Scaling Up Agricultural Insurance

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Agriculture is Risky

Long and rich tradition in development economics studying effects of risk, especially in agricultural settings (Paxson 1992; Rosenzweig and Binswanger 1993; Udry 1994, 1995; Mobarak and Rosenzweig 2013; Donovan 2021)

- Risk lowers utility because households prefer stable consumption
- Risk can lower output if high-return investments are risky
- This may explain apparent underutilization of inputs and inefficient crop choice

A potential solution is to offer insurance

- Microeconomic research studying effects of insurance (Karlan et al. 2014)

In parallel, macroeconomic work thinking about GE effects of scaling up interventions

- e.g. Buera et al. (2021), Lagakos et al. (2023), Bergquist et al. (2025); see JEL review by Buera et al. (2023)

Insurance Unlocks Investment (Karlan et al. 2014)

Our paper begins with the RCT of Karlan, Osei, Osei-Akoto, and Udry (2014)

- Study rainfall insurance, which pays out if there is not enough rain (or too much)
  - Sidesteps moral hazard/adverse selection: rain is exogenous and common knowledge
- Randomize grants of insurance, and insurance prices
- Insurance raises farmer's agricultural investment
- Insurance shifts crop choice towards risky, high-return crop (maize vs. mangoes)

Strong evidence that risk aversion plays a role in constraining farmers

In the background, Ghanaian rainfall insurance market is maturing:

- Experimental product in Years 1-2
- Commercial product in Year 3 and beyond

Our Paper: Scaling Up Agricultural Insurance

Should government “scale up” agricultural insurance?

- In practice, this means subsidizing it or offering it at below-market cost

Experiment identifies a partial equilibrium effect:

- Compares treated and control households within the same economy
- If scaled up, there will be important GE effects

To determine optimal policy, we need to understand:

- Is there a market failure?
- *If so, does subsidizing insurance fix the incompleteness?*

Pecuniary externality in GE: Price changes redistribute resources across states

Outline of the Talk

To answer these questions:

- Model: Agricultural households that can (imperfectly) share risk
- Optimal Policy: Subsidy balances “fiscal” vs. “pecuniary” externality
- (Preliminary) Calibration: Use experimental moments, plus additional data
- Counterfactuals: What happens when we subsidize insurance?

This project is work in progress:

- Later, plan to add dynamic model and tighten calibration
- **Your comments and suggestions are much appreciated!**

Model

Environment and Utility

Continuum of ex-ante identical regions, $i \in [0,1]$

Representative household in each region, all agents price takers, competitive markets

In each region, s_i^H is good state (rain) and s_i^L is bad state (drought)

States are drawn iid across regions, so no aggregate uncertainty

Household utility in region i:

$$\begin{aligned} U_i &= \mathbb{E}\left[u\left(c_i\left(s_i\right)\right)\right] \\ &= P\left(s_i^H\right) \cdot u\left(c_i\left(s_i^H\right)\right) + P\left(s_i^L\right) \cdot u\left(c_i\left(s_i^L\right)\right) \end{aligned}$$

where $u\left(c\right) = \frac{c^{1-\gamma}-1}{1-\gamma}$ is CRRA

Farm Production

Household makes income by farming; G different crops, indexed by g

Before knowing the state, allocates unit of land across crops:

$$y_{g,i}\left(s_i, l_{g,i}\right) = z_g\left(s_i\right) \cdot l_{g,i}^{\theta_g}$$
$$\sum_{g=1}^{G} l_{g,i} = 1$$

Curvature θ_g reflects that plots have heterogeneous suitability

- As more land is allocated to maize, marginal land is less suited to maize

Crop choice entails risk-return tradeoff:

- For farmers in Karlan et al. (2014), maize has higher expected return, but mangoes are drought-resistant

Aggregation and Agricultural Profits

Farmer takes prices as given, agricultural profits are:

$$\pi_i \left(s_i, \{l_{g,i}\}_{g=1}^{G} \right) = \sum_{g=1}^{G} p_g \cdot y_{g,i} \left(s_i, l_{g,i} \right)$$

Agricultural goods are aggregated, CES, into a final good

$$Y_g = \int_0^1 y_{g,i} \left(s_i \right) di \, \forall g$$

$$Y = \left(\sum_{g=1}^{G} Y_g^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}}$$

Final good is numeraire, so $P = 1$. Competitive pricing:

$$p_g = \frac{dY}{dY_g} = \left(\frac{Y_g}{Y} \right)^{-1/\sigma}$$

Agricultural Insurance

Each household can buy insurance, x_i

- Costs $p_{x,i} \cdot x_i$, paid regardless of state
- Pays out x_i in the bad state, 0 in good state
- For simplicity, constrain $x_i \geq 0$ (household doesn't sell insurance)

Insurance Firm

Insurance is sold by a representative insurance firm

- Actuarially fair price of insurance is $P\left(s_i^L\right)$
- Firm pays per-unit service cost τ, and earns markup μ

Firm thus offers prices:

$$p_{x,i} = P\left(s_i^L\right) + \tau + \mu \,\forall i$$

and makes profits

$$\Pi^I = \int_0^1 \left(p_{x,i} - P\left(s_i^L\right) - \tau\right) \cdot x_i di = \mu \cdot \int_0^1 x_i di$$

Firm is owned by households, so profits are rebated to households

Note that τ and μ are both frictions, but they are distinct:

- Service cost τ is a resource cost; can't just undo it
- Markup μ is a pure wedge; can undo it with a subsidy

Household's Problem

Household budget constraint is:

$$c_i\left(s_i^H\right) = \pi_i\left(s_i^H\right) + \Pi^I - p_{x,i} \cdot x_i$$
$$c_i\left(s_i^L\right) = \pi_i\left(s_i^L\right) + \Pi^I - p_{x,i} \cdot x_i + x_i$$

Each household solves:

$$\max_{x,\{l_g\}_{g=1}^{G}} \mathbb{E}\left[u\left(c_i\left(s_i\right)\right)\right]$$
$$s.t. \sum_{g=1}^{G} l_{g,i} = 1$$

Separation and Efficiency

Household first order conditions:

$$\text{Production: } \mathbb{E}\left[\frac{u'\left(c_i\left(s_i\right)\right)}{\mathbb{E}\left[u'\left(c_i\right)\right]}\cdot p_g \frac{\partial y_{g,i}}{\partial l_{g,i}}\right] = \lambda_i \,\forall g$$

$$\text{Insurance: } \mathbb{E}\left[u'\left(c_i\right)\right]\cdot p_{x,i} = u'\left(c_i\left(s_i^L\right)\right) P\left(s_i^L\right)$$

As long as $x_i > 0$, we get a nice separation result:

$$\mathbb{E}\left[\frac{u'\left(c_i\left(s_i\right)\right)}{\mathbb{E}\left[u'\left(c_i\right)\right]}\cdot p_g \frac{\partial y_{g,i}}{\partial l_{g,i}}\right] = p_{x,i}\cdot p_g \frac{\partial y_{g,i}\left(s_i^L\right)}{\partial l_{g,i}} + \left(1-p_{x,i}\right)\cdot p_g \frac{\partial y_{g,i}\left(s_i^H\right)}{\partial l_{g,i}}$$

- Farm maximizes marginal-utility-weighted profits
- With insurance, weight by state-prices, $p_{x,i}$ and $1 - p_{x,i}$
- With actuarially fair insurance, maximize (true) expected profits

Distortion in insurance market leads to production inefficiency

Welfare and Optimal Policy

Subsides as Markups

To scale up agricultural insurance, government provides a subsidy

Subsidy lowers the price consumer pays, and is funded through lump-sum taxation

Markups work in exactly the same way!

- Markup raises price, and profits returned lump-sum to households as dividend

For clarity, we will lump them together:

- Using subsidies as a tool, government chooses the markup

$$\mu = \mu^{\text{Baseline}} - \text{Insurance Subsidy}$$

Indirect Utility and Consumption

How do subsidies affect household welfare, in general equilibrium?

- Differentiate welfare with respect to the markup
- Household treats prices and insurer profits as exogenous
- Land and insurance are choices, so fall out with Envelope Theorem

$$\frac{dU}{d\mu} = \frac{\partial U}{\partial p_x} \cdot \frac{dp_x}{d\mu} + \frac{\partial U}{\partial \Pi^I} \cdot \frac{d\Pi^I}{d\mu} + \sum_{g=1}^{G} \frac{\partial U}{\partial p_g} \cdot \frac{dp_g}{d\mu}$$

$$= \mathbb{E}\left[u'(c) \cdot \left(\underbrace{\frac{\partial c}{\partial p_x} \cdot \frac{dp_x}{d\mu}}_{\text{Cost of Insurance}} + \underbrace{\frac{\partial c}{\partial \Pi^I} \cdot \frac{d\Pi^I}{d\mu}}_{\text{Insurer Profits}} + \underbrace{\sum_{g=1}^{G} \frac{\partial c}{\partial p_g} \cdot \frac{dp_g}{d\mu}}_{\text{Farmer Profits}} \right)\right]$$

Note: $\frac{d}{d\mu}$ reflects the derivative of a variable in general equilibrium

Optimal Subsidies

At the optimal subsidy:

$$\underbrace{-\mu \cdot \frac{dx}{d\mu}}_{\text{Fiscal Externality}} = \underbrace{\mathbb{E}\left[\frac{u'(c)}{\mathbb{E}[u'(c)]} \cdot \left(\sum_{g=1}^{G} y_g \cdot \frac{dp_g}{d\mu}\right)\right]}_{\text{Pecuniary Externality/Risk-Sharing}}$$

- When $\mu = 0$, marginal benefit to consumers from lower p_x exactly cancels marginal cost to the insurer/government
- When $\mu < 0$, subsidy imposes a fiscal externality
- Pecuniary externality: change in crop prices transfers resources across states
- Formula very similar to Baily-Chetty: balance fiscal externality against risk term

Pecuniary Externality Reduces Consumption Risk

$$\underbrace{-\mu \cdot \frac{dx}{d\mu}}_{\text{Fiscal Externality}} = \underbrace{\mathbb{E}\left[\frac{u'(c)}{\mathbb{E}[u'(c)]} \cdot \left(\sum_{g=1}^{G} y_g \cdot \frac{dp_g}{d\mu}\right)\right]}_{\text{Pecuniary Externality/Risk-Sharing}}$$

Why does pecuniary externality reduce consumption risk?

- Under incomplete insurance, marginal utility higher in the bad state
- Insurance subsidy $\Rightarrow$ more production of risky crop
- $\Rightarrow$lower relative price of risky crop $\Rightarrow$ transfers resources to bad state

Note that $\mathbb{E}\left[\sum_{g=1}^{G} y_g \cdot \frac{dp_g}{d\mu}\right] = 0$, *so no effect on average income*

- Pecuniary externality is just about transfers *across* states through *relative* prices

Pecuniary Externalities Under Incomplete Markets

When and why are pecuniary externalities non-zero?

Can rewrite risk-sharing/pecuniary externality term:

$$\mathbb{E}\left[\frac{u'(c)}{\mathbb{E}[u'(c)]}\cdot\left(\sum_{g=1}^{G} y_g \cdot \frac{dp_g}{d\mu}\right)\right] = (\mu+\tau)\cdot\sum_{g=1}^{G}\left(y_g\left(s^L\right) - y_g\left(s^H\right)\right)\cdot\frac{dp_g}{d\mu}$$

- Holds for arbitrary production functions and (homothetic) crop demand
- Under full insurance, $\mu + \tau = 0$, the pecuniary externality is zero
- When markets are competitive ($\mu = 0$) and complete ($\tau = 0$), both fiscal and pecuniary externality are zero

Special case of more general principle:

- First Welfare Theorem: Competitive and complete markets achieve the first-best $\implies$ pecuniary externalities cancel out
- Theory of the Second Best: Away from first-best, they no longer cancel out!

The Optimal Subsidy Implements A Negative Markup

$$\underbrace{-\mu \cdot \frac{dx}{d\mu}}_{\text{Fiscal Externality}} = \underbrace{\mathbb{E}\left[\frac{u'(c)}{\mathbb{E}[u'(c)]} \cdot \left(\sum_{g=1}^{G} y_g \cdot \frac{dp_g}{d\mu}\right)\right]}_{\text{Pecuniary Externality/Risk-Sharing}}$$

What markup, μ, will solve the above FOC?

- If $\tau > 0$, then pecuniary externality of a subsidy will be beneficial as long as insurance is less than actuarially fair
- At $\mu = 0$, fiscal externality is zero; at $\mu + \tau = 0$ the pecuniary externality is zero
- So, optimal $\mu < 0$ (subsidy larger than markup), but still not full insurance

Result highlights importance of macroeconomic analysis for optimal policy

- Without pecuniary externality: just set subsidy to undo markup
- The interesting term is inherently a general equilibrium object
- Micro RCTs inform calibration, but cannot directly tell us optimal subsidy

Calibration

Calibration Strategy

Calibrate to agricultural economy in Ghana

Three sources for calibration:

- Experimental moments from Karlan et al. (2014)
- Supplemental moments from Ghana Living Standards Survey (GLSS)
- External calibration to parameters from Sotelo (2020)

Model is just-identified; search for parameters that exactly hit target moments

- In principle, joint identification from all moments
- But, highlight which moments most closely linked to each parameter

Identification of Risk Aversion (γ)

Karlan et al. (2014) offer farmers insurance at (randomized) prices, to estimate insurance demand elasticity

- Estimate demand elasticity of 2.0 between market price and actuarially fair price

We use this to identify γ

- If farmer is nearly risk-neutral, demand will quickly drop to zero away from actuarially fair price
- If farmer is very risk averse, demand will be less elastic

This is a partial equilibrium elasticity

- To obtain moment from model, first solve in GE
- Then vary $p_{x,i}$, while holding fixed Π^I and $\{p_g\}_{g=1}^G$

Not quite same as $\frac{dx}{d\mu}$ in optimal subsidy formula (PE vs. GE), but very closely related!

Identifying Production Parameters

For each crop, need to identify three production function parameters:

- Curvature (returns-to-scale) parameter θ_g
- Productivity, $z_g(s_i)$, in good state and bad state

We identify these using data on land use and yields

First, suppose you know θ_g:

$$z_g(s_i) = y_{g,i}(s_i) / l_{g,i}^{\theta_g}$$

Need data on land shares for each crop, and (state-specific) output

Subtlety: We measure revenue, rather than output.

- Back out p_g from $\mathbb{E}[p_g \cdot y_g]$, then can back out $y_g(s_i)$
- Normalization: Demand has no crop-specific multipliers, so need to infer "units"

Identifying Production Parameters (θ_g)

How do we identify curvature parameter θ_g?

Risk-neutral farmers would equalize marginal revenue product of land across crops

$$\begin{aligned} \frac{d}{dl_g}\mathbb{E}\left[p_g y_{g,i}\right] &= \theta_g \cdot p_g \cdot \mathbb{E}\left[z_g \cdot l_{g,i}^{\theta_g - 1}\right] \\ &= \theta_g \cdot \underbrace{\frac{p_g \cdot \mathbb{E}\left[y_{g,i}\right]}{l_g}}_{\text{Average Yield for Crop } g} \end{aligned}$$

So, ratio of average yields gives ratio of θ_g parameters

- Pin down $\theta_{\text{Maize}} = 0.4$ from Sotelo (2020)

With risk aversion, $\mathbb{E}[\cdot]$ replaced with risk-adjusted probabilities

- If demand for insurance is positive, this is pinned down by p_x

Ghana Living Standards Survey (GLSS) Data

Pin down production parameters with moments from GLSS

Data on revenue and land allocation by crop

- Revenue data available from rounds 4-7 (1998-1999, 2005-2006, 2012-2013, 2016-2017)
- Land data is only available for a subset of crops
- For round 7, we are able to impute area harvested; verify accuracy for the crops where we observe land directly

We focus on the top ten crops by area harvested, and then drop cocoa

- Maize, sorghum, groundnut (peanut), beans, rice, cassava, plantain, yam, cocoyam (taro)

Imputation Details Data Cleaning Details

Rainfall Data

Daily rainfall data from Google Earth Engine (UC Santa Barbara CHIRPS data):

- Data from 1981-2025, with 0.05 degree (≈5.5 km) pixel resolution
- For each pixel, compute "Bad Weather" dummy for a year
  Following exact definition used in Karlan et al.'s Year 2 insurance product
  - Growing season from June-September
  - Day is "dry" if less than 1mm rain, and "wet" if more than 1mm
  - Bad weather trigger if 12 or more consecutive dry days and/or 7 or more consecutive wet days

Take average to get $P\left(s^L\right) = 0.68$

Productivity Regressions

To back out average yields, we run (in round 7):

$$\log\left(\text{Yield}_{irg}\right) = \alpha_r + \delta_g + \varepsilon_{irg}$$

To back out how yields depend on weather, we regress on Bad Weather_{irt} (rounds 4-7)

- Bad Weather_{irt} variable is average across all pixels in that region

For crops where we can observe yields:

$$\log\left(\text{Yield}_{irgt}\right) = \beta_g \cdot \text{Bad Weather}_{irt} + \gamma_{rg} + \theta_{gt} + \varepsilon_{irgt}$$

For crops where we cannot observe yields:

$$\log\left(\text{Harvest Value}_{irgt}\right) = \beta_g \cdot \text{Bad Weather}_{irt} + \gamma_{rg} + \theta_{gt} + \varepsilon_{irgt}$$

where i is a household, r is a region, g is a crop, t is a year

More Calibration Details   Regression Results

Insurance Servicing Costs (τ) and Markups (μ)

The supply side of insurance depends on three terms:

- Probability of bad state, $P\left(s^L\right)$: Actuarially fair price of insurance
- Servicing cost, τ: Additional resource cost of providing insurance
- Markup, μ: Pure markup between price and resource cost of insurance
- $p_x = P\left(s^L\right) + \tau + \mu$

We calibrate $\tau + \mu$ using the actuarially fair price and estimated market price of the Year 2 insurance product in Karlan et al. (2014):

- $\frac{\text{Market Price}}{\text{Actuarially Fair Price}} = \frac{P\left(s^L\right)+\tau+\mu}{P\left(s^L\right)} = \frac{14}{10} \implies \frac{\tau+\mu}{P\left(s^L\right)} = \left(\frac{14}{10} - 1\right) = 0.4$
- We will calibrate $\mu^{\text{Baseline}} = 0$, so $\tau = 0.4 \times P\left(s^L\right)$

Elasticity of Substitution Across Crops σ

For elasticity of subsitution across crops, we use estimate from Sotelo (2020)

- Estimate $\sigma = 2.4$ in Peruvian data

Elasticity of substitution across crops is important for the pecuniary externality

- Insurance subsidy will increase quantity of risky crops
- How that translates into price effect, $\frac{dp_g}{d\mu}$, depends on σ
- If σ is very high (near-perfect substitutes), then price effect is small

Estimate of $\sigma = 2.4$ is on the lower end of literature

- Gives the pecuniary externality the best chance to matter

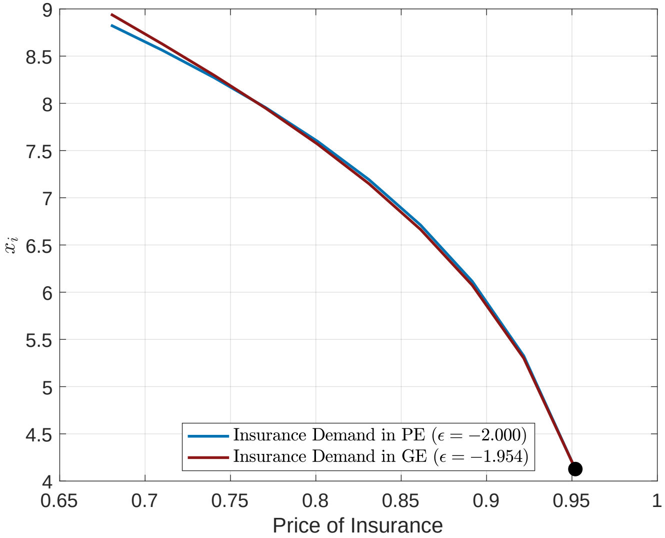
Calibration Table

Parameter	Description	Value	Calibration Target
σ	Elasticity of Substitution Across Crops	2.4	Sotelo (2020)
γ	Coefficient of Relative Risk Aversion	7.4	Elasticity of Demand for Insurance
$P\left(s^L\right)$	Probability of Low Rainfall	0.68	Rainfall Data
$\{\theta_g\}_{g=1}^{G}$	Curvature Parameter by Crop	—	Relative Yields Across Crops
$\{z_g\left(s_i\right)\}_{g=1}^{G}$	State-Dependent Productivity by Crop	—	Yield Regressions and Land Shares
τ	Servicing Cost of Insurance	$0.4 \times P\left(s^L\right)$	Computed in Karlan et al. (2014)
μ^{Baseline}	Markup on Insurance	0	By Assumption

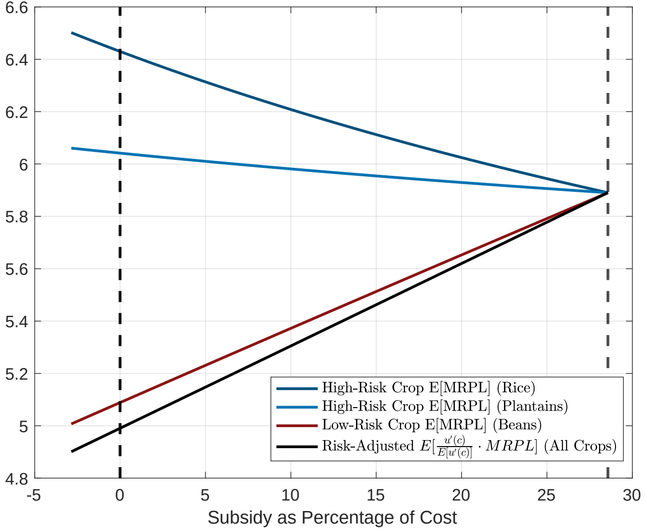
Table 1: Calibration Table for Model Parameters

Results and Counterfactuals

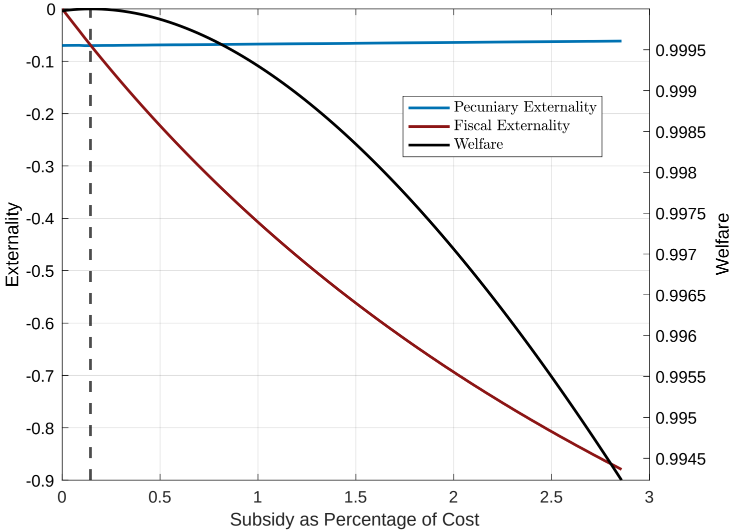
Insurance Demand (PE vs. GE)



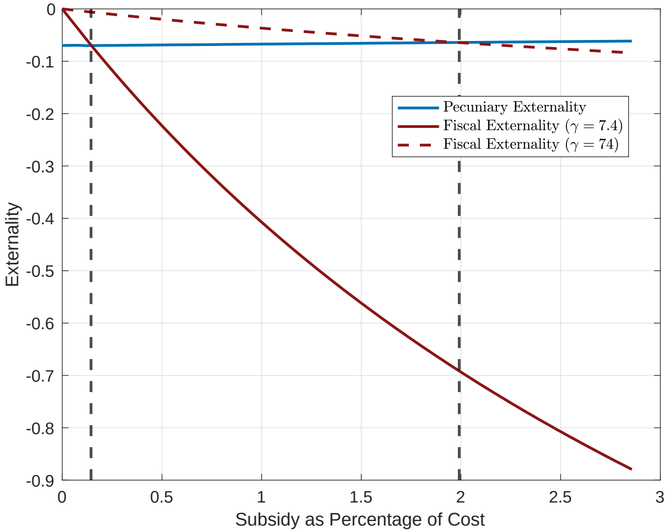
Marginal Revenue Product of Land



Optimal Subsidy



The Optimal Increases with Risk Aversion



Conclusion

The optimal insurance subsidy solves the following equation:

$$\underbrace{-\mu \cdot \frac{dx}{d\mu}}_{\text{Fiscal Externality}} = \underbrace{\mathbb{E}\left[\frac{u'(c)}{\mathbb{E}\left[u'(c)\right]} \cdot \left(\sum_{g=1}^{G} y_g \cdot \frac{dp_g}{d\mu}\right)\right]}_{\text{Pecuniary Externality/Risk-Sharing}}$$

Optimal subsidy undoes the markup, plus a little more:

- Macroeconomic modeling is essential to measuring the pecuniary externality
- Microeconomic experiments can help calibrate the model
- But, just the fact that farmers respond to insurance does not tell us that we should subsidize it

Quantitatively small: If $\mu^{\text{Baseline}} = 0$, optimal subsidy is 0.1% of cost

Thank you for your comments and suggestions!

Appendix

Imputation of Land in GLSS

GLSS divides crops into two groups, based on typical harvest frequency

- For frequently harvested crops, does not ask household for total acreage
- But, we have total harvest value for all crops

In round 7, we have area of plot, and all crops harvested on it (may be multiple)

Imputation procedure:

- Trim harvest value by crop (1st and 99th percentile)
- For each region-crop, compute yield among single-cropped plots
- Divide harvest value by relevant imputed yield to get acreage

Confirm accuracy for the crops where we observe actual acreage Back

Data Cleaning for GLSS Regressions

For productivity regressions:

- Trim harvest value by crop-year at 1st and 99th percentile
- Compute yields (actual or imputed acreage)
- Then trim yields by crop-year at 1st and 99th percentile

For crop fixed effect regressions use round 7 yields

For rainfall regressions use rounds 4-7

- Use yields for crops where we can compute them
- Harvest value is the outcome for other crops

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GLSS Estimates

Crop	Acreage	Imputed Acreage	δ_g	β_g
Beans	2,815.74	3,093.89	0.00	0.23
Cassava		4,907.58	0.51	-0.66
Cocoyam		2,557.52	0.06	-0.65
Groundnut	4,031.86	4,916.80	0.56	-0.51
Maize	11,053.42	11,691.24	0.37	-0.21
Plantain		2,960.37	0.55	-0.59
Rice	2,061.25	3,037.53	0.69	-0.37
Sorghum	5,542.16	4,184.56	-0.04	-0.21
Yam		2,889.68	1.66	-0.53

Table 2: Estimated Moments from Ghana Living Standards Survey

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Calibration of Productivity Parameters (Details)

Calibrate model to match:

- $\frac{p_g \cdot \mathbb{E}[y_{g,i}]}{l_g} = \exp(\delta_g)$
- $\frac{p_g \cdot y_{g,i}(s_i^L)}{l_g} = \exp(\beta_g) \cdot \frac{p_g \cdot y_{g,i}(s_i^H)}{l_g}$
- $\mathbb{E}[l_g]$ from land shares in round 7

Separation means we can solve for production decisions without solving household problem

- Solve for $p_x = P(s^L) + \tau$, since $\mu^{\text{Baseline}} = 0$
- Solve land FOCs to get θ_g from δ_g and β_g
- Use σ to get p_g from δ_g
- Solve for state-specific productivities
- Everything is closed-form :-)

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