stored crops is determined using district-level consumption prices, while the values of livestock and household assets are based on self-reported values if the household were to sell the asset at the current moment.

While in the calibration wealth only includes liquid assets, for the empirical analysis, wealth encompasses all assets owned by the household, including also farm capital and land value.[22]

3.4 Consumption, Income, and Wealth Summary

Table 12 in the Appendix summarizes household consumption, income, and wealth for rural Uganda (columns 2-4) and the entire country (columns 5-7), highlighting three insights. First, income and consumption estimates closely align, indicating high data quality. Income estimates from surveys in developing countries typically lag behind consumption estimates for various reasons (see Deaton 2005), including those related to the difficulties of measuring agricultural income. Second, Uganda remains a very poor economy. In rural areas, average household income and consumption are around \$1,505 annually, rising to \$1,736 nationwide. On a per capita basis, this equates to \$286 in rural areas and \$338 nationally. Third, while consumption inequality and wealth inequality are comparatively low (Gini index of 0.33 and 0.63, respectively) income inequality levels are high with a Gini index of 0.57.

4 CALIBRATION

For the quantitative analysis, a set of parameters is chosen directly from the literature (preference parameters and the intermediate input shares) while the rest of parameters are calibrated or estimated from the UNPS data. The calibration targets the following moments in rural Uganda: crop output, crop risk, the dispersion on agricultural production, average household income, and liquid wealth.

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

Technology parameters and inputs price. Common to the literature, I set the intermediates shares α, γ equal to 0.4, the intermediates share in agriculture in the United States (Restuccia, Yang, and Zhu 2008). Next, I calibrate the inputs price p and the constant factors in each technology, A and B, to match the high-yield crops and low-yield crops output average across waves.[23]

[22] To value land, in the first two waves, households reported their value, allowing for the computation of per-acre land prices grouped by counties and plot characteristics. For the other waves, land value is estimated by applying the country per-acre prices from 2010–11 according to plot characteristics.

[23] I attempted to match intermediates expenditure in the data. Nevertheless, since intermediates expenditure is minimal in Uganda, the model could only replicate both agricultural output and intermediates usage by setting unreasonable low exponent values in the technology functions. Thus, I do not target the intermediates expenditure in the data, but I use a combination of A, B, and p that generates a relatively low expenditure (211\$, 131\$) but still much higher than in the data (41\$, 38\$).

Table 3: Parameter Values of the Model

	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	276	Calibration
Low-technology constant factor	B	180	Calibration
SD permanent productivity	σ_z	0.277	Calibration
Depreciation rate	δ	0.1055	Calibration
SD high-technology shock	σ_θ	1.0325	Calibration
SD low-technology shock	σ_ε	0.853	Calibration
Covariance high and low shocks	$\sigma_{\theta,\varepsilon}$	0.108	Calibration
constant term non-agric earnings	$\bar{y}_{na}$	log(497)	Calibration
Persistence non-agric earnings	ρ_{na}	0.399	UNPS estimate
SD non-agricultural eanings	σ_{na}	1.330	UNPS estimate

Notes: p, A, B, $\bar{y}_{na}$, σ_z, δ calibrated targeting time-averaged cross-sectional moments. Risk parameters—σ^2_θ,σ^2_ε $\sigma_{\theta,\varepsilon}$—calibrated targeting volatility measures of residuals in output. ρ, β, α, and γ see references in the text.

Agricultural shocks. A crucial aspect of quantifying the model is capturing the agricultural risk across the two types of crops. While in the model, crops output fluctuations are driven solely by household shocks and changes in intermediate usage, in the data, production fluctuations are influenced by many other factors. To account for these factors, 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 included in the model that can lead to output variation for the high-yield crops, equation (16), and for the low-yield crops, equation (17).

$$ln(y^h_{it}) = \phi ln(Z^h_{it}) + \beta X_{it} + \gamma F_i + \psi T_t + ln\theta_{it} \tag{16}$$
$$ln(y^l_{it}) = \phi ln(Z^l_{it}) + \beta X_{it} + \gamma F_i + \psi T_t + ln\varepsilon_{it} \tag{17}$$

y_{it} represents crop output for a household i in wave t while Z_{it} represents a vector of household-crop-specific variables, such as land size and labor hours. X_{it} is a vector of household characteristics that might change over time, including 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.

Second, using the estimated residuals from 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.[24]

Non-agricultural earnings process. For the non-agricultural earnings process, the OLS regression on $lny_{it}^{na} = \bar{y}_{na} + \rho_{na} lny_{it-1}^{na} + u_{it}, u_{it} \sim N(0, \sigma_{na}^2)$ delivers the estimates of $\hat{\bar{y}}_{na} = 3.642$, $\hat{\rho}_{na} = 0.3994$, and $\hat{\sigma}_{na} = 1.330$. To match the average non-agricultural earnings in the data (502$)—and therefore total household income—I set $\bar{y}_{na}$ in the model equal to $log(497)$. Interestingly, with the estimated $\hat{\rho}_{na} = 0.3994$ and $\hat{\sigma}_{na} = 1.330$ together with the calibrated agricultural shocks, the model generates a level of household income volatility (0.605) that is very close to the data counterpart (0.600). The income volatility counterpart is again computed with average time-variance of the residuals in household income after factoring out variables neither in the model or associated with risk. Lastly, I discretize the previous AR(1) process into a five-state Markov chain using the Rouwenhorst procedure.

Permanent component. To calibrate the permanent component in agricultural production, first, following the procedure in Huggett and Parra (2010), 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 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 $\delta = 0.1055$, consistent with the significant costs to save in developing countries—for a summary, see Karlan, Ratan, and Zinman (2014)—and very close to the calibrated value in (Donovan 2021).

4.1 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 present the results for 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 distributions, (3) and the levels of income and consumption volatility.

Table 4 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 high precision. To capture the entire agricultural production distribution, the model also targets the Gini of agricultural production with a model value of 0.002 Gini points lower than the data counterpart. The model also targets the average household income and liquid wealth.

[24] The volatility of the estimated residuals are $\overline{Var_i(ln\hat{\theta}_{it})} = 1.052$, $\overline{Var_i(ln\hat{\varepsilon}_{it})} = 0.722$, $\overline{Cov_i(ln\hat{\theta}_{it}, ln\hat{\varepsilon}_{it})} = 0.115$. Volatilities are measured as the average individual's time variances and covariances of output (model) and residual output (data).

Table 4: Benchmark Economy Targeted Moments

Description	Model Value	Data Target
Avg high-yield crops output	653.82	651.12
Avg low-yield crops output	355.00	353.39
Avg Income	1506	1506
Avg Liquid Wealth	1855	1858
high-yield crops volatility	1.050	1.052
low-yield crops volatility	0.725	0.722
High-low-yield crops correlation across time	0.118	0.115
Gini agricultural output	0.618	0.620

Notes: average and Gini index moments are computed from the time-average across waves. Volatility moments are computed on the estimated residuals of regressions $ln(y_{it}) = \beta X_{it} + \gamma F_i + \psi T_t + u_{it}$. *Source:* UNPS 2009/10–2015/16.

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

Crop choice along wealth. Figure 5 plots the share of agricultural output coming from high-yield crops and low-yield crops along the wealth distribution in the data versus the model. The solid lines represent the crop shares in the data while the dotted lines represent the model counterparts. The model generates a higher share in high-yield crops along the wealth distribution than the share observed in the data particularly on the poor. While in the data the bottom 20% have a share of high-yield crops on total output of around 44%, the model generates a share of 57%. Yet, the model approximates relatively well the trend of crop shares along the wealth distribution. It predicts an increase in the share of high crops of 22% while in the data the increase is of 26%.[25]

[25] The model incapacity to replicate the shares levels across the wealth distribution is due to its inability to fully replicate the wealth distribution. This arises because the model considers only liquid wealth, whereas in the data in Figure 5 includes all wealth. Moreover, as discussed below, the model underestimates liquid wealth inequality.

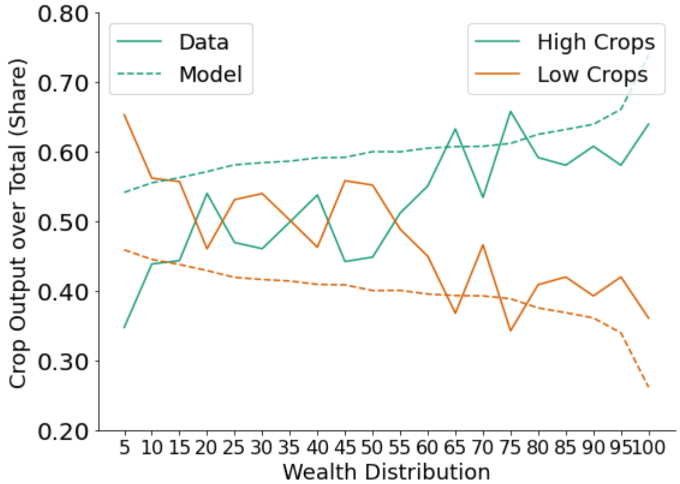
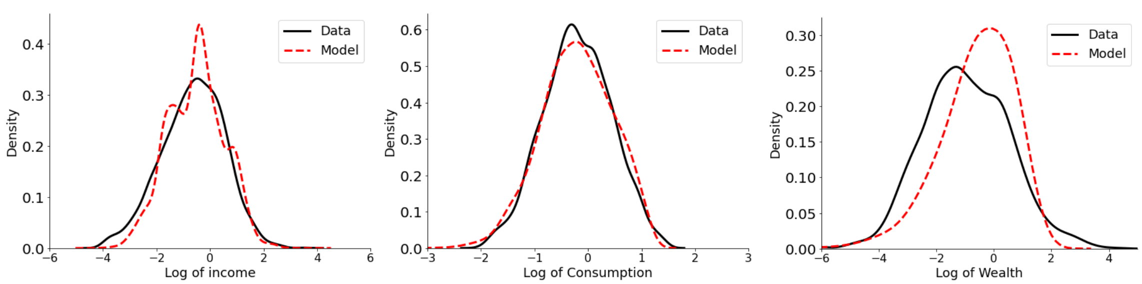


Figure 5: Crop Production along the Wealth Distribution: Model vs. Data
Notes: Dotted lines represent the share of output preditcted by the model while solid lines the data counterparts. *Source:* UNPS 2009/10–2015/16.

Consumption, income, and liquid wealth distributions. The calibration of the model targets the Gini of agricultural production (0.620) with no additional targets on cross-sectional distributional moments. 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 2011–12 UNPS wave. Note that the model generates an income distribution relatively close to the data—except for the multiple peaks observed in the model due to the discretization of the permanent component. For consumption, the distribution that the model generates closely aligns with the distribution from the data, while for liquid wealth, the distribution generated by the model is much more concentrated than 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 2011-12 .

Table 5 compares the percentiles shares of the income, liquid wealth, and consumption distributions generated by the model with the data counterparts. The model approximates well the shares of income across the income distribution. The model prediction of the top

50% share of income is 84.69%, in the data is 86.93%. In the extremes of the distribution, the model undershoots income inequality. In the data, the shares of the top 5% and bottom 5% are 28.39% and 0.22%, respectively, while in the model they are 24.02% and 0.37%. The model under-predicts inequality in liquid wealth. The top 50% in rural Uganda hold 93.88% of the total liquid wealth, while the share is 85.90% in the model. The model predicts that the top 10% hold 32% of the total liquid wealth, while in the data, it is 51%.

To my surprise, the model generates a consumption distribution that is very close to the data counterpart. The share of the top 50% in the model is 74.50%, while in the data, the share is 73.76%. The top 1%, 5%, and 10% respectively hold 3.82%, 14.67%, and 25.13% of total consumption in the data. In the model, the shares are 3.52%, 14.65%, and 25.87%, respectively.[26] Notice that the calibration have no parameter targeting consumption moments; rather, it takes assumptions and parameterized preferences standard to the literature. Namely, rational agents with identical preference under a CRRA utility function with coefficient $\rho = 2$, a discount factor of $\beta = 0.96$, a no-borrowing constraint, and a depreciating risk-free asset. Incomplete markets models can account for the consumption distribution in poor countries as well, making them a useful tool for research and policymaking in development.

Table 5: 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	0.67	3.28	13.10	86.93	65.72	41.42	28.39	10.90
L. Wealth	0.01	0.10	0.29	1.43	6.13	93.88	80.55	60.67	47.46	21.73
Consumption	0.17	1.15	2.79	9.49	26.28	73.76	48.13	25.13	14.67	3.82
Model										
Income	0.04	0.36	1.02	4.13	15.25	84.75	63.55	37.26	23.55	8.33
L. Wealth	0.00	0.06	0.35	2.61	12.53	87.47	64.27	36.94	23.01	6.87
Consumption	0.11	0.91	2.29	8.38	24.15	75.85	50.42	25.87	14.65	3.52

Notes: 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 2011-12.

Income and consumption volatility. In the calibration, I target the volatility in high-yield and low-yield crops, and then I estimate an AR(1) process on the non-agricultural earnings in the data. With that, the model generates a total household income volatility equal to 0.605, while in the data income volatility is 0.600. Interestingly, although the calibration does not target any consumption moment, the model predicts a level of consumption volatility (0.104) that is close to its data counterpart (0.117). See Table 13 in the Appendix.

[26]Similarly, in the data, the bottom 1%, 5%, and 10% hold 0.17%, 1.15%, and 2.79% of total consumption. While in the model the shares are 0.11%, 0.91%, and 2.29%, respectively.

5 Complete Markets in Agriculture: the Planner's Problem

I obtain the main quantitative results of this paper by comparing the previous benchmark economy to an economy with complete financial markets on agriculture. To solve this counterfactual world, I develop the following social planner's problem.[27]

The planner is able to allocate intermediates and consumption allocations from the total agricultural production. To formulate the problem, I follow the approach in L. Maliar and S. 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

$$U(C_t) = \underset{c_{it}}{\text{Max}} \int_i \omega_i u(c_{it}) di \tag{18}$$

$$\text{subject to} \qquad \int_i c_{it} di = C_t \tag{19}$$

in which ω_i is the Pareto weight on individual i. The second sub-problem is to solve for the aggregate consumption that maximizes the social preferences

$$\underset{\{C_t, m_{it}^h, m_{it}^l\}_{t=0}^{\infty}}{\text{Max}} \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t U(C_t) \tag{20}$$

$$\text{subject to} \quad C_t = \int_i \left[\theta_{it} z_i A {m_{it-1}^h}^{\alpha} + \varepsilon_{it} z_i B {m_{it-1}^l}^{\gamma} \right] di - p \int_i \left[m_{it}^h + m_{it}^l \right] di \tag{21}$$

$$C_t = Y_t - pM_t \tag{22}$$

in which aggregate consumption at period t is fully determined by the investment decisions on intermediates across individuals and technologies. Hence, the first-order conditions with respect to m_{it}^h and m_{it}^l are

$$\left[m_{it}^h \right] : \mathbb{E}_t \left[\beta^{t+1} U_c(C_{t+1}) \alpha \theta_{it+1} z_i A {m_{it}^h}^{\alpha-1} \right] = \beta^t u_c(C_t) p \tag{23}$$

$$\left[m_{it}^l \right] : \mathbb{E} \left[\beta^{t+1} U_c(C_{t+1}) \gamma \varepsilon_{it+1} z_i B {m_{it}^l}^{\gamma-1} \right] = \beta^t u_c(C_t) p \tag{24}$$

for all individuals $i \in \mathcal{I}$ at period of time $t > 0$. Given that θ_{it+1} and ε_{it+1} are independently distributed across time and unobservable by the planner, the intermediates allocations m_{it}^h, m_{it}^l are also independent of the idiosyncratic shocks realizations θ_{it+1} and ε_{it+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 expec-

[27] To replicate complete markets in agriculture, the planner provides full insurance for the agricultural output, but the planner cannot observe nor dictate on the realizations of the non-agricultural earnings.

tations on the first-order conditions simplify to

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

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

in which $\mathbb{E}\left[\theta_{it+1}\right] = 1$ and $\mathbb{E}\left[\varepsilon_{it+1}\right] = 1$. 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

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

$$\beta\gamma z_i A(m_{it}^{l})^{\gamma-1} = p. \tag{28}$$

For optimality, the planner equalizes the discounted expected marginal product of each individual i on both technologies h, l to the marginal cost, the price. Input allocations are equal to expected discounted profit maximization. Isolating the input allocations from equations (27) and (28), we obtain the optimal levels of intermediate inputs

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

Moreover, note that conditions (27) and (28) imply that the marginal products across farmers (30) and technologies (31) equalize

$$\alpha z_i A(m_{it}^{h})^{\alpha-1} = \alpha z_j A(m_{jt}^{h})^{\alpha-1} \qquad \forall i,j \in \mathcal{Z} \tag{30}$$

$$\alpha z_i A(m_{it}^{h})^{\alpha-1} = \gamma z_i B(m_{it}^{l})^{\gamma-1}. \tag{31}$$

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

$$c^{*}(z_i) = c_{it}(z_i) = z_i(A m_{h,i}^{*})^{\alpha} + z_i B(m_{l,i}^{*})^{\gamma} - p\left(m_{h,i}^{*} + m_{l,i}^{*}\right). \tag{32}$$

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

$$\int_i \omega_i = 1 \qquad \frac{\omega_i}{\omega_j} = \frac{u^{-1}\left(c^{*}(z_j)\right)}{u^{-1}\left(c^{*}(z_i)\right)}. \tag{33}$$

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 earnings process under the financial market of the benchmark economy.[28]

6 Quantitative Results

In this section, I present the numerical results of completing financial markets in agriculture. The first sub-section presents the gains in agricultural productivity and the risk-induced misallocation of intermediate inputs. The second sub-section presents the gains related to welfare: aggregate consumption, distributional effects, and an ex-ante welfare measure.

6.1 Agricultural Productivity

Completing financial markets leads to a 12.20% gain in agricultural output—–and, equivalently, in agricultural productivity. Table 6 details the gains in agricultural output and input usage both in aggregate and for the two types of crops separately. Completing markets results in a 26.65% increase in intermediate inputs expenditure. In Sub-Saharan Africa, the exceptionally low use of intermediate inputs is a major factor contributing to the region's low agricultural productivity (Restuccia, Yang, and Zhu 2008). Uninsurable risk partially explains the low investment in intermediates observed in the region.

Uninsurable risk distorts investment across crops. When financial markets are complete, expenditure on intermediates for low-yield crops increases by 8.62%, resulting in a 4.94% rise in output. In contrast, high-yield crops experience a fourfold greater increase in intermediates expenditure (37.86%), with a corresponding threefold increase in output (16.14%). Thus, completing markets can yield substantial efficiency gains by enabling a more optimal allocation of investment across different crops.

Table 6: Gains Agricultural Output and Intermediates Usage

	Aggregate (%)	Low-yield Crops (%)	High-yield Crops (%)
Output	12.20	4.94	16.14
Intermediate Inputs	26.65	8.62	37.86

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

Uninsurable risk also distorts investment among heterogeneous farmers. Under incomplete markets, farmers' intermediates investment depends not only on their permanent component but also on their current income realizations and wealth holdings. However, if markets are

[28] The Appendix A.2 states the household problem under complete financial markets in agriculture and provides the solution of the stationary equilibrium under this economy.

complete, farmers' investment depends solely on the permanent component. Table 7 presents the changes in input usage and agricultural output across farmers' permanent components. For farmers with a low permanent component, completing markets reduces input usage by 3.64% and slightly lowers output by 0.44%. In contrast, farmers with a middle permanent component increase intermediate inputs usage by 16.14% while the output gain is 7.39%. Those with a high permanent component see input usage rise by 32.50%, with a boost in output of 13.74%. Thus, completing markets can generate significant efficiency gains by reallocating resources across farmers along the income-wealth dimension as well as across permanent components.[29]

Table 7: Agricultural Gains across Farmer's Permanent Component

	Input Usage			Output		
	Total (%)	High-Crops (%)	Low-Crops (%)	Total (%)	High-Crops (%)	Low-Crops (%)
Average	26.65	37.86	8.62	12.20	16.14	4.94
Permanent Component (z_i)						
Low	-3.64	0.71	-11.43	-0.44	1.56	-4.29
Mid-Low	5.82	12.38	-5.45	2.98	5.59	-1.95
Middle	16.14	25.22	1.20	7.38	10.92	0.80
Mid-High	25.60	37.00	7.39	11.21	15.14	3.99
High	32.50	45.34	12.27	13.74	18.02	5.92

Notes: columns 1 to 3 present the proportioal change in input expenditure—columns 3 to 6 in output—from the allocations in the incomplete markets economy to the allocations in complete markets per each group.

6.1.1 Efficiency Gains and the Risk-Induced Misallocation

To compute the efficiency gains of eliminating the risk-induced misallocation of inputs across farmers and crops, I constrain the complete markets solution to a scenario with a distorted level of investment. Specifically, I use the planner's framework to maintain the investment shares across the crop portfolio and among heterogeneous farmers as in the complete markets scenario, but with the aggregate level of intermediate expenditure matching that of the benchmark economy. By keeping these shares constant, the counterfactual exercise ensures that the marginal products across crops and among farmers with different permanent components are equalized, thereby satisfying the optimal conditions outlined in equations (30) and (31). This approach preserves the efficient allocation of investment, even though the overall investment level is distorted.

[29] Farmers with low permanent components see a slight 0.71% increase in input expenditure for high-yield crops but a significant 11.43% drop for low-yield crops, farmers with middle permanent components increase input expenditure by 25.22% in high-yield crops and 1.20% in low-yield crops, leading to output gains of 10.92% and 0.80%, respectively. Those with high permanent components increase by 45.34% in high-yield crops and 12.27% in low-yield crops, driving substantial output increases of 18.02% and 5.92%.

From this counterfactual analysis, I find that efficiency gains contribute 46.54% to the total increase in agricultural productivity. In other words, the current risk-induced misallocation of intermediate inputs implies a 5.02% reduction in agricultural output in Uganda.

6.2 Consumption and Welfare

6.2.1 Aggregate Consumption

In the absence of complete financial markets, households mitigate agricultural risk through income choices and costly precautionary savings. Completing markets eliminates the two mechanisms, resulting in a substantially larger impact on aggregate consumption than on income.

Table 8 compares household averages of agricultural output, income, assets, and consumption between the benchmark economy and the complete markets economy. In this quantitative exercise, completing markets increases agricultural output by 12.20% translating into an 8.18% rise in household income. Without complete markets, households accumulate wealth through costly means—–such as livestock, crop storage, or hoarding cash. This exercise quantifies the decrease in costly assets after completing markets in agriculture in a 64.11% decrease. Combined with the impact on income, this results in a total 17.18% increase in aggregate consumption.[30]

Table 8: Aggregate Gains Completing Markets

	Incomplete Markets ($)	Complete Markets ($)	$\triangle_{CM}$ ($)	$\triangle_{CM}$ (%)
Agric. Output	1008.83	1131.87	123.04	12.20
Income	1506.67	1629.95	123.28	8.18
L. Wealth	1855.65	665.93	-1189.72	-64.11
Consumption	959.58	1124.42	164.84	17.18

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

6.2.2 The Distributional Effects of Completing Markets

Table 9 shows the impact of completing markets on the distributions of 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% bottom) while columns (7–11) presents the percentage changes for the same percentile groups in the top of the distribution.

[30]Completing markets reduces consumption volatility from 0.093 to 0.072 while it increases income volatility from 0.605 to 0.617.

In this model, completing markets have theoretically ambiguous effects on inequality. The underlying sources of inequality are risk—under three different income sources—and permanent differences in agricultural production. 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 by shutting down all differences in consumption 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 concentrated in the middle and top of the distribution. Thus, we observe larger income increases for the households in the top of the income distribution: the income Gini index increases by 1.34%, with the bottom 50% experiencing a 5.08% gain in their income while the top 50% an 8.37% gain. Second, completing markets decreases costly savings by 64.11%. Savings are concentrated at the top of the distribution, making the reduction in costly savings more impactful for these households.

Table 9: Distributional Gains Completing Markets

	Gini			Bottom					Top		
		1	**5**	**10**	**25**	**50**	**50**	**25**	**10**	**5**	**1**
	(%)			(%)					(%)		
Income	1.34	3.62	3.64	5.48	5.08	5.40	8.37	8.99	8.99	10.70	14.25
Consumption	0.56	23.90	15.36	12.99	12.36	14.13	18.15	17.67	11.10	8.89	12.43

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

Altogether, while across the entire consumption distribution the gains of completing markets are significant, they are more significant for richer households. Households in the top 50% of the distribution experience a consumption increase by 18.15% while households in the bottom 50% experience a 14.13% increase. Thus, under this calibration, completing markets slightly increases inequality with increasing the consumption Gini index in 0.56%.

One way to understand these effects is that the very poor might have too little to significantly benefit from insurance. Individuals with low permanent components, such as individuals with low skills in agriculture, little land, or residing in remote and unproductive areas will not experience big gains from insurance products.

6.2.3 Computing the Welfare Gains

Consider the ex-ante welfare comparison of the benchmark economy with the complete markets economy. The average welfare gain, in terms of consumption-equivalent variation (cev), 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:

$$\int \mathbb{E}_0 \left[\sum_{t=0}^{\infty} \beta^t u((1+g)c_{it}^{IM}) \right] d\lambda^* = \int \mathbb{E}_0 \left[\sum_{t=0}^{\infty} \beta^t u(c_{it}^{CM}) \right] d\lambda^*. \tag{34}$$

With the baseline calibration, I find that the welfare gains (g) are equivalent to a 15.20% increase in lifetime consumption.

7 Conclusion

This paper shows that uninsurable risk distorts intermediates investment and crop-portfolios among heterogeneous farmers, leading to lower aggregate output and welfare. Two main quantitative findings support this conclusion.

First, incomplete financial markets reduce agricultural productivity and cause a misallocation of resources. Without complete markets, average intermediate inputs usage is low, while the risk-induced misallocation of intermediates is substantial. A 5.67% gain in agricultural output is directly attributed to the reallocation of intermediate inputs across farmers and crops. Second, the quantitative results suggest that despite high consumption smoothing levels in rural Uganda—which the model captures well—completing financial markets for agricultural risk would yield considerable welfare gains mainly through higher levels of income and consumption.

Are these quantitative results large? It depends on the perspective. Considering the scope of the experiment, the results may not appear remarkably large. Even with a 17.2% increase in consumption, rural Uganda would still remain among the poorest regions in the world. Nevertheless, the findings here imply that, in these economies where households smooth consumption well but in a costly manner, formal consumption–insurance mechanisms—such as index-based insurance, cash transfers, or credit products——could improve the living standards of the rural poor mainly through higher disposable income across all the distribution.

Data Source: Uganda Bureau of Statistics. Uganda National Panel Survey (UNPS) 2009–2016. Ref: UGA_2005-2009_UNPS_v02_M, ..., UGA_2015_UNPS_v02_M. Datasets downloaded from the World Bank Microdata Library, UNPS 2009, 2010, 2011, 2013, and 2015 on 31/05/2019.

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A APPENDIX

A.1 Stationary Recursive Competitive Equilibria

A.2 The Stationary Equilibria under Complete Financial Markets in Agriculture

The set of pareto optima allocations—in section 5—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).

$$m^*_{h,i} = \left(\frac{p}{\beta\alpha A z_i}\right)^{\frac{1}{\alpha-1}} \text{ and } m^*_{l,i} = \left(\frac{p}{\beta\gamma B z_i}\right)^{\frac{1}{\gamma-1}} \tag{35}$$

$$c^*(z_i) = c_{it}(z_i) = z_i(Am^*_{h,i})^{\alpha} + z_i B(m^*_{l,i})^{\gamma} - p\left(m^*_{h,i} + m^*_{l,i}\right). \tag{36}$$

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

$$V(a, z, y_{na}) = \underset{a',c}{\text{Max}} \quad u\left(c^*(z_i) + c\right) + \beta\mathbb{E}\left[V(a', z, y'_{na})\right] \tag{37}$$

subject to

$$a' \geq \underline{a} \tag{38}$$

$$c(a, z, y_{na}) + a'(a, z, y_{na}) = (1 - \delta)a + y_{na} \tag{39}$$

$$lny'_{na} = b + \rho_y lny_{na} + u, \qquad u \sim N(0, \sigma_u^2). \tag{40}$$

Finally, the definition of the stationary equilibria in the economy under complete markets on agriculture is analogous to the definition in section 2 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 $\mathcal{A} = [0, \infty]$.

A.3 Tables and Figures

Table 10: Agricultural Production Allocations in Uganda

Wave	Share Production to: (%)				Proportion Farmers did: (%)			
	Sell	Cons	Stored	Gift	Sell	Cons	Stored	Gift
2009–10	24.98	57.01	4.38	5.80	72.74	93.16	35.00	57.57
2010–11	23.94	59.66	4.58	6.41	77.73	97.68	34.27	62.51
2011–12	25.54	59.17	4.61	6.30	78.62	98.38	33.08	63.91
2013–14	28.63	54.48	6.41	6.25	74.64	96.30	40.13	59.11
2015–16	29.37	55.70	6.80	5.19	77.05	98.76	44.27	57.41

Notes: Columns (1) to (4) show the share of agricultural production devoted to the market (1), 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) part of their agricultural production. *Source:* UNPS 2009/10–2015/16.

Table 11: intermediates Summary

A. Expenditure	Total (m) ($)	High-Yield Crops (m_h) ($)	Low-Yield Crops (m_l) ($)
Avg	59.40	41.23	38.50

B. Composition	Chem. fert. (%) ($)	Org. Fert. (%) ($)	Pesticides (%) ($)	Seeds (%) ($)	Transport (%) ($)
Usage	3.92	9.16	10.25	57.45	13.08
Expend	48.74	52.00	34.43	19.58	15.31

Notes: Panel A shows the average expenditure in intermediates). Panel B shows the proportion of farmers using the intermediate products, and their expenditure, across intermediates.*Source:* UNPS 2009/10–2015/16.

Table 12: Consumption, Income, and Wealth in Uganda

A. Household Level

	Rural Cons ($) ([0,1])	Rural Income ($) ([0,1])	Rural Wealth ($) ([0,1])	National Cons ($) ([0,1])	National Income ($) ([0,1])	National Wealth ($) ([0,1])
2009-10	1,474.07	1,409.14	4,062.45	1,720.24	1,605.71	4,557.87
	(0.35)	(0.58)	(0.62)	(0.38)	(0.59)	(0.67)
2010-11	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)
2011-12	1,593.48	1,555.10	5,301.17	1,810.99	1,720.46	6,045.38
	(0.34)	(0.56)	(0.67)	(0.37)	(0.57)	(0.66)
2013-14	1,541.70	1,524.65	4,403.02	1,738.67	1,719.70	5,086.97
	(0.30)	(0.57)	(0.61)	(0.32)	(0.56)	(0.64)
2015-16	1,476.09	1,729.39	3,782.00	1,705.83	2,079.71	4,489.40
	(0.31)	(0.58)	(0.6)	(0.33)	(0.58)	(0.68)
Average	1,502.99	1,506.64	4,343.67	1,734.87	1,738.98	5,241.76
	(0.33)	(0.57)	(0.63)	(0.36)	(0.58)	(0.68)

B. Per Capita Level

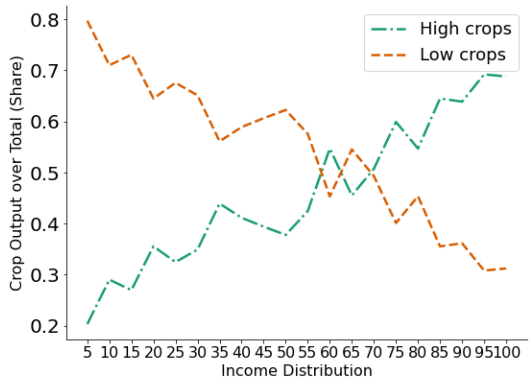
	Rural Cons ($)	Rural Income ($)	Rural Wealth ($)	Rural Hh Size (N)	National Cons ($)	National Income ($)	National Wealth ($)	National Hh Size (N)
2009-10	264.49	258.95	699.97	6.55	320.36	301.82	736.84	6.39
	(0.36)	(0.6)	(0.62)		(0.4)	(0.61)	(0.65)	
2010-11	236.15	225.21	656.54	7.19	276.29	256.18	954.64	7.15
	(0.38)	(0.59)	(0.64)		(0.41)	(0.6)	(0.75)	
2011-12	257.99	251.72	686.66	7.53	290.35	277.19	745.01	7.51
	(0.38)	(0.59)	(0.63)		(0.41)	(0.59)	(0.65)	
2013-14	320.22	322.51	848.24	5.82	377.01	386.30	978.75	5.67
	(0.33)	(0.59)	(0.6)		(0.37)	(0.6)	(0.65)	
2015-16	326.26	402.70	838.02	5.65	395.71	495.39	939.35	5.52
	(0.35)	(0.6)	(0.6)		(0.4)	(0.63)	(0.65)	
Average	281.02	292.22	745.89	6.55	331.95	343.38	870.92	6.45
	(0.36)	(0.59)	(0.62)		(0.4)	(0.61)	(0.67)	

Notes: Panel A provides the household average (in 2013$) and Gini index within parenthesis while Panel B provides the same statistics but at per capita level—dividing household totals over household size. the measurements of consumption, income, and wealth are provided in the text. Wealth includes farm capital and land value. *Source:* UNPS 2009/10–2015/16.

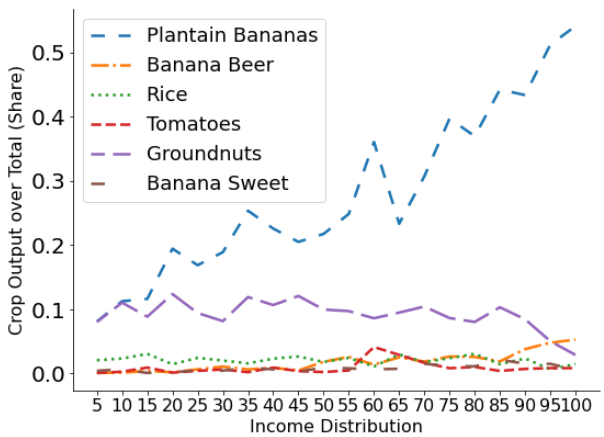
Table 13: Income and Consumption Volatility. Model vs. Data

Description	Model Value	Data Value
Income volatility	0.605	0.600
Consumption volatility	0.104	0.117

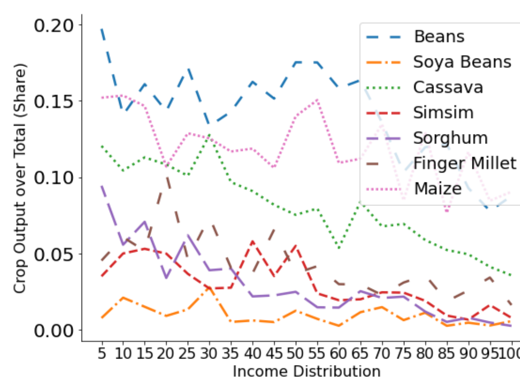
Notes: Volatility moments are computed on the estimated residuals of regressions $ln(y_{it}) = \beta X_{it} + \gamma F_i + \psi T_t + u_{it}$. In which y is the variable for the volatility, X_t represents household characteristics, and F_i and T_t represent household and time fixed-effects. *Source:* UNPS 2009/10–2015/16.



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



(b) High-yield Crops



(c) Low-yield Crops

Figure 7: Crop Production along the Income Distribution

Notes: Farmer's crop production and income ranking are computed as their average across the five waves. *Source:* UNPS 2009/10–2015/16.