

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

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STEG Annual Conference 2026

Motivation

Two key facts in macro-development:

- (1) **Agricultural productivity gap:** agricultural productivity in LI countries is particularly low (Restuccia, et al., 2008; Gollin et al., 2014)

$$\frac{y_{HI}^a}{y_{LI}^a} = \underbrace{2}_{Large} \frac{y_{HI}}{y_{LI}}$$

- (2) **Risk and insurance:** high levels of risk, yet high consumption smoothing (Townsend, 1994):

$$\Delta c_{it} = \underbrace{\beta}_{Small} \Delta y_{it},$$

What are the aggregate and welfare effects of completing financial markets in agriculture in rural Uganda?

- ▷ **Empirically:** UNPS (ISA-LSMS), study relationship between crop yields, crop risk, and crop selection across farmers.
- ▷ **Model:** incomplete markets model with a crop-portfolio choice.
 1. **Precautionary savings:** wealth accumulation under a depreciation rate.
 2. **Income smoothing:** poor households optimally under-invest in intermediates (2.1) and shift the investment to low productive crops (2.2).
- ▷ **Quantitatively:**
 - **Calibrate** the model for rural Uganda, using the UNPS.
 - **Counterfactual Exercise:** benchmark economy vs economy complete financial markets in agriculture.

- ▷ **Donovan (2021)**: 2-sectors IM-model, shows uninsurable risk reduces intermediates share and generates a large agricultural productivity gap.
 - (1) *Risk distorts investment across technologies.*
 - (2) *welfare gains of CM.*
 - (3) *Different model assumptions, different context (rural Uganda).*
- ▷ **Risk and agriculture (micro)**. Dercon (1996), Rosenzweig & Binswanger (1993), Kurosaki & Fafchamps (2002), Dercon & Christiaensen (2011).
 - *Equilibrium impact of risk, agricultural decisions, and the wealth distribution.*
- ▷ **The low agricultural productivity (macro)**: Restuccia, Yang, Zhu (2008), Gollin, Lagakos, Waugh (2014), Chen, Restuccia, Santaauláia-Llopis (2022), ..., Adamopoulos, Restuccia (2022).
 - *Endogenous risk-induced misallocation.*

Empirical Findings

Model

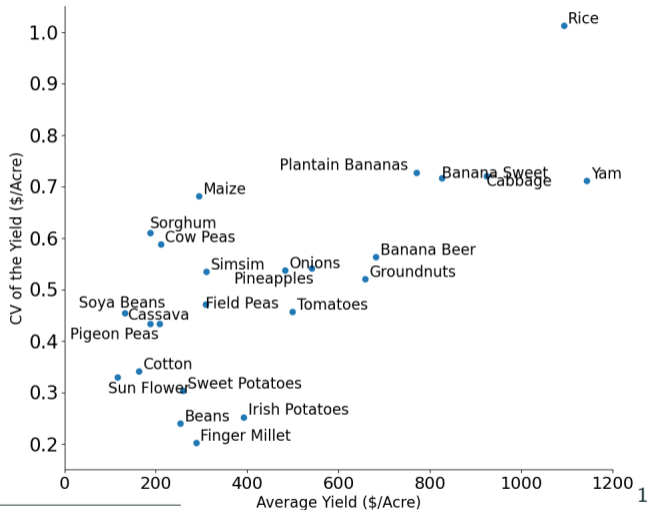
Data

Calibration

Quantitative Results

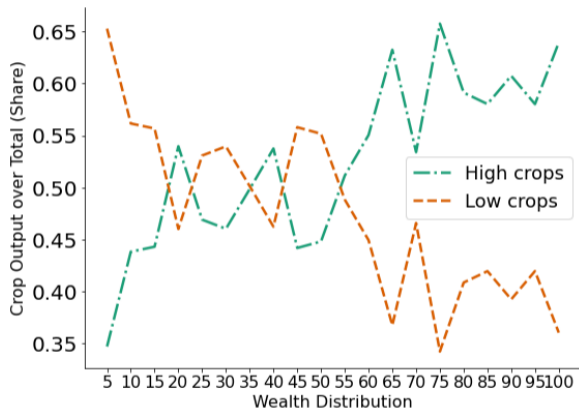
Conclusion

Finding (1): trade-off crop yields vs. crop risk



¹Yields (y/A): agricultural revenue from the crop over land usage of the crop. Correlation robust to measures of risk, pooling at hh-wave/wave, across regions, etc.

Finding (2): crop-selection and wealth distribution



Finding (2): crop-selection and wealth distribution

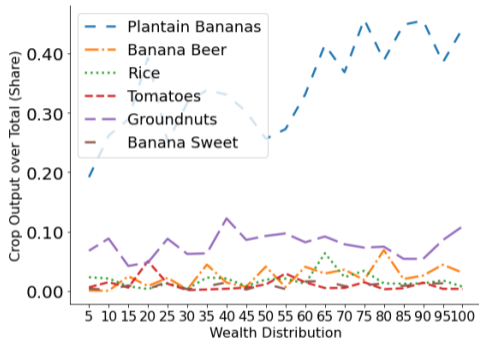


Figure 1: high-yield crops

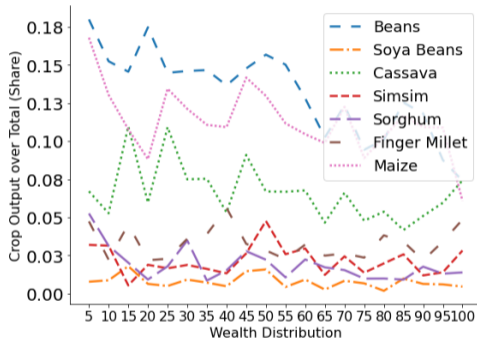


Figure 2: low-yield crops

Finding (3): growing both low-yield and high-yield crops

Most farmers grow simultaneously low-yield crops and high-yield crops.

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

Model ingredients

Economy: Continuum of agents—household-farms—with measure one. Ex-ante only differ in a permanent agric. component (z)

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

Financial market: save (but not borrow) in a risk-free asset, a , at depreciation rate δ .

Income sources: high-returns technology, low-returns technology, and non-agric earnings.

$$y_{it}^h = \theta_{it} z_i A (m_{it}^h)^\alpha \quad y_{it}^l = \varepsilon_{it} z_i B (m_{it}^l)^\gamma \quad y_{it}^{na}$$

Risk: agricultural shocks from M-Log-N distr. Non-agric earnings are AR(1).

$$\ln \theta_{it}, \ln \varepsilon_{it} \sim MN \left(\begin{bmatrix} 0 \\ 0 \end{bmatrix}, \begin{bmatrix} \sigma_\theta^2 & \sigma_{\theta\varepsilon} \\ \sigma_{\theta\varepsilon} & \sigma_\varepsilon^2 \end{bmatrix} \right) \quad \ln y_{i,t+1}^{na} = b + \rho_z \ln y_{it}^{na} + u_{it} \quad u \sim N(0, \sigma_{y_{na}}^2)$$

Equilibria: stationary equilibria, small open economy: input prices and asset returns δ are fixed.

Household's problem

Define x as "cash on hand" on agric. income and assets: $x = \theta z A m_h^\alpha + \varepsilon z B m_l^\gamma + (1 - \delta)a$.

▷ The recursive formulation of the household-farm problem is

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

subject to

$$a' \geq 0$$

$$c + a' + p m'_h + p m'_l = x + y_{na}$$

$$x' = \theta' z A (m'_h)^\alpha + \varepsilon' z B (m'_l)^\gamma + (1 - \delta)a'$$

$$\ln \theta', \ln \varepsilon' \sim MN(0, \Sigma)$$

$$\ln y'_{na} = b + \rho_y \ln y_{na} + u, \quad u \sim N(0, \sigma_u^2)$$

Where c, a', m'_h, m'_l represent the policy functions on state (x, z, y_{na}) .

Household problem: optimality conditions of inputs

FOC of m'_h , m'_l can be written as

$$\text{[high-yield crops]} \quad p = \frac{\mathbb{E} [u_c(c(x', z, y'_{na}))\theta']}{u_c(c(x, z, y_{na}))} \beta^\alpha z A (m'_h(x, z, y_{na}))^{\alpha-1}$$

$$\text{[low-yield crops]} \quad p = \frac{\mathbb{E} [u_c(c(x', z, y'_{na}))\varepsilon']}{u_c(c(x, z, y_{na}))} \beta^\gamma z B (m'_l(x, z, y_{na}))^{\gamma-1}$$

→ $MP \geq MC$: (Poor) households under-invest in the two technologies to limit risk exposure (1st margin).

Household problem: optimality conditions of inputs

$$\gamma Bz(m'_l(x, z, y_{na}))^{\gamma-1} = \underbrace{\frac{\mathbb{E}[\theta' u_c(c(x', z, y'_{na}))]}{\mathbb{E}[\varepsilon' u_c(c(x', z, y'_{na}))]}}_{\leq 1} \alpha Az(m'_h(x, z, y_{na}))^{\alpha-1}$$

$MP_h \geq MP_l$: (Poor) Households shift investment from the high technology towards the low technology to limit risk exposure (2nd margin)

Optimal household choices: input policy functions

Figure 3: Policy function $m'_l(x, z, y_{na})$

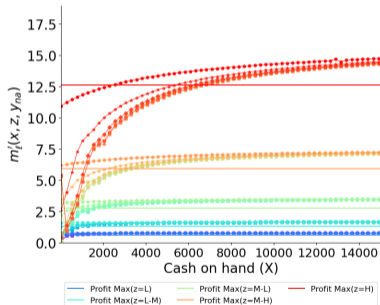


Figure 4: Policy function $m'_h(x, z, y_{na})$

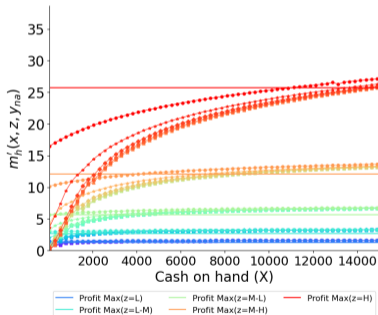
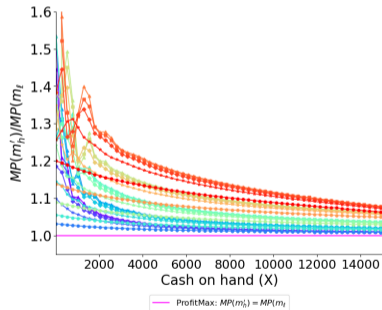


Figure 5: Ratio Exp. marginal products: $\frac{zA\alpha m_h^{\alpha-1}}{zB\gamma m_l^{\gamma-1}}$



Data: Uganda, UNPS (LSMS-ISA)

UNPS: Around 3000 hhs, 5 waves (09/10–15/16):

- ▷ **Consumption:** food + non-durables.
- ▷ **Income:** agricultural revenue + (livestock profits + W. labor + business profits).
 - **Agricultural revenue:** reported value sells + own consumption + gifts + feed animals + food products.²
- ▷ **Liquid Wealth:** crop storage + livestock + household assets + (remittances, alimony, etc).
- ▷ **Intermediates (m):** chem. and org. fertilizer + pesticides + seeds + transport + labor payment.

²**KG production:** crop-season-unit median kg conversions. **Monetary value:** district level median consumption prices.

Calibration: parameter values benchmark economy

| | Parameter | Value | Source |
|----------------------------------|--------------------------------|-------------|---------------|
| Curvature of consumption | ρ | 2 | Literature |
| Discount factor | β | 0.96 | Literature |
| technologies input elasticities | α, 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 earnings | σ_{na} | 1.330 | UNPS estimate |

- **Technologies factors and input price** (A, B, p): match average output high-yield and low-yield crops.
- **Covariance matrix agric. shocks** ($\sigma_\theta, \sigma_\varepsilon, \sigma_{\theta,\varepsilon}$): match crop output risk in the data. 2-step procedure (Kaboski & Townsend, 2010):
 1. Run OLS regression ³

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

2. Calibrate σ_θ to replicate volatility on residuals from (1)

$$\overline{\text{var}_t(\log y_{it}^h)} \Rightarrow \overline{\text{var}_t(\log \hat{\theta}_{it})}$$

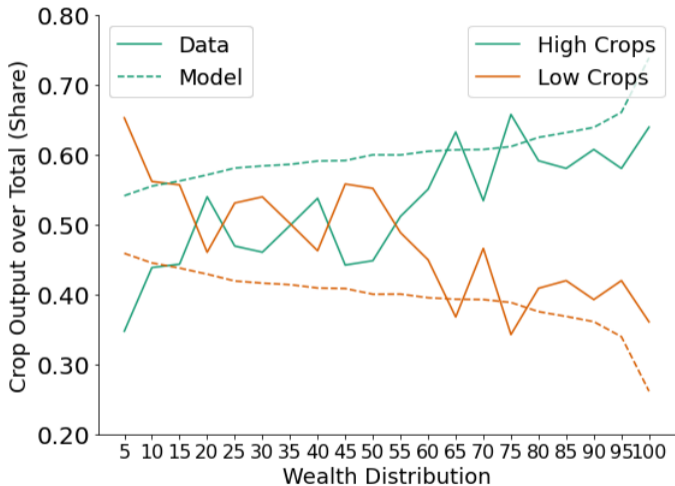
³Z: Land size, labor hours; X: household size, head gender, education, age; F household fixed effects; T_t wave time effects.

- **Depreciation rate (δ):** Aggregate savings match liquid wealth Donovan (2021) and Lagakos, Mobarak, and Waugh (2020).
- **Agric. Permanent Component (z):** 5 evenly-spaced points in logs on interval $[-3\sigma_z, +3\sigma_z]$. Set σ_z to match Gini agricultural production.
 - σ_z captures part of agriculture dispersion not by risk.
- **Non-agricultural earnings process (ρ_{na}, σ_{na}):** Estimate ρ_{na}, σ_{na} with OLS on AR(1) process.

Model vs. data: targeted moments

| Description | Model Value | Data Target |
|------------------------------------|-------------|-------------|
| Avg high-yield crops output | 651.11 | 651.12 |
| Avg low-yield crops output | 353.99 | 353.39 |
| Avg Income | 1499 | 1506 |
| Avg Liquid Wealth | 1860 | 1858 |
| high-yield crops volatility | 1.0507 | 1.0521 |
| low-yield crops volatility | 0.7255 | 0.7220 |
| High & low- crops time-correlation | 0.1154 | 0.1147 |
| Gini agricultural output | 0.6185 | 0.6200 |

Model vs. data 1: crop selection and wealth distribution



Model vs. data 2: CIW inequality (shares)

| | 1 | 5 | Bottom (%) | | | Top (%) | | | 5 | 1 |
|--------------|------|------|---------------|------|-------|------------|-------|-------|-------|-------|
| | | | 10 | 25 | 50 | 50 | 25 | 10 | | |
| 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: Data: UNPS wave 2011–12.

⁴

⁴Income and consumption volatility. model income volatility is 0.605, in the data 0.600. Model consumption volatility is 0.104, in the data 0.117.

Counterfactual world: complete markets in agriculture

▷ Allocations agric. inputs and consumption given by solution Social Planner that replicates CM. *Intuition:*

- SP maximizes aggregate consumption

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

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

- SP distributes aggregate consumption

$$c^*(z_i) = c_{it}(z_i) = z_i(Am_{h,i}^*)^\alpha + z_i B(m_{l,i}^*)^\gamma - p(m_{h,i}^* + m_{l,i}^*)$$

Quantitative results: comparing the benchmark economy vs. counterfactual economy (CM in agriculture).

- (1) Agricultural productivity results.
- (2) Consumption and welfare results.

Results agricultural productivity

- ▷ Completing markets increases agricultural output—and agricultural productivity—by **12.20%**.

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

- ▷ Through two channels
 - (1) **Higher intermediates share.** Intermediate inputs increase by 26.65%.
 - (2) **Efficiency gains.** Reallocation of intermediate inputs across heterogeneous farmers and crops.

(2) Computing the **efficiency gains**: gains eliminate risk-induced misallocation.

- ▷ Set SP solution such that $\bar{m}_{SP} = \bar{m}_{BMK}$ but keeping intermediates shares across crop portfolio and farmers equal to the CM scenario.

$$\begin{aligned}\alpha z_i A(m_{it}^h)^{\alpha-1} &= \alpha z_j A(m_{jt}^h)^{\alpha-1} & \forall i, j \in \mathcal{Z} \\ \alpha z_i A(m_{it}^h)^{\alpha-1} &= \gamma z_i B(m_{it}^l)^{\gamma-1}.\end{aligned}$$

- ▷ Efficiency gains account for **46.5%** of the total output increase.

Consumption and welfare results: aggregate consumption gains

- ▷ CM increases aggregate consumption by **17.18%**.

| | Benchmark (\$) | Complete Markets (\$) | Δ_{CM} (\$) | Δ_{CM} (%) |
|-------------|-------------------|--------------------------|-----------------------|----------------------|
| 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: Aggregate resource constraint: $C = Y_a - pM + Y_{na} - \delta A$.

Consumption and welfare results: distributional effects

CM has non-obvious heterogeneous effects along the distribution.

(↓) Consumption not a function of agricultural shocks.

(↑) Hh with high permanent components most benefited by CM.

(↑) Strong decrease costly savings mainly hold by those in the top.

▷ Small increase in inequality:

| | Gini | Bottom | | | | | Top | | | | |
|-------------|------|--------|-------|-------|-------|-------|-------|-------|-------|------|-------|
| | (%) | 1 | 5 | 10 | 25 | 50 | 50 | 25 | 10 | 5 | 1 |
| | | | | (%) | | | | | (%) | | |
| Consumption | 0.56 | 23.90 | 15.36 | 12.99 | 12.36 | 14.13 | 18.15 | 17.67 | 11.10 | 8.89 | 12.43 |

The ex-ante welfare comparison of completing the markets is defined as the CEV, g , such that

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

$$g = 15.2 \%$$

- ▷ **Risk** and incomplete financial markets to **explain the low agricultural productivity** in SSA.
 - Importance of **risk and technology choice** in misallocation of resources in agriculture.
- ▷ Although high levels of consumption smoothing, **large welfare gains of CM**.
 - Not by reduction on consumption fluctuations but **through increasing income and consumption levels**.
 - Policies providing better consumption insurance (savings, credit, CCT, etc.) might have large output and productivity effects.