The Dual Role of Insurance in Input Use: Mitigating Risk Versus Curtailing Incentives

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Motivation

- Governments around the developing world spend billions of dollars on fertilizer subsidies
  - Indian government: ≈ \$11bn in 2019 (GOI 19)
- More fertilizer → higher agricultural productivity (Ellis 92, Sachs 04)
- Puzzle: why aren't farmers using more fertilizer?
- Fertilizer may be a risky input
  - More insurance should increase fertilizer use
- **Insurance can decrease people's incentives to exert effort** when the latter is difficult to monitor
- **This effort reduction can go hand in hand with a decrease in the use of effort-complementary inputs**

Research question

- *What is the relationship between input use and insurance when the latter can create incentive problems?*
- I use this relationship to shed light on how risk-sharing arrangements affect fertilizer use in rural India
- Households rely on **risk-sharing** to cope with income shocks
  - Yet informal insurance is incomplete (Townsend 94, Udry 94)
  - A leading explanation for this is **private information frictions in production decisions** (evidence)
- **Fertilizer and effort are complements** (evidence)
- Hypothesis
  1. **risk-sharing can discourage effort supply**
  2. **effort reductions can lead to decreases in the use of effort-complementary inputs**

This paper (▸ contribution)

- **Mechanism**: model of risk-sharing with hidden effort and fertilizer, and effort and fertilizer are complements

- **Evidence**: use the latest (10-14) ICRISAT panel from rural India to structurally estimate the model

- Exploit variation in fertilizer prices to rationalize observed household choices of effort and fertilizer given
  1. preferences: disutility of effort at the household level
  2. technology: CES between effort and fertilizer
  3. market conditions: risk-sharing at the village-month level

- Use retrieved structural parameters to conduct
  1. **counterfactual**: median fertilizer use is between 1.3 and 3.6 times higher under no sharing than under full insurance
  2. **policy simulation**: 50% decrease in fertilizer prices leads to a welfare-equivalent increase in farmers' aggregate consumption of 8%

Sketch of the model (details)

- Static economy with n household-farms, each choosing
  1. how much effort e_i to exert at a marginal utility cost κ_i
  2. how much fertilizer f_i to buy at a given price p_i
- Each household gets hit by an idiosyncratic shock $\rightarrow$ agricultural output: $y(e_i, f_i)\,\varepsilon_i$
- Risk sharing: households keep a fraction $1-\alpha$ of incomes and contribute the rest to a common pool
- **Private information frictions** in production decisions: farmers' choices of effort and fertilizer are not perfectly observable
- A utilitarian social planner chooses $\alpha, \boldsymbol{e}, \boldsymbol{f}$ taking into account incentive compatibility

Sketch of the model

- **Predictions**: insurance has two opposing effects on e_i and f_i
  1. Risk channel: risk-sharing increases the expected marginal benefits of inputs because it makes them less risky
  2. Free-riding channel: when farmers share more, they appropriate a smaller fraction of the marginal product of their effort
- If the free-riding channel is strong enough, $\alpha \uparrow$, $e_i^* \downarrow$
- If the free-riding channel is strong enough, $\alpha \uparrow$, $f_i^* \downarrow$ iff e_i and f_i are complements
- **Fertilizer subsidy**: increases welfare because it decreases input costs and leads households to work harder

Data

- "Village Dynamics Studies in South Asia" (VDSA) project by ICRISAT
- Widely used dataset: Townsend 94, Ligon 98, Mazzocco and Saini 12, Morten 19, ...
- Monthly panel data with individual- and household-level information on **farming, expenditure, and income** for 18 villages in the Indian semi-arid tropics, from 2010 to 2014
- On average, 55 households per village
- Summary statistics map

Structural equation

- Strategy: use variation in fertilizer prices to estimate the relative demand for fertilizer to effort

- Assuming CES technology with elasticity σ and measurement error in fertilizer/effort,

$$\log\left(\frac{f_{it}}{e_{it}}\right) = \sigma \log\left(\kappa_i\right) - \sigma \log\left(1 - \frac{n_{vt}-1}{n_{vt}}\alpha_{vt}\right) - \sigma \log\left(p_{it}\right) + \epsilon_{it}$$

  - Assume measurement error in fertilizer/effort is uncorrelated with fertilizer prices

- Use OLS to consistently estimate

$$\log\left(\frac{f_{it}}{e_{it}}\right) = \varphi_i + \phi_{vt} - \sigma \log\left(p_{it}\right) + \epsilon_{it}$$

Structural equation

Dep. variable: $\log\left(\frac{f_{it}}{e_{it}}\right)$	$\widehat{\beta}$ (s.e.)
$\log(p_{it})$	$-.3499^{***}$ (0.0241)
Household fixed effects	Yes
Village-month fixed effects	Yes
R-squared	0.640
Observations	9,941

Notes: OLS regressions of log fertilizer used per worked hours on log fertilizer prices. Standard errors are clustered at the village-month level.

- Estimates:
  1. $\widehat{\sigma} \approx 0.35$
  2. Distribution of marginal disutility of effort: Go to figure
  3. Distribution of risk-sharing coefficients: Go to figure

Counterfactual

- I compute

$$\widetilde{\log\left(\frac{f_{it}}{e_{it}}\right)} = \widehat{\sigma}\widehat{\log\left(\kappa_i\right)} - \widehat{\sigma}\log\left(1 - \frac{\widetilde{n}_{vt} - 1}{\widetilde{n}_{vt}}\widetilde{\alpha}_{vt}\right) - \widehat{\sigma}\log\left(p_{it}\right)$$

- Counterfactual: move $\widetilde{\alpha}_{vt}$ from 1 (full insurance) to 0 (no sharing)
- When moving $\widetilde{\alpha}_{vt}$ from 1 to 0, the median fertilizer over effort goes from 2.21 to 0.97: go to table go to figure
- Disentangling the effect of risk-sharing on the change of effort and fertilizer (details):
  - Median fertilizer use is between 1.3 to 3.6 times higher
  - Median effort supply is 4 to 12 times higher
- discussion

Fertilizer subsidy

- How much can a fertilizer price subsidy increase welfare for the farmers who are treated by this policy?
- Compute the **equivalent variation in aggregate consumption** from a fertilizer price subsidy
- Percentage increase in aggregate consumption that would make the planner indifferent between the subsidized prices and the actual prices, i.e. Δ such that

$$W\left(\sum_{i \in N} c_i + \Delta, \boldsymbol{p}\right) = W\left(\sum_{i \in N} c_i, \boldsymbol{p}^s\right)$$

- Hypothetical fertilizer subsidy: decreases the observed prices of fertilizer by 50%.
- **Welfare-equivalent increase in aggregate consumption:** 8%

Fertilizer subsidy and risk-sharing

- I quantify the effect of a fertilizer subsidy on risk-sharing
- To do this, I compute $\alpha^*(p)$, solving $\partial W(\alpha)/\partial\alpha = 0$
  - The derivative depends on ρ (absolute risk aversion) and χ (land share)
  - I calibrate ρ and χ so that $\underline{\alpha^*(p)}$ matches the average of estimated risk-sharing levels, $\widehat{\alpha_{vt}} = 0.66$
  - This implies $\rho = 0.36$ and $\chi = 0.58$
- I numerically solve the derivative for $\rho = 0.36$ and $\chi = 0.58$ (go to figure)
- Optimal risk-sharing is increasing in the subsidy (go to figure)
  - As people use more inputs, production becomes riskier, so it's optimal to insure them more

Taking stock

- I analyze the **impact of risk-sharing on fertilizer returns** under private information frictions in production decisions
- Two insights/pieces of evidence:
  - Risk-sharing can discourage effort provision (Marshallian inefficiency)
  - Effort and fertilizer are complements
- Build a model of risk-sharing that combines these insights
- Structurally estimate the model using a household survey panel data from rural India
- Use the structural estimates to quantify
  - the effect of risk-sharing on effort supply and fertilizer use
  - the welfare gains from a fertilizer price subsidy

Private effort (go back)

- Ligon 98 uses private effort to rationalize imperfect insurance in 3 Indian villages
  - Compares models of risk-sharing (full insurance, private effort)
  - Private effort model better predicts consumption allocations in 2 villages

- Papers similar to Ligon 98:
  1. Paulson et al. 06 (Thailand)
  2. Kocherlakota and Pistaferri 09 (Italy, USA, UK)
  3. Attanasio and Pavoni 11 (UK)
  4. Karaivanov and Townsend 13 (Thailand)

- Jain 20 provides experimental evidence that private effort decreases risk-sharing in Kenya

- Sharecropping literature provides evidence that better risk-sharing leads to lower effort:
  1. Laffont and Matoussi 95 (Tunisia)
  2. Burchardi et al. 19 (Uganda)

Effort and fertilizer (go back)

- Kamanga et al. 14: experimental evidence from Malawi showing that
  1. it takes labor to apply fertilizer
  2. fertilizer application results in more weed growth, which requires more labor
  3. fertilizer application results in more output per acre and thus more harvest labor per acre

- Beaman et al. 13: experimental evidence from Mali showing that farmers receiving fertilizer grants increase labor demand

- Hours of work and fertilizer use are positively correlated:
  1. Foster and Rosenzweig 09, 10, 11 (India)
  2. Ricker-Gilbert 13 (Malawi)
  3. Haider et al. 18 (Burkina Faso)

- Kopper 18: labor-constrained households in Ethiopia use less fertilizer

Contribution (▸ go back ▸ related literature)

- **Mechanism**: interaction between insurance and input use through complementarity between inputs and effort
  - More insurance is isomorphic to higher effort costs
  - It induces agents to use smaller quantities of effort-complementary inputs
- A subset of the parameters are identified from the distributions of effort and fertilizer choices and of fertilizer prices
  - Use estimates to quantify how risk-sharing affects input choices
- Estimate the model with data from 18 Indian villages
  - Most of the estimated parameters satisfy the model's restrictions without being imposed
- Quantification of the effect of risk-sharing on fertilizer use and of fertilizer price subsidy on welfare

Related literature (go back)

- This paper relates consumption allocations with a private effort restriction to the complementarity between effort and fertilizer
  - Quantify by how much risk-sharing can crowd out fertilizer use
  - Calculate by how much a fertilizer subsidy can alleviate this market failure
- Literature on **agricultural input (especially fertilizer) use in developing countries** (Dercon and Christiaensen 11, Duflo et al. 11, Beaman et al. 13, ...)
  - Foster and Rosenzweig (10): what is the role of complementarity between inputs?
- Literature on the **impact of risk-sharing on the village economy**
  - Munshi and Rosenzweig (16): migration
  - Morten (19): temporary migration
  - Mazur (20): irrigation

Model (▸ go back)

- Static economy inhabited by n household-farms, $i = 1, \ldots, n$
- Output depends on effort, fertilizer, and an idiosyncratic shock: $y_i = y(e_i, f_i)\,\varepsilon_i$
- i's expected utility depends on consumption and effort (▸ discussion):

$$U(c_i, e_i) = \mathbb{E}c_i - \frac{\rho}{2}\mathbb{V}\mathrm{ar}(c_i) - \kappa_i e_i$$

- Let $\pi_i = y_i - p_i f_i$ and assume linear contracts (▸ discussion):

$$c_i(\alpha) = (1-\alpha)\,\pi_i + \alpha\overline{\pi}$$

where $\alpha \in [0,1]$ is the degree of risk-sharing and $\overline{\pi}$ is average profit

Constrained-efficient allocation

- The planner's problem is

$$\max_{\alpha,\boldsymbol{e},\boldsymbol{f}} \sum_{i\in N} U\left(c_i\left(\alpha\right), e_i\right) \quad \text{s.t.} \quad e_i, f_i \in \arg\max_{\widehat{e}_i,\widehat{f}_i} U\left(c_i\left(\alpha\right), \widehat{e}_i\right)$$

Claim

An optimal allocation of $\boldsymbol{e}$ *and* $\boldsymbol{f}$ *for a given* α *implies*

$$\frac{y_e\left(e_i^*, f_i^*\right)}{y_f\left(e_i^*, f_i^*\right)} = \frac{\kappa_i}{\left(1 - \frac{n-1}{n}\alpha\right) p_i},$$

- Insurance induces farmers to free-ride on each others' efforts
- If the free-riding channel is strong enough, $\partial e_i{}^*/\partial\alpha < 0$
- As long as e_i and f_i are complements (discussion) and this channel is strong enough, $\partial f_i{}^*/\partial\alpha < 0$

Optimal sharing and fertilizer subsidy

- $W(\alpha)$: welfare evaluated at $(\boldsymbol{e}^*(\alpha), \boldsymbol{f}^*(\alpha))$. An optimal sharing rule is pinned down by setting

$$\frac{\partial W(\alpha)}{\partial \alpha} = \sum_{i \in N} \left(\underbrace{A_i}_{(+)} \underbrace{\frac{\partial e_i^*(\alpha)}{\partial \alpha}}_{?} + \underbrace{B_i}_{(+)} \underbrace{\frac{\partial f_i^*(\alpha)}{\partial \alpha}}_{?} \right) \underbrace{- \rho (1-\alpha) \left(\frac{n-1}{n} \right) \eta^2 \sum_{i \in N} [y(a_i)]^2}_{(+)}$$

to zero

- The effect of a **marginal decrease in** p on welfare is

$$-\frac{\mathrm{d}W(\alpha^*(p), p)}{\mathrm{d}p} = -\frac{\partial W(\alpha^*(p), p)}{\partial p} - \underbrace{\frac{\partial W(\alpha^*(p), p)}{\partial \alpha}}_{=0} \frac{\partial \alpha^*(p)}{\partial p}$$

$$= -\sum_{i \in N} \left\{ \underbrace{A_i}_{\geq 0} \underbrace{\frac{\partial e_i^*(\alpha)}{\partial p}}_{(-)} + \underbrace{B_i}_{(+)} \underbrace{\frac{\partial f_i^*(\alpha)}{\partial p}}_{(-)} - f_i^*(\alpha) \right\}$$

Household utility (go back)

- Model can be extended to

$$U(c_i, e_i) = \mathbb{E}u(c_i) - \kappa_i e_i$$

where $u' > 0$ and $u'' < 0$

- Separability in consumption and effort is standard in the moral hazard literature

- Costant marginal disutility of effort: κ_i can be interpreted as a price
  1. Arcand et al. (07)
  2. Conlon (09)

- **Mean-variance** holds when u is CARA and ε_i is normal, and **greatly simplifies strategic interactions**
  - Assume i takes j's choices as given
  - With linear contracts, i's choices of e_i and f_i do not depend on j's choices

Sharing contract (go back)

- Model can be changed to households sharing revenues y_i instead of profits π_i
  - Risk-sharing affects fertilizer use both directly and through its complementarity with effort
  - Profit sharing is consistent with risk-sharing being an ex-post consumption smoothing mechanism and temporal sequencing of agricultural production
- Linear sharing simplifies the analysis but often not optimal under private information
  - However, linear contracts are widespread (Dutta and Prasad 02)
  - Explaining why linear contracts are so common is a longstanding problem in contract theory (Carroll 15)
- Model can be generalized to $(c_i(\boldsymbol{\pi}))_i$, which are generic functions such that $\sum_i c_i(\boldsymbol{\pi}) \leq \sum_i \pi_i$
  - If the optimal sharing contract is differentiable and the first-order aproach is valid, my qualitative results hold

Complementarity (go back)

- e_i and f_i are complements, i.e. y **is strictly supermodular** in (e_i, f_i)
- Since y is $\mathcal{C}^2$, strict supermodularity is equivalent to

$$\frac{\partial^2 y\left(e_i, f_i\right)}{\partial f_i \partial e_i} > 0$$

- E.g.

$$y\left(e_i, f_i\right) = \left[e_i^{\frac{\sigma-1}{\sigma}} + f_i^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\chi\sigma}{\sigma-1}} \ell_i^{1-\chi}$$

  where ℓ_i is land
  - If y exhibits constant returns to scale in (e_i, f_i) $(\chi = 1)$ then it is strictly supermodular in (e_i, f_i)
  - If $\chi < 1$, then strict supermodularity in $(e_i, f_i) \longleftrightarrow \sigma \in [0, 1)$ (gross complementarity)

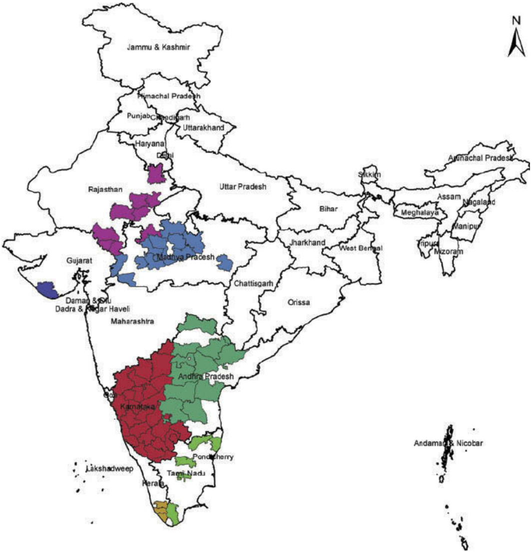
Summary statistics (go back)

Variable	Average	Std. Dev.
Household size	5.17	2.24
Number of infants	0.05	0.23
Average adult age	40.76	8.57
Age-sex weight	4.48	1.77
Monthly consumption	151.18	410.38
Monthly income	105.27	1384.07
Monthly effort (hr)	20.57	22.76
Monthly fertilizer (kg)	22.51	62.06
Number of households	698	
Observations	11234	

Notes: All money values in 1975 rupees. Consumption, income, effort, and fertilizer expressed in adult-equivalent terms. Household-month observations.

▶ Details

Indian semi-arid tropics (go back)



Data details (go back)

- Random sample of ≈ 40 households per village

- Cultivation schedule: for each operation in each crop, quantity and value of inputs used
  1. Effort: hours of family labor supplied to own plots
  2. Fertilizer: physical quantity of inputs used in fertilizer application operations
  3. Price of fertilizer: divide the value of fertilizer inputs by the corresponding quantity

- Transaction schedule: for each transaction, quantity and value of item
  1. Consumption: total value of expenditures in food and non-food items
  2. Income: following Mazzocco and Saini 12,

$$\text{expenditure} - \text{borrowing} + \text{lending} + \text{saving} - \text{gov't benefit}$$

- Conversion to PC terms using the age-sex weight (Townsend 94)

Marginal disutility of effort (go back)

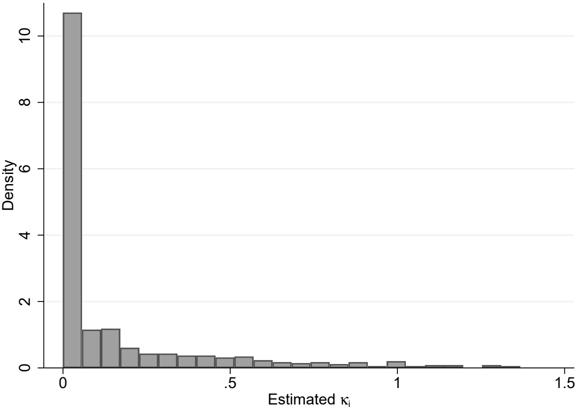
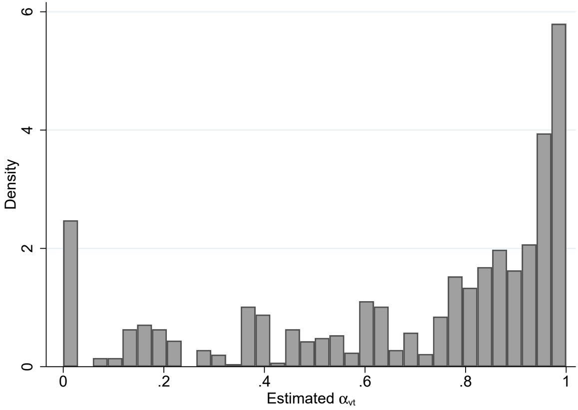


Figure: Histogram of $\widehat{k_i}$

Risk-sharing coefficients (▸ go back)

Figure: Histogram of $\widehat{\alpha}_{vt}$



- Average $\widehat{\alpha}_{vt} \approx 0.67$, s.d. $(\widehat{\alpha}_{vt}) \approx 0.33$

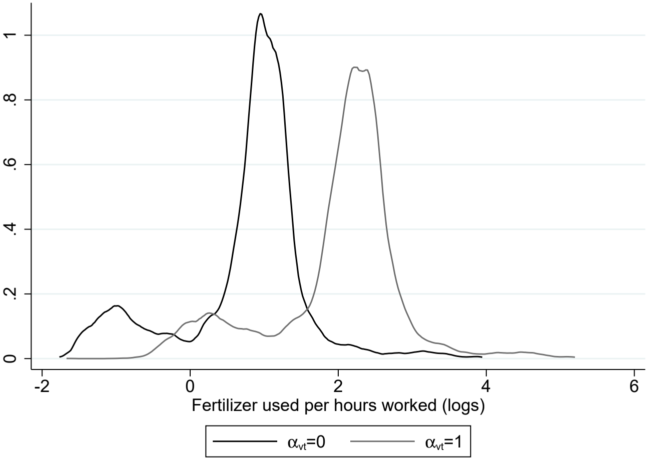
Counterfactual (go back)

Table: Summary statistics for $\widetilde{\log\left(\frac{f_{it}}{e_{it}}\right)}$

	Average	S.d.	Min	Max
$\widetilde{\alpha}_{vt} = 0$	2.4541	14.0909	-1.7666	387.3596
$\widetilde{\alpha}_{vt} = 1$	3.6874	14.0827	-1.6697	388.5255

Counterfactual (go back)

Figure: Comparative statics



Disentangling the effect of risk-sharing on the change of effort and fertilizer (go back)

- I numerically solve

$$\left\{\left(1-\frac{n-1}{n}\alpha\right)\left[1-\rho\left(1-\frac{n-1}{n}\alpha\right)y\left(a_i^*\left(\alpha\right)\right)\eta^2\right]\right\}y_e\left(a_i^*\left(\alpha\right)\right)=\kappa_i,$$

$$\left[1-\rho\left(1-\frac{n-1}{n}\alpha\right)y\left(a_i^*\left(\alpha\right)\right)\eta^2\right]y_f\left(a_i^*\left(\alpha\right)\right)=p_i,$$

  taking ρ and η as given

- I solve the these first-order conditions for $\rho \in [0, 1]$
- These values correspond to risk premia between 0% and approximately 99% of the standard deviation of household income
- I analyze how the solutions change when we move the level of risk-sharing α

Counterfactual: discussion (go back)

- The identification of the κ_i's and σ does NOT rely on
  - the linearity of the risk-sharing contract
  - the expected benefit of consumption admitting a mean-variance representation

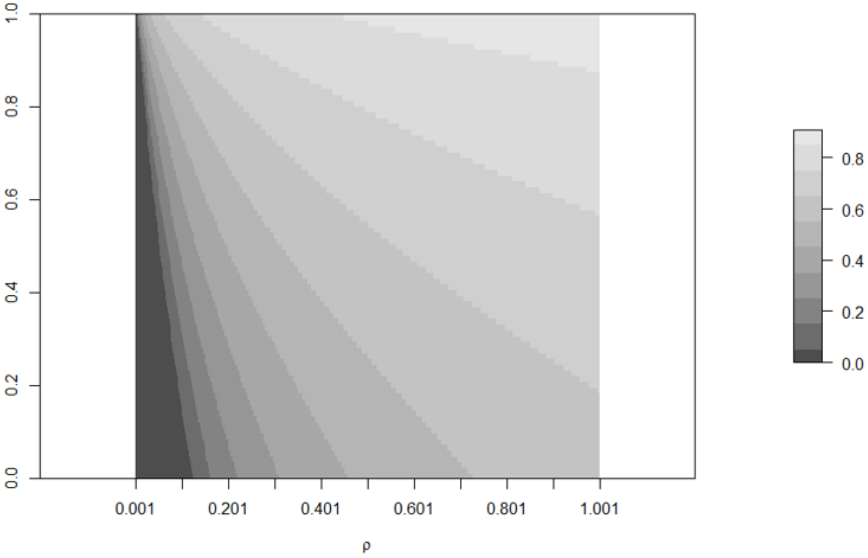
- Suppose the first-order approach is valid and the optimal risk-sharing contract is differentiable
  - Household i's relative demand for fertilizer to effort would be

$$\log\left(\frac{f_i^*}{e_i^*}\right) = \sigma \log(\kappa_i) - \sigma \log\left(\int u'\left(c_i^*(\boldsymbol{\pi})\right) \frac{\partial c_i^*(\boldsymbol{\pi})}{\partial \pi_i} \mathrm{d}\Phi^{\boldsymbol{\varepsilon}}(\boldsymbol{\varepsilon})\right) - \sigma \log(p_i)$$

  - If the risk-sharing contract is village and month specific, can still use a simple OLS to estimate the κ_i's and σ

- Linearity of the risk-sharing contract is used to compute the effect of a change in risk-sharing on input choices

Welfare-maximizing sharing rule (▸ go back)



Welfare-maximizing sharing rule and subsidy